Clean Coal Technology

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Week-07

Lecture-31

Hi, I Prof. Barun Kumar Nandi welcome you in NPTEL online certification course on clean coal technology. Today we are starting module 7. In this module we will discuss emission control or pollution control from various combustion utilities. So, these are the details of concepts which will be discussed like we will discuss about the air quality, emission control strategies for power plants, emission and pollution control guidelines, use of ESP, cyclone separator, filters, settling chambers, etc. So, let's start lecture 1, Pollutant control from coal combustion utilities.

So if we see the different type of pollutants which can be generated from coal combustion utilities, they are of different types like there can have some amount of bottom ash, fly ash, unburned carbon in bottom ash, unburned carbon or unburned hydrocarbons in fly ash, unburned hydrocarbon in flue gas which may contain Tar, carbon monoxides as well as different hydrocarbons, SO2 in flue gas, NOx in flue gas, heavy metals in coal flyers. So if we discuss one by one why any how these pollutants are created so if any coal is burned whatever the ash is produced they are divided in two parts like whatever the coal is getting charged some of the coal particle will go along with the flue gas whereas the some of the coal particles which are typically heavier in nature they will precipitate or they will fall in the bottom which is known as the bottom ash. So, any coal particles after combustion if the mineral matter particle density or size is on the higher side which easily falls down. So, they report to the bottom ash. So typically, bigger size coal particles report to the bottom ash in the coal combustion utilities or if unburned carbon particles are on the higher side, they also go to the bottom ash. Whereas in the fly ash are those particles where the particles are of very light density and light size very smaller size. So that all these particles will go along with the velocity of air or air flow rate which is going as flue gas. So typically, these particles are very lighter in nature most of them are in the 1 micron 2 micron or similar sizes and some of they may be less than 1 micron like they are in the nanoparticle range. So, these are the two types of ash typically generated in any coal combustion utilities. Apart from that, there can have some amount of unburned coal or unburned hydrocarbons in the bottom ash. If coal particles do not get their desirable combustion due to various reasons, as we have discussed earlier, so if there is any combustion issues related to the coal particles, so those coal particles will remain unburned So this unburned percentage may be like that whatever the hydrocarbons are there, 80% has been burned, remaining 20% is not burned or maybe remaining 5% has not been burned. So those unburned hydrocarbons will be reported to the bottom ash. Similarly, if there are very, very lightweight hydrocarbons, which does not get good amount of combustion times reactions due to various reasons, so they also can be present at the fly ash.

Apart from that, again due to the in efficient or not proper mixing of oxygen gas or air in the combustion chamber there can be zones where released volatile material as well as hydrocarbons are not getting adequate time or adequate contact with the oxygen gas. So, all these hydrocarbons fuel gas they can released in forms of tar or carbon monoxide or in different forms of hydrocarbons. So unburned hydrocarbons are also possible in the gaseous phase or they also can be like in a solid phase particle. So, in both the phase we can have unburned hydrocarbons in fly ash and unburned hydrocarbons in the flue gas. And apart from this, there can have sulfur dioxide or SOx gases in the flue gas if sulfur is present in the coal. If nitrogen reacts with the oxygen, it can form NOx in the flue gas or there can have different type of heavy metals also present in the coal ash. So, if we see the overall scenario, typically in Indian scenario, power sector accounts for about 51% of sulfur dioxide emission of overall. Whatever the sulfur emission we got in the environment, they come from the different sources like thermal power plants.

Some of them may be cement plants. Some of the other sections are also there who use sulfur rich compounds in their process. So overall, whatever the sulfur dioxide emissions are there, typically 51% or major part of the sulfur emission comes from the power sector. Apart from that, the automobile sector also causes some amount of sulfur oxides emission. So, if we see a significant amount of sulfur oxides emissions are originated from the coal or thermal power plant.

Apart from that, Overall amount of CO2 released in the environment, that is out of 100% CO2 released, about 43% of the CO2 originates from the coal-fired combustion utilities. It can also have some 20% of NOx emission and 7% of PM2.5 emissions or PM2.5 fly ash particles or coal particles. And in some of the cases, tail particles are also there and they are also problematic. Now, if we see here, what is the definition or what is the meaning of this PM 2.5?

PM 2.5 typically represents coal particles or fine particles present in air which are size is of less than 2.5 micron or above 2.5 micron. If any particles, fine particles suspended in the air or like some dust particles suspended in air, if their sizes are in the range of 2.5 micron, they are called PM2.5. Similarly, if the particle diameter or particle size is 10 microns, they are called PM10. As we can see, among these PM10 and PM2.5, The bigger the fine particles or the bigger the dust particle size, they will be trapped by our body or by normal filtration equipment. So typically, bigger size dust particles are problematic, but they can be captured much more easily. So, they make They are dangerous, but their extent of danger is a little bit lower. But if we see the PM2.5, they are very fine particles. So, our body cannot separate those particles, and they directly go to our lungs during the inhalation of oxygen gas. So PM2.5 particles, if they are there, they are much more environmentally dangerous and should be on the lower side. That's why although PM10 is there, in most cases, PM2.5 is measured as the extent of particulate matter present in the air. If this percentage is on the higher side, it is very dangerous, whereas PM10 is also dangerous, but the extent of danger is on the lower side, as our normal body, through masks and other things, can filter those particles. But it is very difficult for PM2.5 particles to get filtered by normal filtration methods or others. So PM2.5 particles are considered very dangerous particles, and they are taken as a measure of the air quality index as per environmental norms. And if we see from this Combustion utilities or thermal power plants, cement plants, or similar plants account for a major amount of pollution in the air. Like 51% of sulfur emissions, 43% of carbon dioxide emissions, 20% of NOx emissions, as well as 7% of dust particles, PM2.5, they originate from coal. So, we have to reduce or use some equipment or methods so that we can reduce the harmful release of compounds or materials into the air if we want to burn coal in a more environmentally friendly manner.

Like if we want to continue to utilize this coal in the future also, we have to take care of all these pollutants which are released into the environment from coal-fired utilities. And if we see in this context, particularly pollutants or dust particles from biomass, they are even smaller in size and can even be in nanoparticle size also. So, if any Thermal power plant biomass is also burned. So that biomass burning can also cause the release of nano-sized ash particles. So we have to also take some additional steps if we are co-firing biomass in the coal-fired utilities. We have to also take some additional steps or protections so that these nanosized ash particles do not come into the air. Ambient air pollution has severe negative impacts on human health. If air pollution is in the severe range, like depending on the particulate matter concentration of PM 2.5, there are different air quality index parameters. If they are below 50, it is very excellent. If they are between 50 to 100, they are satisfactory. But if they cross above 100, they come into severe, very severe, and such category ranges. Similarly, if SO2 is present in the atmosphere, it causes acid rain as well as other injuries to our body. Human health and others, so when emitted into the atmosphere, SOX, NOX, and in some cases, mercury, lead, and other harmful metals also present in the coal, so they undergo different types of chemical reactions to form some compounds which can even traverse a long distance like If we release SOX and NOX along with different types of metallic pollutants, it is observed that these pollutants can even travel long distances.

The significance is that even if coal-fired thermal power plants or combustion utilities are located at some particular position, their pollutants can travel long distances of 50 kilometers, 100 kilometers, and maybe beyond that. As these coal particles or these pollutants are released in the top layer of the air, they can easily be transported at the velocity or natural velocity of air at some particular heights. Like, if this is the location of that air chimney, it releases pollutants from here, so they can even travel a long distance. So, even these pollutants can travel up to 50 kilometers, 100 kilometers, depending on the velocity of air, direction of air, and particular size and temperature. If the temperature is low, like in winter conditions. So, in winter conditions, the density of air is on the higher side. So, this particular matter will always stay in the lower heights of the atmosphere. So, in such cases, it will be very severe pollution. But in the summer season and other seasons when the temperature is relatively on the higher side, the density of air is low. So, these particles can disperse even up to much longer distances. So, these fine particles and compounds contribute to death and serious respiratory illnesses like asthma, chronic bronchitis, and other diseases. So, the pollutants released from all these coal-fired utilities can cause different types of serious respiratory illnesses as well as even death in some cases. If we see the present data as of May 2023, as per the Ministry of Power data, about 50.7% of India's total installed capacity is coal-based. This value is decreasing day by day as the contribution from different types of renewable energy sources like solar energy and wind energy is increasing. But still, in the Indian context, about 50%, or you can say half, of the power production originates from coal-fired utilities. And this 50% is only in terms of percentage share. As our power demand is increasing day by day—in all the villages and all the cities—we are consuming more electricity as an index of our growth, per capita consumption of electricity, etc. So, this is only the percentage; if we see the megawatts or gigawatts of electricity produced, that is increasing every year or every month. Every year, we are adding some more coal-fired utilities or coal-fired thermal power plants to increase the electricity output or electricity generation capacity. So, although this percentage is decreasing, the overall amount of thermal power production is increasing day by day. And considering all other fossil fuels like diesel engines and gaseous fuels, some of the thermal power plants consume diesel. Some of the thermal power plants are even based on gas-based power plants like gas turbines and others.

So, they also consume. Contributes to this pollution by the release of SO2, CO2, and other pollutants. So overall, if you see the contribution from total fossil fuels like only from coal, it is about 50.7%, and adding diesel, which is also a fossil fuel, as well as natural gas and others, they are also fossil fuels. So Overall, fossil fuel-based power production is around 56.8%. So, this is a significant amount, and this overall capacity is increasing day by day, although the percentage remains the same. So, these are the pollution guidelines, recent pollution guidelines by the Ministry of Environmental Regulations, released on 7th December 2015. By the Government of India. So here we can see that the government or ministry has fixed the emission guidelines for thermal power plant utilities. For example, if the thermal power plants are very old plants, retrofitting different equipment is very difficult, and typically their capacity is on the lower side. As we can see in the present thermal power plant scenario, whatever plants were installed 25 or 30 years ago, they were of smaller capacity, like 75 megawatts, 100 megawatts, or 200 megawatts, and so on. So, as they are in such plants, the ministry has allowed for higher particulate matter emissions. But for any power plants installed after 2017, we can see that their emission criteria are very strict—only 30 mg per cubic meter. Whereas for old power plants, the extent of pollution is still on the much higher side. The same is the case for sulfur emissions, where it is about 600 mg if the power plant capacity is less than 500 megawatts, or it can be 200 mg if the capacity is more.

And at present, whatever plants are being installed nowadays, those should have much stricter capacity SOx emission guidelines, like only 100 mg per cubic meter. The same is the case for NOx, which is already being reduced to significantly lower values, and there are also guidelines for mercury emissions, which must be in very small quantities. So, if we see that day by day, The environmental guidelines or environmental pollution guidelines are getting much stricter.

So all the thermal power plants or power utilities has to be ready with their very strong and robust pollution control mechanism to meet the environmental regulations so they can burn coal to produce electricity to run the plant smoothly so they have to adopt new and newer technologies to control or to reduce the environmental pollution in terms of particulate matter sulfur dioxide NOx and other pollutants so if we see the real time pictures of some of the pollutants like if you see the coal ash it is the solid residue what we get from the combustion utilities like solid waste material which is can be released from the power plant now if we see the coal ash which is broadly divided into different parts as we have discussed one is the bottom ash one is the fly ash the heavier ash particles they are settled downs they are known as the bottom ash so these are the typical pictures Of the bottom ash particles what we can see if coal is burned at bigger size like fuel bed combustion there we can have bigger size ash particles whereas if the coal particles are burned in a smaller size like FBC units as well as the pulverized units or similar units coal can be having similar size of ash particles depending on the feed size. whereas the fly ash particle this is the actual image of the fly ash particle which are almost very fine their fineness range in the below even the below talcum powder range so typically the light ash particles where the particle size is on the lower side as well as the particle density is also less so they can easily fly along with the flue gas so they are known as the fly ash now here important aspect is that that composition of bottom ash and fly ash are completely different whenever we do any proximate analysis whenever we do any ash analysis if we go for the ash composition analysis so we will find a metallic oxides or non-metal oxides present in ash. They are completely different as ash contains different metal and non-metal oxides, some of them are very much toxic and very much harmful for the environment, which can cause all type of pollution like air pollution, soil pollution and groundwater pollution. And based on combustion methods, mass of fly ash and bottom ash may vary. So, if we particularly discuss about this particular two point like this point and this point if we discuss in details like. The amount of fly ash generated from the different types of combustion utilities.

So, if we see, if we burn the coal in the fuel bed combustion, there we burn bigger size coal particles. So, as their bigger size coal particles is there, most of the coal will be in the bottom ash like in this picture, either this or this. So, in case of fuel bed combustion, most of the ash particle will report to the bottom ash. coal particles are burned in the bigger size. Similarly, in the FBC unit, as the coal particles are burned even in 2 mm or 10 mm size, their bottom ash, quantity of bottom ash will be on the higher side.

So, about 60 to 70% or 80% of the ash generated will be reported as bottom ash. But if we consider pulverized coal combustion, in the case of pulverized coal combustion, since we are already grinding the coal to less than 75 microns, the generated ash will always have very fine particles, maybe 2 microns, 10 microns, 5 microns, and some particles may even be in the sub-micron range. So, as these particles report to the fly ash or to the bottom ash, whether any generated ash particle will go as fly ash or bottom ash depends on the particle density. Or, more deeply, if we consider particle composition—if this fly ash or ash particle contains heavier metals like silica, alumina, iron, etc., meaning their overall mass is higher—they will always precipitate as bottom ash. But if these ash particles contain alkali-rich materials or other lightweight metal oxides, their overall weight is less, and their molecular weight is less. So, even for a 1-micron particle, if the elemental composition shows that all the lightweight metal oxides are present, their overall weight will be less. So, in most cases, they will go to the fly ash. Whereas, even for a 1-micron particle, if their particle matter density is higher—like if lead oxides and other heavy oxides are present—they can be reported as bottom ash due to their high density. As a result, we can see that the chemical composition of bottom ash and fly ash are completely different.

This part is sometimes neglected, and we are not aware of this particular aspect. Typically, in laboratories or other cases, we generally analyze the ash composition of the raw coal. That means after burning the raw coal, we get some amount of ash, and we know that this ash is present in both bottom ash and fly ash. But we must analyze individual bottom ash as well as fly ash because their chemical compositions are different. So, any environmental pollution created by fly ash will be of a different nature, and any environmental pollution created by bottom ash will also be different chemical composition and, based on the combustion method—whether we are going for pulverized coal combustion, fluidized bed combustion, or fuel bed combustion—the amount of ash quantity will also vary. So, if we want to reduce the fly ash content, we have to go for fluidized bed combustion, but their thermal efficiency and other efficiencies are lower. So, to improve the combustion efficiency again, we have to return to pulverized coal combustion. The overall final decision is taken considering all aspects, whether the plant will be able to maintain the desired environmental guidelines as well as the desired thermal efficiency. And if we observe the unburned carbon particles, typically, these unburned carbon particles originate from the incomplete combustion of coal due to various reasons that we have discussed in our previous lectures. For example, if combustion is not properly completed, coal is not igniting properly, or there is a mismatch between coal design and combustor design, etc. There may be a shortage or inadequate supply of oxygen, etc.

So, for these various reasons, unburned hydrocarbons can be present in the ash. This means if a coal particle does not achieve the desired level of combustion or burning, some of the coal particles are converted into coke particles within the coal. They will remain as unburned carbon or unburned hydrocarbons present in the coal. Improper mixing of air and coal also results in not all coal particles receiving adequate oxygen for combustion. This is another reason. There can also be a shortage of residence time during combustion, where particles enter the combustion chamber but escape the main combustion zone, where the temperature is higher, so they are burned at a lower temperature.

They do not receive the desired activation energy and may escape due to the velocity of the primary air or flue gas. They can escape from the main combustion zone where they should be burned. As a result, there can be some incomplete combustion. Also, there can be a mismatch in particle density, such as a mismatch if the primary air velocity is either too high or too low. So, if the primary air velocity is too high because primary air velocity should be based on particle density. If we use a constant primary air velocity, so very lightweight coal particles may not get adequate residence time, they will directly go to the flue gas. or if their particle density is very higher side, they will quickly settle down and deported to the bottom ash. Similarly, there can have lower volatile material delay in ignition and there can have significant differences between the theoretical or actual ignition temperature and burnout temperature for which burner has been designed and their value is not there in the feed coal. There can have higher fixed carbon, space time required for the combustion and others.

There can have higher burnout temperature for coal. It can may have some flat DTG curve where rate of combustion is steady but slow. There can have issues with the bigger size coal particle residence time and ash layer not allowing the gas diffusions. So, all these are the different points or different reasons for which we can get unburned carbon particles in the ash. So, details of this on this topic I have already discussed in previous class in coal combustion modules and others.

So, if there are any unburned carbon particles in ash is observed either it is a bottom ash or in the fly ash we have to identify the. different reasons for which it can have. And accordingly, combustor has to be modified or operated with some different parameters so that we can avoid any amount of unburned carbon particle in ash. If there is any unburned carbon particle, that means effectively it is the fuel loss. We are paying money for the fuel coal to buy and we are not utilizing the amount of energy available in that coal particle.

Similarly, if there are any unburned hydrocarbons in the flue gas, unburned hydrocarbons in the flue gas also can be different reasons due to incomplete combustion and other. Like there can have methane, hydrogen, there can have different aromatic hydrocarbons or aliphatic hydrocarbons may be present along with the carbon monoxide. So, all are the different type of unburned hydrocarbon gases which can be present in the flue gas. Their main reason is that inadequate oxygen supply during combustion making it limiting reactant as well as not proper mixing. They can have low temperature during combustion. Like if you are not burning all these hydrocarbon gases at suitable temperature, so they may not get that desired activation energy or maybe at lower temperature. The bigger hydrocarbons are only thermally cracked to get low molecular weight hydrocarbons and these low molecular weight hydrocarbons are releasing from the coal combustion utilities without getting properly burned by the oxygen. So, it may be reason that there is excess primary air but no secondary or tertiary air is supplied. As in combustion always some secondary and tertiary air is required. We cannot supply the entire oxygen as primary air.

So, we have to divide the amount of air supplied or 100 percent air supplied to make it in two or three different parts like some amount of air as primary air and remaining amount of air as secondary air as well as tertiary air depending on requirement. So, you always have to supply suitable amount of secondary air and tertiary air if you are not supplying this there can have unburned hydrocarbon gases and this is the major reason for unburned hydrocarbon in the flue gas like the coal can be there and we are maybe providing excess primary air so as per the Le -chatelier's principle as During coal combustion, once they form or release from the coal surface, either as volatile material or as well as CO, they will leave the coal surface and even go out without proper burning. there can have reason like delay in combustion if combustion is occurring but that may be occurring at higher temperature. So, furnace may not have that amount of temperature. So, but maybe that coal particle is ignited at later. So, coal particle will not get desirable time for burning. So maybe only the de-volatilization of coal or only the carbon monoxide production reaction has been completed but other reaction is yet to happen and they are leaving the combustion chamber as flue gas. VM reduced during the combustion, they may not get adequate time or oxygen for combustion. Similarly, they can have high primary air velocity. Cool combustion characteristics does not match with the combustor design and they can have improper mixing of coal and air. So, all these points I have discussed in previous class.

So, even overall if we see the main reasons for unburned hydrocarbon in flue gas is the combustion issues like there is mismatch in the combustion properties of coal as well as the reactor design there can have problem with the primary air or secondary air or there can have that very high velocity of primary air or very low temperature of combustion etc. So, these are the major reasons for which we can get significant number of hydrocarbons in the flue gas. So, if we see any flue gas contains all these hydrocarbons we have to think that there are some combustion issues in the boiler or in the combustor. Accordingly, we have to act and we have to check what is the main reasons, so that these materials do not release to the environment similarly If we want to identify how to identify what are the problems in the combustion systems. So, if we want to identify if there are any problems in the combustion system. First of all we have to go for the flue gas composition analysis. This flue gas composition analysis is analyzed by the flow gas analyzer. Readymade equipment as well as the gas chromatography GC or similar type of equipments are available to the thermal power plants. So, this flue gas composition analysis is very important and it gives detailed information about the exact combustion characteristics, what is happening inside the combustor. It is like a blood test.

Like in our human body, if we do a blood test, we identify different types of materials present in blood—whether they are as per the rule, as per the guideline, or if they are in excess or too low. Some lower or higher values signify that there are some problems in our human body, and accordingly, we take medicines. Similarly, if we analyze the flue gas composition, it gives detailed information about what is happening inside the combustor. Typically, in flue gas analyzers in thermal power plants, we measure the amount of carbon monoxide, oxygen, nitrogen, hydrocarbons, hydrogen gas, NO_x gas, and SO_2 gases. These are the different gases which are typically measured in flue gas analysis.

Why? From coal combustion, we will always get carbon dioxide. If oxygen is in excess, we will detect oxygen present there. Nitrogen will always be present. If there is incomplete combustion, we will get carbon monoxide. If there is incomplete combustion, we will get hydrocarbons and hydrogen gas. If the temperature is excessively high and it allows NO_x formation, we can get NO_x. If sulfur is present, we can get SO_x or SO_2 gases. So, in most cases, these are the gases that are analyzed. Now, how do we identify combustion utility issues by analyzing the flue gas?

Like if we see only CO_2 and SO_2 is present. If in the flue gas the CO_2 and SO_2 are the main component and there are negligible number of other gases. Like nitrogen will always be there. So, if we found that only CO_2 and SO_2 is there. That means sulfur is converted to sulfur dioxide. CO_2 is converted to the carbon dioxide. So, it is the absolutely perfect condition. CO_2 and SO_2 is present along with this oxygen and nitrogen like these are the common gases will always be present if excess air is there. So, and along with some H_2O will also be there. So, if these are the material present it is okay but if there is some amount of carbon monoxide presence like CO_2 is also present and carbon dioxide is also present that means it is not getting desirable amount of oxygen or desirable amount of mixing inside the reactor, inside the combustor. Like any presence of carbon monoxide means there is some combustion issues, it is not getting desired amount of oxygen as well as it is not getting desired amount of residence time in the reactor. So, we have to accordingly modify the air velocity, primary air, secondary air, etc., Similarly, if there is any hydrogen or hydrocarbon as present, that means it is also not getting desirable combustion. So, this represents incomplete combustion. Maybe shortage of oxygen or maybe temperature in the reactor is not on higher side. So, that hydrogen and hydrocarbons reach their activation energy level to get it completely burned.

Presence of nitrogen is very normal. It originates from the air. But if NOx concentration is on the higher side, some amount of NOx may form in trace quantity that may form. But if NOx percentage is on the alarmic range that it is on the higher side, that means there is some zone or some of the location in the combustor which has created some hot spot like temperature is exceeding 1300 1400 or may be 1600 degree centigrade so there can have some of the hot spot where temperature is very high so at that particular zone nitrogen is reacting with oxygen so if NOx is present that means there is some temperature profile issues inside the combustor which may not be the desirable temperature range in the combustor. If presence of oxygen is there which typically originates from the excess air. So, if we are using excess air always some amount of oxygen will be there in the flue gas. But if excess air is not used but we are finding some oxygen is there. That means we have not used any excess air but still we are finding some oxygen.

That means some incomplete mixing of coal particles and air is there. That although we are supplying air but it is not properly mixed with the coal particle or fuel droplets or fuel particles. So, it is coming out of the reactor without doing the chemical reaction. Similarly, if both CO and oxygen are there, like if both carbon monoxide is there, carbon monoxides are generated if oxygen is there is some shortage. But if we found both, that carbon monoxide is there as well as oxygen is also there. That means there is a major problem in terms of combustion. Like there are some coal properties is not matching with the desired reactor design. Reactor is smaller in size. Whether coal particle residence time needs to be higher. There is not proper mixing and others.

So, all these issues, some major issues in the combustion system. So, if we want to control the unburned hydrocarbon as well as unburned hydrocarbon in the flue gas as well as in the unburned hydrocarbons in the ash. We have to think that it's originated from incomplete combustion of the coal particles or fuel particles inside the reactor. So, first of all we have to identify where is the combustion issues whether it is a mismatch of coal particle and design of boiler or not properly air is supplied mixing of fuel particles and air is not there or there can have need some secondary air or tertiary air all these things we have to first of all identify and accordingly we have to act. So that there is no release of unburned hydrocarbon or unburned carbon particles either in the ash, bottom ash or as well as in the flue gas.

Thank you.