Clean Coal Technology

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Hi, I Professor Barun Kumar Nandi welcome you in NPTEL online certification course on clean coal technology. At module 6, we are discussing various industrial coal combustion methods. So, in this lecture 4, we will be discussing CFBC, PFBC and PICFBC. These are the different types of fluidized bed combustor used in coal combustion. So, if we see the fluidized bed combustion, this fluidized bed combustor can be of different types or different design is available based on some of the modification or some of the improvement from one unit to another units.

So that this fluidized bed combustion can be utilized much more efficiently in different ways and also we can improve the combustion efficiency as well as the pollution from all these combustion units. So, this atmospheric fluidized bed combustion or bubbling bed fluidized bed combustion well known as the AFBC. They are the very basic type of fluidized bed combustor and there are some improvements in there in the circulating fluidized bed combustor well known as the CFBC. So, in this circulating fluidized bed combustor apart from AFBC some arrangement of circulating the coal particles is there. So that they can get burned much more efficiently. In the internal circulating fluidized bed combustor, so as its name shows, there is some recirculating arrangement in fluidized bed combustor.

It has been incorporated inside the combustor. So, it is named as the ICFBC. And there are also different types of pressurized fluidized bed combustor, well known as the PFBC, where pressurized means the reaction happens at higher temperature. So, there can also have the arrangement of circulating as well as internal circulating. So, depending on the type of arrangement there, whether it is pressurized or internal circulating or only internal circulating, or only pressurized without any circulating, different types of nomenclature is available in different units. So, this is the basic structure of Fluidized bed combustor what is used in different type of thermal power plants or as well as the other units who use fluidized bed combustor. So, these units is the main unit where coal combustion takes place. This represents the boiler tube which mention water in and steam out.

This is the main zone where flue gas stays there and this is the zone where typically coal combustion occurs. So, in this units where coal combustion is there from the bottom of this unit. So, from this bottom side some hot air is there which fluidize the material. So, from the bottom side fluidization of the material is done and there is one storage tank which mixed the feed coal particle as well as the limestone particle. So, this loading of this limestone is on lower side depending on the amount of surfer available in the hole If the coal has higher amount of sulfur or we are burning high sulfur coal, then the limestone dosing will be changed and it is varied accordingly. So, from one silo or one bunker storage, this limestone is sent and another storage coal particles, crushed coal are sent to this reactor. And if required, some of the bed material, they are also mixed in this reactor. same line if they are continuously to be added in the system so all these feed like coal limestone and the bed material if required they are mixed in this bunker and they are feed they are sent to this fluidized bed combustor. So, in the fluidized bed combustor this coal particle gets burned and energy is released and whatever the coal particles they get released from this combustor and they are may have some amount of unburned particle. So, all these fly ash particles and unburned coal particles are typically sent to this cyclone separator. So, this cyclone separator it removes the dust particles, so that whatever the fly ash and other materials some of the materials is recycled back like maybe there may be some bad material is also there which are typically recycled back to this combustor so that proper combustion or 100% combustion of the coal particles takes place. Then further this flue gas goes to the other units like air-free heaters and others where they are utilized for their purpose where it is used, like maybe for energy generation or some other purpose where fluidized bed combustion is applied. So, this is the very basic structure of the fluidized bed combustion units, which are used in most thermal power plants. So, if you see that in the case of AFBC wet boilers, typically coal particle sizes of 1 to 10 mm are used. So, coal particles need to be crushed to around 1 mm to 10 mm. As there is only air velocity, there is no high pressure or significantly higher amount of pressure.

Typically, we can use smaller particle sizes of coal. That means even in the coal particle size range of 1 mm to 10 mm, this is the broad size. Depending on the pressure used, smaller particle sizes of coal are typically used, maybe 1 mm, 2 mm, or 3 mm. They are mostly used. Whereas the bigger-sized coal particles cannot get the desired drag force from the low air velocity. So the percentage of 10 mm particles should be on the lower side. Whereas the smaller-sized coal particles of 1 to 5 mm or 3 mm should be on the higher side. So, the exact coal particle size depends on the rank of coal, whether coal will easily burn, coal of lower particle density, the volatile material, and considering all their combustion characteristics, what will be their typical retention time in the fluidized bed combustor. The suitable size is selected.

That consider different type of heat fuel in the combustion chamber. the atmospheric air which act as and both fluidization as well as the combustion air whatever the air is available they are just compressed and sent through a pump or a compressor so that these air act like an combustion air and that air is also used for fluidization and is delivered at pressure and flows through the bed after being preheated by the exhaust gas as it is the common requirement that air should be preheated for the better thermal efficiency so this atmospheric air is typically preheated like we can see in this unit this is the typical preheater unit from which we can recover some amount of heat and from where we can get this primary air so if we see this entire structure there This whatever the preheated air is there. So, this air is compressed from here. They get some amount of preheating like 200 degrees centigrade from this exhaust flow gas and this preheater that preheated air is used in this unit. The velocity of fluidized bed is on the 1 to 3.7 meter per second. This velocity of air is on the lower side as we are using almost in the atmospheric condition. So, this velocity is not significantly high. So, this in case of AFBC or what is the very much basic design of this fluidized bed combustor the velocity of air is around 1.2 to 3 meter per second and this is linked with the coal particle size in any case of fluidized bed combustor, we can link these two parameters, what velocity and what particles we are using. If we are using low velocity air, we should use the smaller coal particle. If we are using high velocity air, that can be able to lift the bigger size coal particle. So, this velocity of air and this coal particle size are directly correlated.

The rate at which air is blown through the fluidized bed combustor determines the amount of fuel that can be burned. Because we are supplying the primary air, if we use high-velocity air, it contains a higher amount of oxygen or a higher amount of air. So, the rate of combustion will also be higher if you provide high-velocity air, like here, 3.7. If high-velocity air is present, the turbulence generated in the fluidized bed will also be higher. So, the removal efficiency of finely generated ash particles will also be higher. So, overall, depending on the air velocity, the rate of combustion will also vary. Almost used in bed-type evaporator tubes where simply evaporator tubes or bed-type evaporator tubes are used in thermal power plants, and bed materials contain limestone, sand, and fuel for extracting heat from the bed to maintain the bed temperature.

So, these are the bed materials used in this combustor, and typically, a bed depth of 0.9 meters to 1.5 meters is used in this design. So, this AFBC design is the very basic or simple design for a fluidized bed combustor where very small particle-sized coal is used. That means coal still needs to be crushed to around 1 mm to 2 mm or 3 mm. 10 mm is the higher side, where 3.7 meters per second will be the higher side velocity. So, that velocity and the size of coal particles depend entirely on the coal particle characteristics. If they are the high as coal, velocity should be on the higher side or coal particle should be on the lower side. So, they are fine-tuned at the plant side considering the coal characteristics. and limestone is added in some of the cases if we are using the reject coal or any of the high sulfur coal in such case those of limestone will be on the higher side. So, this is the typical floor sheet or floor diagram which is used in a fluidized bed combustor based thermal power plant. So in this case we can say this is a coal and limestone they are burned in this fluidized bed combustor here it is the circulating fluidized bed combustor and from their steam is generated which will go to the cyclone separator to recycle this and it will further go there and we can generate the steam there and which will further this fly ash we will go to the environmental unit like ESP, ID fan and others from bottom side we will get the storage done. Now in this is the design which is particularly suitable or particularly called the CFBC and in simple AFBC cyclone separator is required. So if we are not using high velocity air like if we are using very low velocity air like 1.2 meter per second we may not need a suitable cyclone separator for recycling the generated ash particles or unburned coal particles but if we are increasing the velocity of air like 3.7 meter per second or even in the higher side we always need a suitable cyclone separator this purpose of this cyclone separator is that whatever the Unburned coal particle is there That means there can have some unburned coal particle which is just going out of this reactor as we are increasing the velocity of the air flow rate. Like if we are using the velocity of 1.2 in such case coal particles will may reach may up to this height. They may not cross the reactor.

But if you are using a velocity of 3.7 some of the coal particle will reach here and they will go out of this reactor. So, if we want to burn these lightweight coal particles which are getting out of the reactor or fluidized bed combustor before getting completely burned to ensure that all these cold particles get completely burned we need some recycle arrangement so that any particles which is going out at Outside this reactor, they should recycle back. And that's why this circulating terminology; this particular term C comes. The C means it is circulating. That means whatever ash particles or unburned coal particles are there may go out due to the higher velocity of the reactor. We need very high-velocity air so that the entire combustion process is completed within a short span of time. As well as the bigger-sized coal particles or heavier-sized coal particles remain in the fluid state. That means they remain in the air. They will not be lifted if the air velocity is on the lower side. So, to ensure that all the coal particles get fluidized irrespective of their particle size, particle density, or particle mass. So, to ensure that bigger-sized coal particles also get fluidized, we always need one cyclone separator or one circulating arrangement so that due to the high velocity of air, if some coal particles go out, they should recycle back or come back to the reactor to ensure that there is complete combustion of coal and no unburned carbon particles go out from the reactor. And this is also suitable if we see the different types of combustion characteristics of coal, particularly if the coal particles are of high-ash coal particles or if we use the high-ash tailings, meaning high-ash fine coal particles we get from the froth flotation units. So, froth flotation units, as we are using 0.5 mm size or smaller-sized coal particles, their tailings will also be of smaller size, like 0.5 mm or 0.2 mm. So, if we want to burn such coal particles which are fine in nature, we have to ensure that these coal particles remain inside the fluidized bed reactor for sufficient time. As we are using high-velocity air, these fine coal particles may go out of the reactor even without burning or partially burning. So, this circulating arrangement using a cyclone separator, either one cyclone separator or multiple cyclone separators, ensures that no unburned coal particles go out without proper combustion, as well as ensuring that some of the ash particles return back.

If some ash particle also goes out through this reactor, so they will again return back to the combustor to maintain the desirable ash percentage as required to maintain the temperature or consistency in the temperature of the reactor. That means this cyclone separator will also recycle the limestone as well as the bed material depending on their particle size. So, this circulating arrangement is almost we can say it is a compulsory and much needed features required. from its basic version like AFBC. In AFBC typically cyclone separator is there but its role is on the lower side. So, in real time very small quantity or very small number of AFBC units can be find or AFBC units are reality is not there. So, all the design are based on this CFBC units that all the that that means the circulating arrangement is compulsory in all the units and now if we go to their different theoretical parts like generally CFBC consists of a boiler and high temperature cyclone and as we are circulating it, we can go to the higher air velocity. Like we can go to the higher air velocity like 4 to 8 meter per second. If we increase this air velocity, fluidization will be much better. So, coal particles will get burned within the short span of time. and they will get burned properly without having any unburned carbon. So, to ensure that typically high velocity air is used so in case of CFBC we can increase the velocity of air from 4 mm 4 meter per second to 8 meter per second and also we can increase the size of coal particle like in AFBC we need smaller size coal particle as their air velocity is less. So, fluidization velocity requirement is also less but if we go to the smaller size coal particles their crushing cost or material handling cost is also there So, if we are used this bigger size coal particle like 6 to 12 mm coal particle, we can save lot of money, lot of energy consumed in crushing the coal. So, in this CFBC design, even we can burn bigger size coal particle and particularly if the coal has high ash content, sometime crushing of that coal is also difficult. so even getting coal of 1 mm to 2 mm means wear and tear in the coal crusher will be on the higher side So if we can able to utilize them even in the bigger size like 6 to 12 mm, we can easily save lot of money, lot of infrastructure required to further crush the coal and that is the advantage of this CFBC module where we can use high velocity air as well as bigger size coal particle. A coarser fluidized medium and char in the flow gas are collected by the high temperature cyclone and recycling to the boiler. So, purpose of the cyclone separator is to recycling the any unburned coal particle which is called here the char as well as the coarser size any of the bed material which goes out of the reactor. recycling maintains the bed height and increases the de-nitration efficiency if we can maintain the bed height other advantage or NOX formation we can also decreases so it will improve overall the very healthy atmosphere inside the reactor to increase the thermal efficiency a preheater for fluidizing air and combustion air and boiler feed water is also installed that point we have already discussed that if air is preheated overall thermal efficiency of the reactor is improved. Now ICFBC is the another upgraded version of this CFBC unit. So, in this CFBC unit apart from this we can get that it is internal circulating that means whatever the cyclone separator is there if in the previous design we have seen that cyclone separator is typically placed outside the reactor if cyclone separator is placed outside the reactor. So, there should be separate arrangement for heat insulation of this cyclone separator like if this main reactor is maintained at 800 degrees centigrade or 1000-degree centigrade cyclone separators would also be given insulation for 1000 degree centigrade. So, there is an increased insulation cost of the system as cyclone separator is present outside the reactor. So, if we can place this cyclone separator just beside this combustor or in some cases inside this combustor. So, if we can place this cyclone separator at this particular point either just out or maybe just in the exit path like all the particle exist by passing through the internal cyclone that means if we can place this cyclone separator just beside this reactor or maybe inside this reactor we can place the cyclone separator. Even in some of the design just outside path but inside this reactor in such case we can reduce significantly higher amount of heat loss as well as the insulation cost required for the combustor.

So, if we can reduce the insulation cost as the cyclone separator will be placed just beside the reactor as well as maybe inside the reactor. So overall insulation cost will be on the lower side. So, we can reduce the overall furnace size or furnace volume significantly. So that is the major advantage if we use or if we go for the internal circulating part. So in case of ICFBC cyclone separator is placed just nearby or inside the combustor. What other advantage we can also get is that as that it is inside or nearby we can get better temperature control we can reduce the heat loss as well as whatever the residence time coal particles are getting that we can reduce like whenever any coal particle reaches to this particular location it will again get recycled back immediately to the reactor. So, without exiting the main reactor and spending some amount of time in the cyclone separator. So, by that time maybe material will lose its ignition temperature and other. So, if we placed it inside the reactor these materials or unburned carbon particle going out of the reactor they will stay there less span of time. So basically, we can reduce the residence time of this unburned particle in the cyclone separator So time spent by this unburned particle in the cyclone separator, we can reduce if this cyclone separator is just nearby.

So overall path travelled by this particle, we can reduce it if we place this separator just inside or nearby this. So, this makes the design much more energy efficient as well as much more combustion friendly. all the particles or all the unburned carbon particles released or getting out from this reactor will return back immediately, not after spending 3 or 4 seconds or 5 seconds in the cyclone separator. So, this time we can save there. So, as a result, combustion efficiency also increases as well as the thermal efficiency of the reactor also increased. And in the further upgraded version where pressurized reactor is also used which is known as the PFBC. So, it is basically the pressurized unit where this reaction occurs at high pressure. That means if we want to do this entire fluidized bed reaction at high temperature including modification required for the internal circulating like this will be a pressurized fluidized bed reactor along with facilities or methods like internal circulating like it will be a CFBC unit or internal circulating fluidized bed unit along with operating at high pressure. So, if we use this unit at high pressure like 16 bar or 16 atmospheric pressures. So, what we can do is place this entire fluidized bed reactor inside a strong reactor that can withstand very high velocity or high-pressure air. So, in such a case, we call it pressurized fluidized bed combustion or, more specifically, pressurized internal circulating Pressurized internal circulating fluidized bed combustor. So, what advantage can we get if we pressurize this reactor?

The first advantage we can get is that as we increase the pressure of the reactor, the partial pressure of the oxygen supplied into the reactor will be on the higher side. So, if oxygen is supplied at high partial pressure, that means the concentration of air inside the reactor will be high. So, if the concentration of air inside the reactor is on the higher side, the diffusion coefficient for this ash layer diffusion—like this coal particle—we need to supply oxygen inside this coal particle, and after some time, a thick ash layer is formed. If we can increase the partial pressure or concentration of this oxygen, it can easily diffuse, as the diffusion coefficient of oxygen will be high at high pressure.

So, although the ash layer will be there on the coal particle, the coal particle will still easily get access to oxygen and will burn more efficiently. So, if we use high pressure, we can increase the combustion efficiency or conversion rate of the reaction, or we can easily improve the combustion rate for the highest coal particle, which is the typical major problem for the highest coal particle—their rate of combustion is slow due to the formation of a thick ash layer. Already in this arrangement, we are adding bed material, limestone, etc. which continuously removes the generated ash from the coal surface, as well as supplying high-pressure air for a high concentration of oxygen. This will significantly improve the rate of combustion of the coal particle. So, the overall rate of combustion of the coal particle is increased. So that indirectly gives us advantage in different ways like we can use bigger size coal particle like we can use even 10 mm or 12 mm coal particle as concentration of oxygen is high even 12 mm coal particles also get burned within the reasonable amount of time this is the one advantage. Second advantage we get is that as we are using pressurized system high concentration system we can easily reduce the volume of reactor. So entire reactor that's fluidized based reactor volume can be reduced to get same thermal efficiency or same combustion efficiency as we are increasing the pressure. So overall size of the reactor can significantly be reduced. So, heat loss and other advantage we can easily get.

So, this is the typical arrangement for PFBC that all the coal is there and we also use a compressed air here which is sent to the CFBC and remaining units are same as per of normal thermal power plant design. So, if we see there. there are three different designs are available like CFBC. It is the nowadays we can say it is the base model or base variant as AFBC has very less efficiency and very less selectivity about the particle size. So typically CFBC we can consider it like the base model whereas the ICFBC or IC internal circulating pressurized fluid as bed combustion, they are the much more advanced units or better units Internal circulating typically improves the heat transfer inside the fluidized bed reactor and as a result we can get better temperature control and we can also use bigger size coal particle that makes lot of ease for the coal handling plants not to crush the coal to very smaller size. So, we can even we can use the bigger size coal particle.

So, if you are using internal circulating as well as pressurized internal circulating unit, we can save lot of space, lot of investment cost in the coal handling section rather that cost we can incorporate in the And in all the cases increase in residence time that increases the rate of combustion and eliminates the chances of any of the release of unburned carbon particle in the fly ash, bottom ash as well as the unburned carbon in the flow gas. if we use the PFBC that improve the driving force for the combustion as at high pressure, partial pressure of oxygen is increased. So, which increase the rate of combustion. So, whatever the impact of as layer resistance is there that can be overcome or that can be eliminated. So, in this unit particularly in pressurized unit, we can even burn bigger size coal particle or we can burn other coal particle which is difficult to burn in normal combustion units like even normal CFBC type of fuel is not suitable but those fuel can also be used in this reactor. Like if we see like a coke making units, when we make the coke, some amount of coke fines is already there.

So, these coke fines can also be burned in this unit, reducing the energy loss from the coke fines. These coke fines are typically not used in the blast furnace as they do not have the desired properties required for the blast furnace. So even the coke particles which have almost 1% or 2% of volatile material can be burned here, as they have higher residence time, high temperature, and higher oxygen concentration. So effectively, if we use the pressurized unit, we can burn any type of fuel, any type of coal particle. Particularly, in the present scenario where coal is burned along with biomass as co-firing, the characteristics of biomass differ, and their density and size can vary widely depending on the origin of the biomass. Thus, biomass co-firing is possible if we burn them in fluidized bed combustion. They can also be burned in pulverized coal combustion, but they achieve much better efficiency, or we can use a higher quantity of biomass in fluidized bed combustion. That's why, in recent times, many units have adopted biomass co-firing along with fluidized bed combustion to achieve the burning of inferior-quality coal. As we use high-quality coal in thermal power plants as well as in steel plants, there is always some accumulation of high-ash coal particles or reject coal in coal washeries. Since the energy content or calorific value of such coal is lower, typically, these coals are not burned or cannot be burned in very large industrial units.

So even those types of coal—reject coal, tailing coal, coal fines, coke particles, biomass, and even municipal waste—all these materials can be burned in this fluidized bed combustor. Now, depending on the requirement, we can use either CFBC, ICFBC, or pressurized internal circulating fluidized bed combustion.

Thank you.