Clean Coal Technology

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Week-05

Lecture-25

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are discussing the effects of coal properties on combustion in Module 5. In the previous class, I discussed the effects of volatile material, fixed carbon, mineral matter, moisture, coal particle density, particle size, and the role of primary and secondary air. In this class, I will show the methods used in the calculations of flue gas composition when coal is burned. So, let us start Lecture 5 on combustion calculations.

In combustion calculations, the ultimate analysis reports of coal or any solid fuel are also applicable to liquid or gaseous fuels. So, their ultimate analysis report is used, or we need the ultimate analysis report of the fossil fuel. In this ultimate analysis, we need C, H, N, S, O—that is, the amount of carbon, hydrogen, nitrogen, sulfur, and oxygen present in coal. In coal, apart from this, there is moisture. Ash or mineral matter is also present, so when we do these calculations, we have to consider that the hydrocarbon part is represented by CHNSO. This CHNSO represents the volatile material and fixed carbon part, and apart from this, there is a moisture percentage. There is also some mineral matter or ash, as during the combustion process, mineral matter is converted to ash. Typically, the weight percentage of ash is on the lower side—for example, if there is 30% mineral matter. When it is burned, there is some mass loss for the mineral matter. So, it makes around 27% ash. That's why, in this calculation, typically, the ash percentage we get from the proximate analysis is multiplied or increased by about 10%. If some sulfur is present, this multiplication factor of 1.1 can be 1.08 or 1.07 like this. So, this is broadly that there is about 10 percent decrease in the mass percentage of the mineral matter when it converted to ash. So that correction factor is taken that's why mineral meter percentage is assumed to be like this about 1.1 some cases 1.08 if sulfur is present if other elements are also present, then we have to take accordingly some necessary corrections factor this. So, this part represents the mineral matter presence in the coal. Then we have to do the moisture percentage present in coal and we should take the CHNSO part. So that should combine will make 100% of coal.

Now, typically, if we see this CHNSO analysis, this is carried out typically on the dry coal sample. As in the fuel, there can have hydrogen, which may start from the moisture presence. Otherwise, it can also come from the different hydrocarbon part. So, to eliminate or to reduce the error of to identify from which source hydrogen is there in the ultimate analysis.

Typically, ultimate analysis is done in dry coal sample where external moisture is not there, maybe some minor quantity or smaller quantity of moisture is there. And also, if moisture is present in higher quantity, typically CHNSO analysis takes lots of time and it can create problems in different type of sensor or equipment that methods used in the analysis. Like TCD detector and IR detector, they will take lot of time to identify amount of sulfur, nitrogen, hydrogen presence in fuel. So typically, this CHNS analysis is done on the dry coal sample or air-dry coal sample. That is, to avoid any of this hydrogen conflict, whether it is coming from fuel hydrocarbon or moisture hydrocarbon, ultimate analysis is carried out on moisture-free coal. But we cannot avoid this part. Some amount of moisture can always be present in coal. Gas emissions from mineral matter and moisture are typically not considered when we perform combustion calculations. For example, when we perform combustion calculations regarding the amount of carbon dioxide, sulfur dioxide, or water released from the coal. Typically, we calculate based on the CHNSO analysis, where any pollutants or gases released from the mineral matter are not considered because we are not analyzing the detailed composition of the mineral matter. So, typically, those calculations are not done, and the contribution of any gaseous emissions from the mineral matter is on the lower side. So, in typical coal combustion calculations, gas emissions from mineral matter are not considered. So, here, that means whenever we perform coal combustion calculations, we only consider the hydrocarbon part, and those calculations are done. All the combustion reactions are based on the stoichiometry of the chemical reactions.

Whenever we perform these combustion calculations, all the chemical reactions we consider during the calculation are based on stoichiometry. In stoichiometry, all the reactions, when we consider the mass of reactant or mass of product taken, all these calculations are done on a mole basis. For example, any reactant reacts like 1 mole of oxygen reacts with 2 moles of hydrogen. 1 mole of carbon reacts with 1 mole of oxygen. So in this way, all the calculations are done on a mole basis. It can be on kg-mole or gram-mole. Depending on the amount of fuel or whatever is there, but it is always done on a mole basis because chemical reactions happen not based on mass. It happens based on a mole basis. Like, not that 1 kg of coal reacts with 1 kg of oxygen.

It is like that 1 kg-mole of coal reacts with 1 kg-mole of oxygen. So, all the stoichiometric calculations are always carried out and reported based on a mole basis. And finally, we can convert them to either mass percentage basis or kg basis, or we can convert them to volume basis—liters, meter cube, whatever. And so, from the element analysis on kg-mole or gram-mole basis, whatever we get, all the elements are then converted into their kg-mole and gram-mole. So whatever the mass percentage we get from the CHNSO, initially they are converted to kg-mole or gram-mole and when we calculate the flue gas composition, typically we calculate carried out calculations based on some basis or considering some fixed amount of mass of coal, like we can consider for 1 kg of coal—if 1 kg of coal is there, what will be the amount of CO_2, SO_2, and other gases generated—and later 1 kg is converted to the actual amount of fuel charged in the combustor. So, calculations are done on some basis of mass, like some fixed amount of mass is taken. It may be like 1 kg or 100 kg or 100 ton or 1 gram, whatever.

It is done based on a fixed amount of mass. So, it can be like 1 kg, 100 kg, or a similar value. based on whatever fuel we take. If it is gaseous fuel or liquid fuel, we can carry out this calculation based on one liter or one cubic meter at certain conditions. In combustion calculations, we typically consider complete combustion. So, the product will be carbon converted to carbon dioxide by this reaction. Hydrogen will be converted to water. By this reaction, sulfur will be converted to SO_2, which is sulfur dioxide. So, if we see that the molecular weight of carbon is 12, the molecular weight of oxygen is 32, the molecular weight of sulfur is 32, nitrogen is 28, carbon dioxide is 44, sulfur dioxide is 64, and H_2O is 18. So, these are the different molecular weights used in the calculations.

If any other gases are formed there or if any other gases take part in any of the chemical reactions, their corresponding molecular weights should be used in the calculations. So, CO_2, H_2O, and SO_2 on a mole basis are later converted to their volume percentage or mass percentage based on the ideal gas law, like PV equals nRT at standard temperature and pressure or natural temperature and pressure, which is 25 degrees Celsius under atmospheric conditions. So, whatever the mass or mole we get, we typically, when we want to express them in volume percentage, convert them to their corresponding volume percentage using the ideal gas law, which is the PV equals nRT formula at natural temperature and pressure or standard temperature and pressure, which is 25 degrees Celsius and 1 bar. Any excess oxygen is used.

As we have seen in our previous lecture that for combustion process always some amount of excess air is required. So excess air is required to supply additional oxygen so that entire combustion reaction completes and all the combustible material forms. either CO_2, SO_2 and H_2O, not any intermediate products or incomplete combustion product like carbon monoxide, any hydrocarbon gases, etc. So, any excess oxygen present used in the combustion process, this amount of oxygen or air will not be used in the reaction. they are supplied only to ensure that reaction is complete so this amount of oxygen will not be used in any of the combustion calculations they will remain part of flue gas composition as an additional amount of oxygen and nitrogen present in the flue gas so whatever the excess amount of oxygen or excess amount of air we used like if we use 20% excess air, that means volume percentage of or mass of oxygen corresponding to this additional 20% of nitrogen and additional 80% of nitrogen and 20% of oxygen will be part of low gas composition. So, any oxygen presents in fuel it will also be used in the oxygen calculations that is available from the fuel and that will be used in the combustion calculations and that will be used to meet the oxygen requirement from the air. And nitrogen as in mole is part of air. It is not used in the combustion calculations.

It will be part of flow gas composition corresponding to its whatever the volume percentage is there. Nitrogen, if it is part of fuel, it is mostly very lower percentage like in any of the coal, it is like 1.5 or 2 percentage nitrogen is there. So, it is also not used in the combustion calculations and it will be reported to the flue gas as a gaseous material until and unless some special condition or special reaction is mentioned or occurring in the combustion. So finally, the flue gas composition, if we see, it will have carbon converted to carbon dioxide, hydrogen converted to moisture or H_2O, sulfur converted to SO_2, if sulfur is present. Nitrogen will come from both sides, from fuel as well as air. And oxygen will come from excess air if it is used. And nitrogen from air also, if it is there, including excess air. Calculation methods are the same for all types of fossil fuels, biomass, biofuels, liquid fuels, or gaseous fuels. These calculation methods are the same and are common for all types of fossil fuels, wherever we use them.

Whether it is gaseous fuel, liquid fuel, solid fuel, biomass, or others. All these calculations are done based on these methods. So, if we see some model calculations reported in the textbook—like this has been taken from the textbook Power Plant Engineering by Professor PK Nag—I have shown that model calculation and how it is used there. It is also mentioned that carbon percentage, hydrogen, oxygen, nitrogen, sulfur, moisture as This correction factor has not been used here. So, that will contribute to 100 percent.

So, if we take oxygen needed for the oxidation process, it can be calculated by the following method. Like if the reaction is C plus O2 equals CO2. So, as these reactions happen on a mole basis. So, 12 kg, that means 1 mole of carbon, which is 12 kg of carbon, will react with 1 mole of oxygen corresponding to 32 kg of oxygen. It will form 44 kg of carbon dioxide. So, if we do it on a 1 kg basis, 1 kg of carbon corresponds to 2.67 kg of oxygen and 3.67 kg of carbon dioxide. Similarly, if we see the hydrogen reaction, it is 2 moles of hydrogen, 2 H2 react with oxygen, 1 H2, 1 O2 makes 2 H2O. So, this reaction is also 4 kg of hydrogen reacts with 32 kg of oxygen, making 36 kg of H2O. So, here the reaction is 1 kg of hydrogen reacts with 8 kg of oxygen, making 9 kg of water. Similarly, for sulfur, it is 32, 32, and 64. And we get that for sulfur calculation, this should be the formula. So, overall, if we see the oxygen requirement for the entire reaction, the oxygen requirement for the entire reaction is oxygen required for carbon, oxygen required for hydrogen, and oxygen required for sulfur. Combining all this, we can get the total oxygen requirement as 2.67 carbon plus 8 times hydrogen plus sulfur minus oxygen available from the fuel side, where oxygen is, O is oxygen in the fuel. So, as air contents, I have discussed earlier, it is 23 percent broadly. We can use a much more precise value if these values are available or these values are analyzed at their locations. So here, 23.2 percent oxygen has been used on a mass basis. So, on a mass percentage basis, it is 23.2 percent. Therefore, the theoretical air requirement for this reaction will be whatever the oxygen requirement we get here, that will be divided by 23.2 percent here, so W by 0.232 percent is there. That is the part. So, it will be this oxygen, this part, all will be divided by 0.232 percent. So, we can get that the theoretical oxygen requirement will be coming from this formula where C, H, O, S are the mass fractions of carbon, hydrogen, oxygen, and sulfur present in coal as given in the ultimate analysis. So, in this way, we can calculate the amount of oxygen required for the calculations. Now, once we get the amount of oxygen required for this calculation, based on that oxygen requirement, we can analyze what will also be the amount of CO_2 generated from the combustion. Like from this entire calculation, if we see, this is the amount of carbon dioxide produced by this combustion, this is the amount of water molecules produced by this reaction, this is the amount of sulfur dioxide produced by this reaction. So, we can balance the feed size, what the gas composition is, what the material is, and on the product side or reactant side, what the composition of gases and products is. So, if we see there, we can make, if you want to make the excess air calculations, excess air means air actually being used in the reaction and air or oxygen actually required. So, this is the amount of air supplied, and this is the amount of air actually required. We can divide it to get the amount of excess air. So, in the combustion of methane, if we do it this way, we can also get CO_2 plus H_2O. So, in other cases, we can also get similar calculations. So, what we do is that we can make one type of table. Like here, we can make C,H, N,S,O available. It is how many kg of carbon there is. We can mention there. In terms of kg-mole, how much is there. We can make it like here. We can also make gases produced like CO2 produced, how much mole. SO2 produced, how much mole. Then H2O produced, how much mole. So, in this way we can make a table. so that our calculations methods are get very easier we can easily monitor what are the product gases and we can easily make some mass balance because in everywhere their mass balance will be maintained, not the mole balance. When we do this combustion calculations, as the conservation of principle of mass is there, all the feed size gas, their mass is used and all the product size gas, their mass will be balanced, whereas the reactions will be happened in the mole basis. So, in this way, we do or we carry out our entire combustion calculations and we can report amount of carbon dioxide produced in the flue gas amount of H2O produced from the flue gas amount of sulfur dioxide produced from the flue gas. So finally, if we say there will be these calculations like will be there in the Product size, we will get CO2 percentage corresponding to this mole of CO2 we can get.

We can get this mole of SO2 is there. We can get this mole of H2O is there. And excess oxygen whatever is there and total nitrogen whatever is there. We can get it like in their kg mole. We can also convert them in their volume percentage. So, whatever the mole balance is there, if we summarize them, how many moles of gas are there? Because when we convert them to their volume percentage, it is like 1 kg mole of gas corresponds to 22.4 liters in their gaseous phase. At the HTP condition. So, 1 kg mole corresponds to 22.3 cubic meters of gas. So, accordingly, we can convert them into their volume percentage. And finally, we can get the amount of—we can also get the composition of carbon dioxide, sulfur dioxide, H2O, SO2, N2, etc. So, in this way, we typically carry out combustion calculations and analyze what the amount of oxygen present is, what the amount of sulfur dioxide and other gases present is. These methods are similar for all types of hydrocarbon-rich fuels, whether they are solid, gas, or liquid fuels. So, if we summarize there, the entire chapter—typically, this coal combustion—highly depends on the coal's inherent properties, and general characteristics do not reflect the combustion properties. So, when we consider the entire combustion properties, like whatever the individual hydrocarbons are there, individual hydrocarbon composition, their mineral matter composition, everything is represented. That is whatever is part of their inherent properties. So, in general characterization, we do not consider their inherent properties; we broadly characterize them by their ultimate analysis, proximate analysis, but that may not represent the exact combusti on characteristics. Analysis of burning profile parameters indicates possible combustion characteristics, and coal must be burned with suitable size and in the presence of a desirable amount of primary air. And secondary air—that during coal combustion, we must use primary air as well as secondary air, and maybe some tertiary air is required depending on the coal properties. If coal has some excessively higher amount of mineral matter or an excessive amount of hydrocarbons, they may also need some—maybe require some—tertiary air also because, always based on Le Chatelier's principle. Otherwise, coal will be converted to gaseous fuel at the first instance, so Always, supplied oxygen will be on the reacted material, and coal will be on the excess material, so always they will be converted to the nearby gaseous well, and that will lift the coal surface. So, to ensure that the released gases—whatever the unburned gases are released from the coal surface—they get burned, maybe in the later section of the reactor, we always have to ensure that primary air. Along with primary air, some amount of secondary air as well as tertiary air is used in the reaction.

Feed coal in the boiler must be used as per the design condition. Like for what is the amount of volatile matter, fixed carbon and other material is there, mineral matter. for which that particular boiler or particular combustor was designed. Because whenever this design is made, some coal property is considered to make their calculations. But after 5 years or 10 years, after a long duration of time, that particular coal is not available. It will be already consumed from the mines. So, whenever we use other type of coal, always there will be issues in the combustion as it will not have required or as per design amount of volatile material, fixed carbon, etc. Or its even coal inherent structure, their hydrocarbon properties already change. So, we should try to always use their feed coal as per the design. Or we should try to verify whether this coal properties are matching with the design or how we can make this matching by blending with some other type of coal or other type of fuel like biomass or alternate liquid fuel, fuel oil, whatever. So just using any type of coal. like if we consider like it is just an coal it will get burned based on its GCV it will result in always some combustion issues so we must always try to use or follow the coal properties as mentioned in the plant manual or design manual if we use just like it is an coal whether it is from mine A or mine B or mine D it will always create some combustion issues as well as it will always create some unburned carbon unburned hydrocarbon carbon monoxide etc. in the flue gas. So, which will create environmental pollution as well as it will always create some loss of energy because all these unburned hydrocarbons and all this carbon monoxide we pay the cost for all these things when we purchase the fuel. So effectively we are purchasing fuel but we are only using 80 percent or 90 percent of fuel value. So, remaining 10 percent or 20 percent if they are lost as unburned carbon in the bottom as unburned carbon in the fly ash or unburned hydrocarbon in the flue gas always they will make some energy loss this is like an energy loss financial loss as well as the creating pollution in the environment. So, whenever we burn coal or whenever we select coal or whenever we decide to use any particular coal we always we have to always ensure that this particular coal is matching our design parameter if not as per their design we have to be ready with that, there will always be some issues, either combustion issues, environmental issues, as well as energy loss. So, in such cases, we should use some blended fuel, maybe blending with other coal, which will be as per the suitable ratio so that we can avoid any of the combustion issues. And we can burn coal or utilize coal in a much more environmentally friendly manner. And particularly in the combustion calculations, if we see, we can easily monitor the excess oxygen being used in the combustor. If any excess oxygen is there, it always creates some energy loss by sensitive temperature and sensitive heat loss from the combustor. So, we should always try to ensure that excess oxygen is not on the higher side.

It should only be on the desirable side to ensure proper combustion of coal and proper mixing of coal particles with the air. So, we always have to monitor the turbulent condition to see whether the ash is getting removed from the coal surface or not. And we have to find different pathways to continuously remove the ash layer formed on the coal surface to keep the coal burning rate within the desirable rate, as well as the desirable heat release rate, so that we can use a lower amount of excess air during the combustion. Any excess air used in the combustion does not react, but it ensures that combustion is complete. There is no unburned carbon and no other environmental issues. So, particularly at present, apart from this energy loss, environmental issues are much bigger. If any thermal power plant or any combustion utility continuously releases some polluted and unburned hydrocarbon gases, they will face some notice or other consequences from the environmental bodies, and that will create a lot of issues in the thermal power plant. So, we always have to ensure that whatever fuel we are feeding or sending into the combustor matches the design and gets completely burned. In the combustor to avoid any environmental issues, and we can utilize this coal in a much cleaner way. These are the textbooks we can use for combustion calculations, particularly combustion-related issues for thermal power plants. These normal textbooks like Fuel and Combustion by Samir Sarkar and Fuel, Furnace, and Refractories by O.P. Gupta. These are the two major books where we can get most of this material, but detailed analysis may not be available. For which we always have to use some online literature sources, journal papers, like when we want to learn about or discuss TGA-DTG analysis, because all these analyses are part of online resources available in different online journals subscribed by various institutes. Also, for combustion issues and different power plant issues, we can Follow this textbook, Power Plant Engineering by Professor P.K. Nag. This is a very good textbook on Power Plant Engineering, as well as for discussing different combustion issues for various types of coal combustion calculations. Combustion calculations can be found in all these three books. So, all these three books are easily available in hard copy in different institutional libraries.

Thank you.