**Clean Coal Technology**

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**Week-05**

**Lecture-23**

Hi, Professor Barun Kumar Nandi. Welcome to the NPTEL online certification course on Clean Coal Technology. We are discussing the effects of coal properties on combustion in Module 5. So, in the previous class, I discussed the effect of coal properties like volatile matter, fixed carbon, mineral matter, and moisture on combustion characteristics. So, in this class, I will discuss the effect of coal particle density and particle size on combustion characteristics.

So, let us start Lecture 3. The role of coal particle size and density on combustion characteristics. During the combustion of coal, as we have seen from the shrinking core model of coal combustion, suitable coal particle size is the most important parameter for efficient combustion. If a coal particle is ground or crushed to the smallest possible size, we can reduce the impact of ash layer formation and the rate of diffusion of oxygen, carbon dioxide, etc. We can improve it. So, we must select a suitable coal particle size to achieve an efficient combustion process. So, if we see that all the ROM coal Whatever ROM coal means—run-of-mine coal—that coal size which is extracted from the coal mines. Typically, they are in very large lump sizes.

So, they are crushed and their further size reduction is done to get the desired particle size. So, all the ROM coal, they are crushed in sequential manner to get the required size as required for combustion purpose and which also is as per the design of the related equipment there are different coal combustion methods in which different size of coal particles are used like in case of fluidized bed combustion or FBC typically coal of 2 to 10 mm size are burned whereas in case of pulverized combustion coal particle size is finer less than 75 micron these coal particles are burned and this same size are also used when we do the gasification of coal. Now if we see smaller is the size of coal particle if we take the very small size of coal particle like if we want to burn coal at 2 to 10 mm size or if we want to burn coal at 75-micron size. So, they need a different coal handling section or coal handling plant which is known as the CHP in the thermal power plant as well as other plant.

That coal handling plant. So, they need major modification. They need major change in their flow sheet how the coal will be handled. And this causes higher material handling cost. And we can also get different type of pollution level and difficulty in coal handling. Now why this particularly this coal particle size and CHP variations are there as if coal burn at 2 mm to 10 mm size typically those can be done by a normal crusher so either two or three crusher gyrator crusher roll crusher etc. They are used in sequential manner in series so that from rom coal which is typically of thousand-millimeter size those are crushed to about 10 mm so they are mostly the bigger size crushers are used 2 to 3 crushers are used and corresponding screens are also used there and even coal are stored in stock file at this particular size of 2 to 10 mm or maybe 25 mm size. So, as it is we can see that if there is only crushing of coal is involved So there are only 2 to 3 or maybe 4 crushers as well as some coal storage stockpile is required. And this can be easily done in any of the coal handling section.

So, their coal handling section will be of smaller size. But if coal particles are grinded further to 75 microns, there needs a major change in the coal handling plants. For grinding of this coal, we need either ball mill or rod mill or similar type of mill is required either vertically operated or horizontally operated. So, another equipment is required which will grind the coal at the desired fineness. Now when we grind the coal at the desired fineness, the coal hardness also plays a major role that coal hardness impacts during crushing to make it 2 mm to 10 mm. But that impact can easily be absorbed by the coal handling plants by modifying just some high-power equipment's. But if we change or grind the coal to at these 75 microns, and if coal is extremely hard or extremely soft then their control is sometimes difficult and to maintain this desired fineness of 75 micron because if fineness is at 100 micron or 150 micron that will impact heavily during the coal combustion. So, to ensure that all the coals are grinded below 75 micron a major different section is required to grind the coal to 75 microns where the high or Hard Groove grindability index plays a major role if these grindability values are on higher side or lower side their mill performance gets significantly varied. So there needs a separate grinder or mill and to feed the mill there needs a separate bunker which will store the coal for at least 12 hours operation or 24-hour operation. So, all these are the additional cost involved in the CHP section. So overall if we find that if we want to grind the coal at much smaller size there can be have higher material handling cost. land requirement is also higher their investment cost is also higher and sometimes we can get also different pollution level as this coal are grinded to 75 micron they can easily get mixed in the air so they can easily pollute the air if there are any issues in the mill So bigger is the coal particle size.

On the other side, if we see, there is uncertainty in the mineral matter and combustible material distribution. If we use the coal at a much bigger size of 10 mm, the distribution of mineral matter and combustible material can be different. So, there can be two different materials, two different particles of the same size, but one particle can have a higher amount of mineral matter whereas the other particle can have a higher amount of combustible material. So, the calorific value or energy content in this coal particle and the other coal particle can be different. So, when we burn both particles, we may get more energy or we may get less energy. There is always some uncertainty as the percentage of mineral matter and combustible material is different. Even in the combustible material, as we have discussed in the previous class, there can be a different distribution of volatile material as well as fixed carbon. The same applies to the mineral matter; there can be changes in the mineral matter composition. So Overall, if we use coal of a bigger size, there will be some uncertainty as to whether that particular coal we are charging into a boiler or burner will be able to meet the desired heat release rate or if it will cause overheating or lower temperature in the combustor.

There is always some uncertainty about the final energy output. from coal, so there will always be some uncertainty in plant operation and output—finally, electricity output or whatever purpose we are burning the coal for. If we consider other aspects, if we increase the coal particle size, typically the ash layer thickness formed during combustion also increases. This part we have already discussed earlier, so the rate of combustion will also slow down, and we will get a lower heat release rate. So, if we burn coal at a bigger size, like 2 mm or 10 mm, it will burn at a much slower rate. In such a case, if we burn at 2 mm size, we may not be able to achieve high temperature. High temperature means in the entire combustor or boiler, the maximum temperature may be 800, 900, or 1000 degrees Celsius. But if we burn this coal at 75 microns or 30 microns, 40 microns, whatever, in such cases, we can easily achieve temperatures of 1500 degrees Celsius or 1400 degrees Celsius. Those can easily be achieved if we burn coal at a much smaller size.

So, if we increase the coal particle size, we will also indirectly limit the maximum temperature that can be achieved in the combustor or wherever we are utilizing this coal. So, if we want high-temperature applications, like in a cement plant, we need around 1500 degrees Celsius. In a thermal power plant, we need around 1300 degrees Celsius. So, in such cases, we should prefer to go for finer coal particle combustion, not bigger-size coal particle combustion.

In domestic applications where we need low temperatures or some small plants, used for changing or modifying the metal into different shapes, foundry 4G—all these plants where the only temperature requirement is on the lower side. They may use bigger-sized coal particle combustion. So, for high-temperature applications, smaller-sized coal particles would be used and if we use bigger-sized coal particles, there will always be some issues with unburned carbon. As combustion will take a lot of time, or we can say it will take infinite time for bigger-sized coal particles. So, there will always be some unburned carbon particles if we burn the coal at a much bigger size.

Similarly, the residence time required for combustion—the time required for combustion—will be much more. If we use bigger-sized coal particles, as we can see from this picture, if they are in bigger-sized coal particles, they will immediately get precipitated. So, they will get less residence time. They may need some more time for burning, but this length is actually not available in the plant. So, they will fall here as unburned carbon. So, if we use bigger-sized coal particles, their settling velocity in the combustor will be high. They will quickly settle down. and they will have low retention time in the air. Now, if we see with the previous point, bigger-sized coal particles need longer residence time to ensure complete combustion because their ash layer resistance and the rate of diffusion of oxygen gas and others are different. They need longer time for combustion. We have to ensure that they stay in the combustor for a longer time, but in actuality, what is happening is that as these particles are bigger, they will precipitate faster. If the particle size is smaller, they will stay here for a longer time, whereas in this path, they will stay for a shorter time. So, bigger particles need longer time, but due to their higher density or higher weight, they will stay there for a shorter time. Their characteristics will be opposite compared to whatever is required. Lightweight particles will stay there longer because their settling velocity will be less; they will stay for some more time in the air before precipitating as bottom ash, whereas they need less time for combustion. Bigger-sized particles will easily precipitate, so they need longer time for combustion but they are getting smaller time whereas the smaller particles they need smaller time for combustion they are getting longer time so this requirement is exactly opposite when we burn in the combustor. Bigger size coal particle if we see they needs higher air velocity when we burn them in the fluidized bed combustor or pulverizer combustor we will be discussing this part in later that they need Because they need higher particle air velocity to lift this particle to remain in the air phase so that they can burn. So, they may need some modification in the burner system. Like in any pulverizer or any fluidized bed combustor, they are designed for some particular density of coal. Accordingly, the compressor or air blower power has been kept fixed like 5 kilowatt or 10 kilowatts so that it gives air velocity of 5 meter per second or 10 meter per second as per design. But if particle size is bigger, they may need higher amount of driving force to keep them in the air phase. So, they need some minor modification or continuous modification in the burner system if we continuously change the particle density or particle size. And if they are in the bigger size particle, they also need suitable ash removal mechanism so that whatever the ash layer is formed to ensure that all the coal particle get burned within the desirable time and to ensure that 100% combustion is there and no unburned carbon is there always there will be some suitable ash removal mechanism must be installed in that plant that whatever ash is forming over the coal particle we should able to or we should be removing this ash layer continuously from the coal particle to get ensure that this coal particle are burning properly within the design length and location of the combustor. So typically, a continuous ash removal mechanism is adopted by ensuring high turbulence in the combustor. So, whatever the ash layer is formed on the coal particle, they are removed continuously by this high velocity turbulent air or in case of other design we can use in case of fluidized bed combustor. We use other material which will continuously remove the ash layer formed over the coal particles so that impact of ash layer we can reduce. And same thing if we see, if we increase the coal particle density, like if the two particles of same size, but their density, they are of different size. If we see there, if their density is different, although two particles will be of same size, maybe 75 microns, as their density is different, their gravitational force and drag force quantity will also be different. And their ash percentage will increase, GCV will reduce, and it will result in a lower heat release rate. The primary air fluidization velocity will be required, and it will vary for different coal particle densities. So, if we change the coal particle density, as we have seen in our previous lectures during the sink-float analysis, we observed that increasing the coal particle density, the ash percentage of the coal increases. If the ash percentage increases, the calorific value decreases, the heat release rate decreases, and if the coal particle density is higher, that means for one cubic meter or a certain volume of coal, its mass will be higher. So, their overall weight will be higher for the same one cubic meter of coal. If there is a density difference, their entire mass will differ. So, we may need higher transportation and conveyor costs. If we consider the transportation cost overall, 1 ton, 2 ton, it will increase from 1 ton to 2 tons for a particular size of truck or rake. Similarly, when using the conveyor belt to transport this coal, the conveyor belt may require higher motor power to move the coal from one distance to another. So, the entire transportation and conveying costs will be higher. Similarly, the primary air or secondary air velocity, fluidization velocity, everything will be higher. That means they need some modifications in the burner.

Now, this part, if we see, needs some modification in the burner system or coal combustion. Typically, in any thermal power plant, once it is designed. If it is designed for coal with a specific gravity of 1.4 or 1.5, and after 5 or 10 years, if we use coal with higher particle density, although it may have the same gross calorific value, but if the particle density changes, we are using heavier coal particles or high-ash coal particles. In such cases, modifications are needed in the entire coal handling section to ensure all the coal is transported suitably. The primary air velocity, secondary fluidization velocity, all corresponding pumps, motors, they always need some modifications. And this modification is sometimes very difficult. It may need for two to three months of maintenance or repairing of that plant or it may need to replace completely new equipments. So those new equipments may not be compatible or may not have other matching with the design parameters. So, it is always very difficult for any thermal power plant to modify or to change or go for any major change in their combustor system. So, all these thermal power plants will face lot of difficulty as a result after 5 years or 10 years or 15 years. They always produce some unburned carbon.

Their regular maintenance frequent shutdown will be there because the coal properties, coal particle density for which it was designed earlier, it has been changed significantly. So, this entire plant is handling some different materials actually during combustion. So, these modifications may not be very easy or very acceptable to plant. And ash layer thickness formed during the combustion is much more, it will reduce the rate of combustion. Unburnt carbon will be much more for high density coal particles. Resilience time required for combustion, it will be more for high density coal particles. As particle density is higher, settling velocity in the combustor will be on higher side. So, they will always settle quick, going for lower retention time, but is opposite the requirement. And needs suitable ash layer, ash removal mechanism, as we have discussed earlier. Now, how will it change if there is any coal particle density change? How will it also impact the performance of the mill? Till date, we have already discussed mostly about the combustion characteristics with their particle density and others, but if their particle density changes. In the mill or grinder, where bigger size coal particles are ground to 75 microns, we call it pulverization, which is done. So, there also needs to be a major change. Like this, the diagram we have taken from the textbook. So, this diagram shows that this is the bigger size coal particle, maybe of 3 mm coal particle, is burned here.

It goes to this particular mill, that ball mill or rod mill. This drum rotates at a constant speed of around 18 to 25 rpm. So, this drum rotates continuously. So, whatever the balls or rods are present there, they continuously grind the coal. Now, how are these fine coals transported? These fine coals are transported through this primary air. Hot primary air is used here, which will have a higher velocity. So, this primary air will transport these smaller size particles, which have been ground to the desired size, and they will be taken through this burner. So here, we will get a mixture of primary air as well as coal particles. Coal is charged from here, bigger size coal.

Primary air is charged here. So, this hot primary air actually blows or they will transport these coal particles to the burner here mixing of primary air and coal particles fine coal particles is there and drums is rotated at ay constant speed may be around 18 to 25 rpm and here as in the burner We have to ensure that we get the desired coal particles. Like if we want to get electricity production of 500 megawatt corresponding by heat balance calculation we can also get that this much amount of steam is required and that steam will have this particular temperature and pressure. To meet that condition in the combustor it will create or it will generate constant amount of heat. So for releasing constant amount of heat always the coal particle or coal is feeding to this burner should be of same amount like suppose 2 kg per minute coal should be burned or coal should be fed to the boiler so whether this 2 kg mass of coal is being grinded or not that depends on the capacity of this grinder for this mill if this mill is unable to grind the coal within this to some fixed time that means from coal particle entering here it will travel here and it will reach by this point it will reach and if coal particle is not grinded it will be come out as which is known as the mill reject. So, if you see the actual diagram like how it rotates we are sending heat ROM coal with correspondence to this picture here. This ROM coal means we are thinking about or discussing about at this point. So, this ROM coal will enter here and we are also sending primary air at this particular point.

So primary air is also entering here. So, coal particle will travel a particular fixed duration then they will become 75-micron coal particles as it will go to the burner. they are not 75 micron the bigger size coal particles or heavier size coal particle will come out of the mill as the mill reject. So, this is designed based on the velocity of primary air so any coal particles. Suppose we see the movement or trajectory of this black size particle. So, this black size particles they are entering here they will move and this green size ball corresponds to the ball or rod present there. So, this is the coal particle, bigger size, and this is the finer size coal particle.

So, the black-sized coal particle will move across this path. In this path, they will move. And once they are ground to the desired size, they will be blown away by this. If they are not ground to the desired size, if they are still at 150 microns or 200 microns, So, they will come out of the mill because coal is continuously being fed.

So, coal will always stay there for a particular residence time corresponding to this length. So, whatever the length of this mill is, corresponding to this length, coal will get either 5 turns or 10 turns or 20 turns as per the design. So, one thing is that their residence time T in the mill is fixed. So, any coal particle has to get ground within this mill within the desired time. Now, why is this concept of mill reject there?

If any heavy material is there, like if there is some coal particle having a higher amount of mineral matter. So, a higher amount of mineral matter is there. That means their specific gravity will be on the higher side. So, it is better not to send them to the combustor because they will not burn properly and create unburned carbon. So, they should be rejected at this point as well as during mining. Different types of other materials, iron, and other wires are used during blasting and other processes. So, there can be those types of materials present which should not go into the boiler and damage it. So, they should be separated as mill rejects. So typically for mill rejects, as per most power plant designs, the mill reject criteria is that their density is around 1.85 or 1.9. That's specific gravity. If the specific gravity of coal is above 1.85 or 1.9, they will be reported to the mill reject part, and any particle less than 1.85 will go to the pulverizer. Because at this density, in most cases, coal has a very low calorific value and mostly consists of very high-density coal particles or other impurities present along with the coal. So, if any coal particle has a higher density, that means there can be some coal particles where the density is on the higher side, such as a coal particle with a density of 2.0, but it can have a GCV of 4000. In some cases, in some mines, it may be possible. So, in such cases, what will happen?

All these 2.0 density coal particles will go to the mill reject, not to the pulverizer because, as they are high-density particles, whatever the primary airflow is there, it will not be able to lift these coal particles, as we have seen in this picture. The primary air will not be able to lift these thick particles; they will rather precipitate. So here, what will happen is all the coal particles having higher density, although they can have a very good amount of calorific value, will always report to the mill. And if most of the coal has higher particle density, although it can have good calorific value, it will always report to the mill. So what is required is that we have to modify the primary air velocity, length of this ball mill, all has to be readjusted or recalibrated for the new type of coal. Now, this recalibration is sometimes difficult for some plants.

So, it may result not accurate grinding or not accurate separation of the coal particles in the mill. So overall if we see lighter coal particle or smaller size particle they will be transported easily to the combustor. And heavier coal particles, they will report to the mill reject due to their higher mass. Or maybe they are also in the bigger size. If they are not grinded properly, like if their HGI value is on the lower side, they are hard material. So it will take much more time for grinding. We have to remember that to travel this distance, it will take some 4 minutes or 5 minutes or 3 minutes. But if coal is on hard coal, it may need 10 minutes for grinding. But in the actual mill, it is not getting 10 minutes for grinding. So even if there is some mismatch in the HGI value of the coal, like HGI value if it is the soft coal, HGI value is on the higher side typically above 50 or 60, they are considered as the soft coal whereas if coal HGI value is less than 40 they are known as the hard coal. So, if their HGI value is also less. So even if their coal particle density is okay but due to their hard coal particle they are not easily getting grinded, mill will perform in the wrong way and some valuable cold particles will also get reported to this mill reject. Entire mill capacity, this motor capacity, its dimension the coal particle density, all should match with the design. If there is we certainly change the source of coal or origin of coal we change like if you are using coal from mines A and replacing coal from mines A to mines B which has completely different characteristics different type of mineral matter and other and if it is hard coal or if it is extremely soft coal. So, this type of issues will come. So, in such case it will be difficult for this mill to perform properly. So, there will always be some issues with the coal particle size that is fed to the burner. Now even if we see the opposite way like if the coal particle is very much soft, like HGI value is on the higher side, so coal particles are very much soft.

If coal particles are very soft, so if we are entry here, so by this distance, it has finished to make it 75 microns. If it is staying there for more distance, it may grind it to 30-micron size. And if we feed 30 micron or 10-micron size coal particle, in the combustor, it will burn immediately. So, it will also modify the temperature profile because as it is a very smaller size coal particle, it will take less time for burning and entire heat release will happen immediately after entering in the combustor. So, the temperature profile inside the combustor will also get modified. It will also get different. So, neither over grinding nor under grinding is desired. Grinding should be as per the design parameters. Neither we can send so much soft coal or so much hard coal that coal particle density, coal particle HGI value also should be there within the design parameter. Else we have to modify the velocity of primary air. Otherwise grinder and mill will not be able to perform its duties to make the coal particle grinding at desirable size. Typically, this velocity of air is designed based on all these, considering all these such that designed coal particles That means good coal particles having lower particle density and lower amount of ash are only carried out and by this primary air and heavier mineral matter rich particles or impurities they do not lift. So, we have to design or use design coal in the mill also as if mill performance is changes if it is not able to supply energy. design coal particles of suitable size and quantity, then combustion performance will also get affected.

So, if we summarize, HGI of coal plays an important role here that grinding needs to be completed within the design residence time in the mill. If not grinded by this mill, it will go to the mill reject. For lightweight, bigger size particles, this can happen. Like coal particles are of lower particle density. But they are very hard particles. So, they are not getting grinded. So, they will not be taken or lift or they will not be blown away by the primary air. So, they will create either to the mill reject. Or they can be in the even bigger size particle. They can be transported to the combustor. Because they are lightweight. air particle may lift them but in the combustor they will get in the bigger size. So bigger size coal particle again will take some more time for combustion may release unburned carbon. So hard coal needs to be grinded more time. So soft coal results in over grinding impact is that in both the cases we can get unburned carbon hydrocarbons in the flue gas or there can have more fly ash generation if over grinding is there. So that will result in higher ESP load. Whatever the load in the fly ash particle removal is there, ESP has to remove more amount of fly ash particles and also get faster heat release if coal particles are get over grinded. Similarly, if particle density is there, higher particle density does not go to the desired velocity for going to the combustor. That means in the mill itself, it may not get the desired velocity. It may not go to the combustor and it may go to the mill reject. Although there can have good calorific value.

So, mill and air. does not know whether it is mineral matter or hydrocarbon this is another parameter like there are some of the hydrocarbons which specific gravity on the higher side that means they are hydrocarbon they will burn properly but their specific gravity is on the higher side and similarly there can have some mineral matter which are lighter in nature. Suppose mineral matter contains sodium-rich compounds, which are lighter in nature, whereas hydrocarbon contains compounds of C200 or C500, which are extremely heavier. So, air does not know whether it is mineral matter or hydrocarbon. It will simply act based on their particle density. So, there can have possibility is that, High density particles having hydrocarbon, they report to the mill reject. And lighter density coal particles having rich in mineral matter, that goes to the combustor. So, they separate only based on the weight of the coal particles. Coal with high particle density reports to the mill reject. Irrespective of its GCV, typically this separation or velocity of primary air is based on the particle density, not considering the GCV. So, this mismatch is also possible in the mill, and typically the cutoff value for Indian coals is around 1.85. This 1.85 value is typically the cutoff value, meaning it has very good GCV. At 1.85, the GCV value is good or satisfactory. So, this particular 1.85 value is considered in most cases, but as we have seen in our previous chapters, changes in coal particle density affect its calorific value, and these changes also depend on the source, seam, or particular mines of that coal. So, the 1.85 cutoff value may not be applicable for all types of coal.

Suppose this plant was designed in 2010. So, in 2010, whatever coal was available may have had a cutoff density of 1.85 for the mill. But in the year 2024 or 2025, it may not have the same properties. This cutoff density may have changed to 1.9, 1.8, or maybe 1.7, depending on the source and type of coal. So, this entire calibration has to be done regularly and frequently, considering the input coal properties. If we are using Indian coal, its properties are different. And if we are using imported coal from South Africa, Indonesia, or other countries, their specific gravity and coal property values are different. Similarly, if we are using coal from the BCCL area, ECL area, or SCCL areas, all these have different densities of mineral matter and different coal properties. So, if we frequently change the source of coal—like today we get coal from BCCL, the next day from ECL, CCL, or other subsidiaries—their 1.5 cutoff density for this mill may not be applicable. They always have to be fine-tuning, have to be there, and we have to continuously monitor this. If we monitor these values, depending on coal properties, we will be able to minimize the loss of coal as well as ensure very good combustion in the combustor. Otherwise, there will always be some unburned carbon in the flue gas, in the bottom ash, unburned hydrocarbons in the flue gas, etc. And there can also be some carbon monoxide, etc. So, when we utilize coal, we have to ensure that all these parameters are properly designed and continuously calibrated, continuously modified based on the input coal properties.

Thank you.