Clean Coal Technology

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Week-11

Lecture-51

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. Today, we will start Module 11, discussing coal-based power generation. So, in this module, we will discuss various aspects of power generation or electricity generation where coal is used as fuel or an energy source to produce electricity. There are different methods available, such as the Rankine cycle-based steam turbine method, gas turbine method, combined cycles, and IGCC. So, in this module, I will discuss all these aspects. One more thing to be discussed at the beginning of the lecture is that typically, all these cycles—Rankine cycle, gas turbine cycle, combined cycle, IGCC—are discussed in mechanical engineering and power plant engineering subjects in detail, covering their energy aspects, entropy analysis, enthalpy analysis, etc.

So, we will not go into the details of all these cycles. We will simply focus on the aspect of coal utilization and how coal can be used in all these power production cycles very efficiently with minimal environmental impact so that our objective of clean coal technology is fulfilled. So, if anyone is interested in the details of these cycles, they should refer to power plant engineering subjects in their UG or PG courses. So, let us start Lecture 1 on coal-based power generation.

Now, if we look at the Indian scenario of coal-based power generation or coal-based electricity generation, typically, pulverized coal combustion units are mostly used, whereas some plants use fluidized bed combustion for steam production and electricity generation. So, about 90% or more of the output capacity from coal-fired plants, 90% or above is typically obtained from pulverized coal combustion units, and a very limited amount is available, maybe around or near 10%, which is obtained from fluidized bed combustion units.

Now we have already discussed that in the pulverized coal combustion units, we used good quality coal where the ash percentage is typically on the lower side, whereas the high ash coal and blending of other type of fuel like biomass and everything is highly possible in fluidized bed combustion. So such plants are very limited number of plant has there and some of the power plant is also based on the gasification methods where coal is initially gasified syngas is produced and syngas is further used to produce electricity through burning either through the gas turbine cycle or through the steam turbine cycle And in case of pulverized coal combustion unit, if we see the feedstock or feed coal for the pulverized coal combustion units, they need good quality coal or typically the ash percentage should be on the lower side. So in such case, this plant received coal either from the run of mines coal, that is the exact coal whatever is available in the mines, which is known as the run of mine that means as it is coal available in the mine that is sent to the power plant for electricity production if the ash percentage of this coal is on the lower side so they can directly be charged to the power plant for electricity production or in some cases the middling coal produced from the coking coal washers they are also sent to the thermal power plant During the coking coal washery, as we have discussed in our previous lectures, that about 18% ash coal, that is the clean coal, is sent to the coke making plants. Whereas the other product, if it is a single product, then the remaining product is known as the middling coal, where ash percentage may be around 35 to 40%. In the other case, if it is the three product washery, the middling part which will have ash percentage around 33 to 34%, that is sent to the thermal power plant for the electricity production. So, pulverized coal combustion unit, they receive coal around 30 to 40% ash.

They can be either ROM coal or can be the coal washery middling coal. Typically, GCV of more than 3,500 kilocalories per kg or ash percentage less than 45% in coal is used in the pulverized coal combustion units. In pulverized coal combustion units, typically the design value for most of the plant is about 4,000 kilocalories per kg of GCV. But depending on the type of coal, ROM coal and other, some of the plants still accept some lower values. Similarly, the ash percentage is typically 45% is still a higher value. But depending on the availability of coal, some plants still accept around 45% ash coal. Whereas their desirable ash percentage is around 33%. 33% ash is their desirable ash percentage. But if coal is not available or it is linked with some particular coal mines, they can still run on some higher percentage of ash of coal. But if GCV of coal is less than 3500, it is very difficult for the plant to operate, to produce the electricity, to maintain the desired electricity output.

So typically, the design value for all such plant is GCV above 4000 kilocalorie per kg. Whereas if coal is not available or if ROM coal has GCV around 3800-3900, plant still run on all such coals because not good quality coal is available everywhere. And if coal has higher amount of ash, like 40%, 45% or higher side, the plant faces lots of difficulty in their coal handling plant or CHP. And it has also very much difficult the combustor to operate the plant to maintain the desired electricity output. So high ash coal, it is always difficult in plant operation and its cost is also on the higher side because there is lot of regular damages and wear and tears with the coal handling section and other units. So desirable value for the thermal power plant is 33 percent ash however if coal is not available particularly with the Indian context where the all the coal having ash percentage more than 33 percent 34 percent or 40 percent. So, such coal is still used in thermal power plant. In case of pulverized coal combustion units grinding of coal to minus 75 micron or 200 mesh is required so here that is as these pulverized coal combustion units, they use the pulverized coal or fine coal particles where 80% or 90% coal particles would pass through the 75-micron screen or less than 75-micron size. So, there is a very big or large coal handling section is there. This CHP or coal handling plants, Initially, they receive the coal, crush it to different sizes, and finally grind the coal using different types of mills, such as rod mills, ball mills, or similar equipment like grinders and crushers. So, this CHP unit is a major part of coal-fired thermal power plants where coal received from the mines is prepared. to make it into a powder of 75 microns or less. So, that is the purpose of the CHP units. At present, some plants have also started, based on the Government of India guidelines, to use some amount of biomass in their electricity production to reduce coal consumption and create a cleaner environment. This helps reduce the impact of carbon emissions.

So, biomass is also being used in some pulverized coal-fired power plants in the form of pellets. There are separate companies or manufacturers for this purpose. They collect biomass, particularly agricultural-based biomass, from farmers and other sources, prepare pellets of different sizes, and mix them directly with the crushed coal before sending them to the grinder. for grinding and burning in a pulverizer. Some plants have adopted this biomass pellet charging method, but not all, as different design aspects need modification for biomass pellet use, and it is still under development or testing. Now, for high-ash coal, reject coal, lignite coal, coal slurry, coal washery tailings, etc., they are all used in fluidized bed combustor plants.

If the plant operates on the fluidized bed combustion method, it can accept a wide variety of feedstocks. So, in such cases, fluidized bed plants receive coal from multiple sources or waste coal sources, such as reject coal from coal washeries, lignite coal if available nearby, as lignite is now mined across India at different locations, so it is also used in FBC units. Coal slurry fines are obtained from the froth flotation units of coal washeries, where fine particle processing circuits generate large amounts of coal fines during crushing and handling in coal preparation units. These coal slurry fines can have very good GCV, while coal washery tailings may have lower GCV.

So, all types of these fine coals are also charged in fluidized bed combustor as the Coal quality for the fluidized bed combustor is there use the inferior quality coal. Overall, their GCV is typically less. So, any coal typically less than GCV of 3500 or less than that or as percentage above 45 or 50%. Mostly such coals are used in the fluidized bed combustor units and in such cases in the fluidized bed combustor co-firing of other fuel is very easy in the fluidized bed combustor as here not major type of crushing is required so coal particle or any other fuel particle can even in the bigger size can be fed to the fluidized bed combustor so here we can use the different type of biomass wood chips leaves and other municipal solid waste having organic compounds coke powders that is the waste material from the coke making plants etc., they all are charged in this fluidized bed combustor unit depending on availability and in this fluidized bed combustion units coal is typically crushed to the less than 10 mm depending on the type of fluidized bed combustor unit it is a simple CFBC units or it is the PFBC unit or it is the ICFBC units all depending on that the different type of size of coal are crushed. So, they are typically crushed to around 10 mm or below that in the fluidized bed combustor unit. So in all such cases depending on the plant, the coal handling circuits ends at crusher if we see the difference between the FBC units as well as the pulverized coal combustion unit is that all such cases coal is received in the plant they are crushed and when there is the coal crushing size of about 10 mm or 5 mm size so that coal can be feed to the fluidized bed combustor unit whereas if it is the pulverized coal combustion units even after 10 mm or 5 mm size this coal is finally grinded in a mill. So for fluidized bed combustion units the coal handling plants or CHP circuit ends at the size of coal size of about 10 mm or that size so whereas in the pulverized coal combustion units they can go further where they has to be further grinded typically bigger plants of 100 megawatts or more typically they are run based on the pulverized coal combustion units whereas the smaller size plants of 5 megawatt to 20 megawatts or even up to 30 megawatts they are in a single unit where the FBC based combustion are used. So, for the FBC based combustion plants the Plant production capacity is on the lower side. Some plant has very smaller capacity of 5 megawatt or if they are the commercial plant they can be up to 20 to 30 megawatts whereas the pulverized core combustion plants 75 to 100 megawatt is very common and in present days, it is much bigger also. In some of the older plants, typically those installed before the year 2000, they have a much smaller capacity per unit, maybe 75 megawatts or 100 megawatts or 135 megawatts. However, the newer plants have a much greater capacity. So, depending on the improvement in technology and the newer plants being installed in thermal power plants nowadays, they can be single units of maybe 500 megawatts or even 1000 megawatts are also possible. So, this is happening with the improvement of technology.

The older plants which were installed before the year 2000 or in the 1990s or 1980s have smaller capacities, maybe 75 megawatts, 100 megawatts, 125 megawatts, or similar. Whereas the newer plants which have been installed after the year 2000 are up to 250 megawatts or 500 megawatts in a single unit. And even in some cases, they are 1000 megawatts in single units. They are also being installed by different power-producing companies like NTPC, DVC, and others. So, this is the overall coal handling section or the overall schematic diagram of the thermal power plants.

This picture has been taken from the power plant engineering book by Professor P. K. Nag. So, a detailed discussion on this circuit is available in this textbook. So, anyone who wants to go into the details of power plant engineering should refer to this textbook. So, in this power plant, if we say here, the first part is the coal unloading part. In this coal unloading part here, coal is unloaded to the wagon triplets and other methods, they go to the transfer building. Here, unloading and loading are done by automated machines through conveyor belts and other means. They go further, where different types of circuits are present. Then, they go to the crusher, then to the silos or bunkers where coal is stored, and further, they are pulverized here. This is the unit for the main power plant boiler. Further, it goes to the air heater preheating section. There, the steam turbine is here—high-pressure steam turbine, low-pressure steam turbine—and finally, there is the condenser, cooler, and here also from this generator, we get the electricity output here. So, it is the input point; this is the output point of coal, whereas the sulfur oxides and other gases, they are cleaned here by the ESP and other methods, and flue gas is released to the stack. So, we will be discussing details on these flow sheets, but typically in the power plant, all these circuits are available. They must be there, and now some of the units can be present in the combustion in the plant based on FBC, or they are the pulverized coal combustion units.

If they are the pulverized coal combustion units, they need this silo and pulverizer unit. This unit will be there if it is the pulverized coal combustion units. But if it is the fluidized bed combustion unit, this unit is not required, whereas the crushed coal will directly be sent to the boiler. This is the basic difference between the circuits of FBC-based units and pulverized combustion units. In the case of pulverized coal combustion units, coal needs to be ground to be pulverized. So, there is a need for a pulverizer. So, this entire circuit or equipment will be additional units if it is the pulverized combustion units. Whereas, if it is the fluidized bed combustion units, they can end up here. The crushed coal from this unit will directly go to the boiler for burning. So, if we see the overall type of coal received or different sizes of coal received in the thermal power plant, typically coal handling plants receive coal from mines.

So, from the mines, coal is transported to the thermal power plant at the coal handling plant or coal handling sections. Here feed size can be about 1000 mm or 1 meter. The coal size here typically received is around 1000 mm. But nowadays this coal source received is around 50 mm as per the coal purchase guideline from the Coal India as well as the receiver. So there are different type of conditions are there whereas the coal India or other company coal mining company will send the coal to the thermal power plant at what particular size so they can be 100 mm they can be 1000 mm or they can be 50 mm so there is a separate type of condition is there so at what size they will make it is as per their tender criteria and others so typically plant is ready with the coal size of about 100 mm and this coal is unloaded in the plant by the wagon tripler here the if coal is received through the railway tracks to the wagons so there is separate wagon tripler arrangement is there where the entire wagon is tripled and they are unloaded within two to three minutes through a particular system a mechanical arrangement system mechanical coal unloading system is there in other cases coal can be transported through the tracks also and in some cases from the railway wagon bottom discharge system is also there where the coal is discharged through the bottom part of the wagon and it goes to some depth inside where it will be unloaded over the conveyor belt so coal is unloaded here that can have the wagon tripler that can be through some tracks if it is a smaller quantity or if the location railway connection is not there or it can go through the bottom discharge system also so here coal is unloaded And all movement of coal it happens through the conveyor belt.

So, there is a separate conveyor belt circuits are there which will handle all the coal and transport all the coal. There is no manual work is there. Everything is automated through the conveyor belt and typical material handling section is there. And in such cases abrasive index of the coal is very important. If coal is highly abrasive then the lifespan of the conveyor belts and other equipment get reduced significantly. Now depending on the amount of coal received coal are either stored in the stockpile because the coal received in a thermal power plant they receive coal in a some batch maybe once in a day or twice in a day they receive the coal so that entire coal cannot directly be sent to the plant so it will be stored in some stockpile or stockyard for some they are storing and from the stockyard coal will directly be sent to the plant so this coal can be the received coal can either be stored in the stockyard Or if coal is directly received, some part of coal can directly go to the CHP for direct crushing and burning. So direct crushing and burning happens only for few hours of the day. Remaining hours coal is sent to the stockpile and from the stockpile coal is sent to the CHP units.

Initially coal is crushed to the below 50 mm size and at this size coal is stored in the stockpile and followed by the coal is crushed. further by 12.5 mm or 3 mm size depending on the crusher circuit. So, initially crusher will crush that the primary crushing will be done to make the coal to below 50 mm size and secondary crushing will be done to make the coal below half inch like 12.5 mm or 3 mm or 6 mm depending on the type of crusher used. So, in between suitable size of screens is also used to ensure that no oversize coal particle goes to the next circuits and they are actually crushed to the required size. Crushed coal then feed to the bunker or silo from where coal will be fed to the boiler.

So, this crushed coal is fed to the bunker or silo which will store the coal for about 12 to 8 hours of planned operation because up to this section these units are in batch. That entire CHP units will not operate 24 hour a day. They will operate depending on requirement may be 10 hours to 12 hours per day or as per the requirement. requirement when coal is unloaded in the plant that will run in certain times of the plant however the entire electricity production happens to the 24 hour so these units operates in an batch whenever it is required not all the times so for batch to continuous mode it is run through this bunker silo where coal will be stored there which will capacity may be 12 hours or 18 hours So, these crushing units or CHP units, they will crush and grind, they will crush the coal and load it to the bunker.

Now, from the bunker, coal will be directly fed or continuously fed to the boiler as per requirement. So, this silo makes the process change from batch to continuous mode. The purpose of this silo is that coal will be stored there for 12 to 18 hours or maybe 24 hours. So, from this unit, this coal will flow continuously to the combustion units. If it is the FBC units, this silo will be the endpoint where coal will be sent to the boiler. But if it is another unit, some more units will be there, like the pulverizer unit. So, for FBC-based units, from the silos, coal will directly go to the combustor. So, in such cases, CHP ends here for the FBC plant units.

However, if it is the pulverized coal combustion units, there will be an additional unit for pulverization of the coal. So, from this silo, coal will be sent to the pulverizer or mill. Here, HGI or grindability, particle density, they are very important, and primary air is used to blow or transport the powdered coal to the combustor. There is no separate screen to check whether the coal particles are 75 microns or not. Here, the This size is decided by the velocity of the primary air. The primary air velocity is designed in such a way that it will only transport coal particles up to 75 microns to the combustor. If coal particle sizes are above 75 microns, they will not be transported to the combustor. So, this particle transport mechanism is decided by the primary air, and only the smaller-sized particles or so, desired density particles will only be transported to the combustor, whereas the heavy particles will not be transported. They will either remain in the pulverizer for further grinding or be rejected at the mill if they are not suitable material. So, here, particle density is important, and after this pulverization, coal is burned in the combustor. So, this unit, the pulverizer unit, is an additional unit in the case of pulverized coal combustion units. If it is the FBC unit, this pulverization aspect is not there. After the combustion, we will have bottom ash, fly ash, and flue gas generated.

So, coal particles are heavier; they will create the or they will generate bottom ash. Lighter coal particles will create or generate fly ash. They will go along with the flue gas. So, all these flue gas and fly ash are captured by different equipment or pollution control devices, like initially a cyclone separator, followed by ESP. If sulfur quantity is on the higher side in the coal, there is a different flue gas desulfurization unit, well known as the FGD units. So, that unit will be used to remove all the sulfur and other toxic elements from the plants, and they will be as per requirement. So, these environmental pollution control units, like cyclone separator, ESP, flue gas desulfurization, and other units, will also be there depending on the type of coal and the pollution level of this flue gas and others. If coal has very inferior combustion properties, for the initial ignition of the boiler—because the boiler needs to be heated to around 1200 to 1300 degrees centigrade so that coal particles can burn—if the boiler is at atmospheric conditions at 25 degrees centigrade, they are initially heated through fuel oil burning so that the temperature rises to 1200 degrees centigrade, and further the fuel is switched to coal particles. Here, fuel oil is used for the initial ignition purpose as well as to maintain the desirable flame temperature inside the boiler. If there is some minor variation in the coal properties, the coal is not able to maintain the desirable temperature, fine-tuning is always done through the fuel oil, which is the heavier fraction after diesel in the oil refinery product. After conventional products like petrol, kerosene, and diesel, the heavier part is known as fuel oil. So, that fuel oil is used in these plants for the initial ignition of the boiler as well as to maintain the desirable temperature inside the boiler. So, if we discuss the entire coal handling section here, coal is unloaded at this point. This coal unloading can be done either through the wagon tripler if the design is available or through the bottom discharge system, where the bottom part of the wagon will be opened, and coal will be unloaded below the tracks. Below the tracks, about 10 feet or 20 feet deep, there will be a separate conveyor belt available, which will collect the unloaded coal and transport it. So, this coal will be transported through this conveyor belt.

Now from this conveyor belt coal will be sent to the transfer building where coal will be either transferred after some initial crushing. It will be either transferred to the stockyard where coal will be stored for further utilization as per requirement. So, either it can be sent back to the stock file. It is a ground where coal can be stored for 15 to 20 days or 30 days of operation. So here coal will be sent to the stockpile or some of the coal can directly be sent to the crusher where it will go for secondary crushing. So, in this section there can have some primary crushing if coal size is on the much bigger size if coal is of 1000 mm on similar side here some amount of crushing is required if coal is a 50 mm size or less than that size this depending on the contract with the coal supplier. So, in such case coal can directly be sent to the reclaimer or sent to the stockpile also from this where we can again use the coal further. So, this circuit is there. If coal is not available from directly not available in such case from the active pile or stockpile here coal will be reclaimed and it will again send to this units. So separate arrangement for conveyor belt is there.

So, coal can be obtained. Either from the direct coal discharging system here or it can be collected also from the stockpile. So, this arrangement to the conveyor belt is there. This direct coal can also go there. It can further transfer to this further unit or it can be again sent to the stockpile. So, depending on the availability of coal requirement either coal can directly be sent from unloaded directly coal can be sent to the next unit or it can be sent to the stockpile and further after the conveyor belt it goes to the crusher and from this crusher it can goes to the stockpile also. This way entire circuit depending whether it will go to the stockpile or it will go to the stockpile it depends on the exact type of coal site is available. If primary grinding is required then in this building also there can have some crusher.

If it is not required it will go to this crusher and it can be reclaimed there. So, it depends on the individual type of coal, their coal sources, what size they are coal receiving and what is the exact plant design is there. Now after that if you see that this crushed coal is sent to the silo's unit where in the silos, coal will be stored there for the 18 to 12 hours or 24-hour operation where coal will be stored and from the silo it will be sent coal to the pulverizer where coal will be pulverized continuously. So, this unit operates 24 hour a day there is no stop it for this pulverizer. So, this size is about 3 mm to 4 mm or up to 12 mm size this coal is directly sent to this pulverizer and from the pulverizer continuously coal is sent to the coal combustor or per boiler. So, this is the exact design of the boiler Here coal is actually burned.

Here coal will be burned through the pulverized coal combustion methods. So here coal will burn and it will produce the flue gas whatever it will go to these units, SOX units, fly ash units and other. So, flue gas units will go to these circuits and the freshly primary air whatever is entering in this point, that primary air will get preheated to the exhaust gases. So, exhaust gas whatever the heat is there, so this heat will be transferred to the primary air so that the exhaust flue gas temperature is on the lower side whereas the primary air temperature will be on the higher side. After the burning, there will be different types of tubes in this location which will convert water to steam and send it to the turbine. There are different types of turbines like high-pressure turbine, intermediate-pressure turbine, as well as low-pressure turbine, depending on the design or capacity of the plant. There will also be different types of other units there. So, in the turbine, it will produce electricity which will go to the external grid. Whatever exhaust steam is there will be condensed here, and the excess heat will be released to the cooling tower and then to the environment. So, there is a requirement for a nearby water body like a river or a very large lake where they can get cooling water for these units. So, each or every thermal power plant must have a very good source of water.

That's why most thermal power plants are installed or located near a river or maybe a very large water body. Only there is the suitable location for a thermal power plant. They need a large quantity of water either for discharging heat or for operating as steam or generating steam and other purposes. So, a water source is compulsory in any thermal power plant.

So, this is the typical circuit used in coal-fired thermal power plants. Now, individual plants can have different types of designs depending on the year they were installed and particularly with the coal handling section, how it operates under different conditions. If they receive very small-sized coal or if they are receiving coal from the coal washeries like middling coal, which is already crushed and smaller in size, they may not need primary crushing at this point. This is the primary crushing point, and this is the secondary crushing point. If the coal is of bigger size, like ROM coal, they need primary crushing here. If the coal is of smaller size, like middling coal, they may not need primary crushing, and only secondary crushing may be adequate. So, this entire circuit varies based on the type of coal and the source of coal available there.

So, this is the typical reference book. I request everyone to follow Power Plant Engineering by P.K. Nag. This is a very good textbook discussing different aspects of the coal handling section and details of different types of cycles in the power plant. How these different thermal heat cycles operate. So, for detailed knowledge, you can go through this Power Plant Engineering textbook.

Thank you.