Clean Coal Technology

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Week-05

Lecture-21

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are at Module 5. In this module, we will be discussing the effects of various coal properties on their combustion characteristics. These are the detailed topics we will cover in this module, such as the effect of volatile material, fixed carbon, mineral matter, coal particle density, particle size, effect of primary air, secondary air, etc. In combustion, as well as we will see some model coal combustion calculations, how to calculate the flue gas composition, calculate the primary air requirement, etc.

So, let's start with Lecture 1: the role of volatile material and fixed carbon on coal combustion. As we have already discussed, Typically, volatile material represents the low molecular weight hydrocarbons either present in coal or derived from high molecular weight hydrocarbons by the action of heat. So, that means some of the volatile materials are directly present or already present in the coal structure, and some of the hydrocarbons which will create volatile material that will be generated by the action of heat. That means once coal is heated, then only that part of volatile material will be released. So, typically, volatile materials are in the gas phase or in the vapor phase. If they are in the vapor phase, they will easily mix with the hot air or air available in the combustion chamber. Now, if we see here, particularly for coal, coal is a solid material, whereas air or gas in air is in the gas phase. So, typically, it becomes a mixture of solid and air. If we see in the case of liquid fuel combustion, they are in liquid and we mix it with a gas. In the case of gaseous fuel combustion, they are already in the gaseous phase. And the oxidant or air is already in the gaseous phase. So, as we have seen, in the case of gas and gas, as all these gases have some Brownian motion, they have a higher diffusion coefficient, and they will easily get mixed.

So even if we add some minor quantity of methane gas with oxygen immediately within very few seconds or millisecond they get mixed without any external interference required by stirring or other thing that is the properties of gas and gas. So any gaseous fuel typically, their gas and air mixture is uniform. As a result, they need minimum amount of air requirement for

combustion and they can easily ignite. In case of liquid fuel, as they form some of during heating, they form some vapor or in most of the engines, IC engines or others. Some liquid fuels are sprayed through a nozzle where they are created like a very small fine droplets are generated.

So they also even gets mixed well with the oxidant air. But in case of coal, This mixing of coal particle and air is little bit difficult or we can say much more difficult. As solid and gas mixture is not uniform, they will take lot of effort to get it mixed. We need other parameters like creating like some turbulence using some other stirers etc.

Many other efforts we have to create so that solid and air get mixed. That is the role of volatile material is that as it is if we mix coal and air it will never get ignited. But from the coal as volatile material is getting released. So this volatile material has some vapor or they are in the gas phase. So this volatile material at the initial stage they mixed with the hot air.

So once they mixed with the hot air very well. So they ignites so if we provide them or if we create some certain condition, certain temperature such that volatile material can ignite then the entire coal particle they also started burning. So if volatile material is there we will get better mixing of air and volatile material. So in such case combustion will be much more better that will be much happens with much more ease due to the brownian motion of the volatile material is vapor phase once this concentration of volatile material in hot air crosses certain limit. So if the concentration exceeds certain limit then this volatile material will catch fire or we call it like an ignition as we have discussed in previous classes that ignition temperature and this combustion process will start. So what we get it that once this combust volatile material air is released. much more quantity of heat provide the required activation energy and required temperature then the fixed carbon of this coal get also ignited so if we see any coal has higher quantity of volatile material so it will release much more quantity of organic compounds or vapors and which will easily mixed with the air So, entire coal will then gets easily ignites or easily burn.

So, what we can see is that higher is the volatile material presence in the coal, then it will have lower ignition temperature. That means if any coal or any biomass it has higher volatile material content, then it ignite very easily so it will have lower ignition temperature and it will burn easily like if we see for example like an methane gas in gaseous fuel like methane natural gas. Even this natural gas is as it is in the vapor phase or in the gas phase even it can ignites at atmospheric condition it doesn't needs to be heated at high temperature As volatile material is

already in vapor phase. So we may consider or we may think like this way that volatile material means there is some low molecular hydrocarbons like methane, ethane, propane etc.

So if any coal has higher amount of volatile material. Once this volatile material released from the coal surface, coal will easily ignite. So if any coal has higher amount of VM, the concentration of released gases will be on higher side. So coal will ignite very easily. it will burn very easily. So its ignition temperature will be less. So major role of volatile material is on the ignition temperature or ignition characteristics of the coal. if volatile material is very less that there are some of the naturally available coal or some of the modified coal or coke if we see or modify solid fuel we can see that volatile material in such fuel is very low like if we see the pet coke or petroleum coke. Petroleum coke is the residue of the oil refineries where after extracting all the valuable naphtha, petrol, diesel, kerosene, fuel oil and etc. Whatever the residue part is there which is mostly rich in carbon but that has difficulty in ignition. So that is known as the pet coke. So if we see the combustion characteristics of pet coke, it has highly 1% or 2% of volatile material and entirely 97 to 98 percentage is the fixed carbon. That means if we do the proximate analysis of coal, we can find moisture content is very less or almost 0% and in pet coke ash percentage is almost less than 1%, we may consider it like 0. So entirely it can have 97 to 98% fixed carbon and only 2% volatile material. So ignition of this petroleum coke or pet coke is very difficult as it has very negligible volatile material. Although this pet coke has very good amount of GCV and sometimes in the range or nearby values of any of the liquid fuel if we analyze in the laboratory petroleum coke can have GCV in the range of 9000 or 8500 kilocalories per kg, so it is an extremely higher value but as it has very low volatile material its ignition is very difficult similarly if we see the coke that is in the coal after coal beneficiation or coal when we make the coke we remove the volatile material to make it a strong coke which is used in the blast furnace. So this coke will have less than 1% or less than 2% volatile material. That is the typical characteristics of coke required in the blast furnace. So if we want to burn coke. Its ignition will also be very much difficult.

It will not ignite very easily. Same thing in the Jhama coal or partially burned coal in the mines itself which is typically available in the Jharia coal field where due to the onset firing or onset ignition of coal even in the coal mines. So some of the coal loses its volatile material and its volatile material content is very less. may be in the range of 5% or 10% or in the similar value may be 12%. So ignition of this Jhama coal coke, pet coke, they are very difficult as they have very lower amount of volatile material.

So we cannot easily burn them in a normal combustor. We have to add externally some amount of volatile material through some other fuels to get it burned. So typically it is observed that if we want to get some travel free combustion like we feed coal and to ensure that this coal will get burned. That means if we want that if we charge coal in a combustor, this coal will burn very easily. Typically around 20% volatile material is required.

If any coal has less than 20% volatile material, then it will always face some ignition difficulty or ignition delay. That means it will ignite in the combustor but this ignition will cause happens in the delayed. So in such case it will not be able to maintain the desired fireball characteristics in the combustor. So typically 20% volatile material is required. It is the lower side how much volatile material should be present in any coal, 25 to 30% range value is very good or satisfactory value. If any coal has volatile material 25% or 27%, even 23%, 24%, that is in the good range. Such coal will burn easily without creating any problem. And if any coal has volatile material more than 35%. if volatile material content is excess like it is beyond 35 percent so in such case coal will burn or ignites very easily if coal ignites very easily so in the combustor in the initial zone or in the just after entry in the combustor it will release all the energy so in such case again that fireball temperature characteristics it will be different and even in some case when coal is mixed with the hot primary air or even during the grinding coal may catch fire so that is very much dangerous condition so if coal has volatile material above 35 percent so it will be very difficult to handle and we have to be very much careful lot of precautions has to be taken when handling such coal in particular, pulverized coal combustion utilities. So, in general, 25 to 30% range value, this range value is good or satisfactory value. If it is less than 20%, we have to be careful that we should expect that there will be some problem in the combustion chamber.

Similarly, if it is beyond 35%, we have to be also prepared that it may create problems in the combustion chamber as well as before combustion whatever the crusher grinder and pulverizer units are there they are coal may also ignites so this is the typical values for the indian coal So if it is less than 20%, it will have difficulty in ignition. And in such case, if it is less than 20% value, like if the volatile material is 15% or 14% or 10%, like if any coal is available, it has only 10% volatile material. So we cannot just avoid it; we will not use such coal as it is a naturally available material. We have to use it in industrial plants or industrial utilities. We cannot just throw it out, saying we will not use this coal now or use it later. Alternative types of coal, like other coal with higher amounts of volatile material, are typically blended with high-volatile coal so that the overall ignition temperature of this blended coal is at a satisfactory

level. Alternatively, we can blend it with biomass, as different types of biomass are nowadays burned in thermal power plants.

So, we can blend some quantity—maybe 5 percent or 10 percent—of biomass in such coal so that its ignition characteristics can be modified or raised above certain limits, such as 20 percent, to ensure proper ignition without any problem. Alternatively, liquid fuels like fuel oil are added in thermal power plants to modify or correct combustion characteristics. When monitoring temperature profiles or firework characteristics, if it is found that volatile material from coal is very low and ignition is not meeting requirements, externally, some amount of fuel oil is added. This fuel oil is obtained from refineries where the cut point is above diesel oil, meaning in the distillation column, after extracting diesel oil, petrol, kerosene, and other valuable fuels, the residual part still contains a higher amount of carbon but may not be suitable for use in automobile engines. So, this part is known as fuel oil, which has a higher amount of carbon and higher viscosity. This fuel oil is typically used in thermal power plants to maintain the temperature profile or to modify ignition characteristics. In general, fuel oil or liquid fuel is very costly, so it is not used in most cases. However, when combustion characteristics of coal are very poor and ignition is not occurring properly, thermal power plants add it as an auxiliary fuel in the burner or boiler to achieve the desired ignition characteristics of the blended fuel. On the other hand, if there is too much volatile material—beyond 35 percent—it is not good because the entire hydrocarbon or gas mixture will burn immediately within a short span of time, leading to unstable combustion. Unstable combustion means sometimes very rapid heat is being released with entire fuel is getting burned and within few seconds combustion comes to almost zero on lower side. Again after few seconds combustion is again at on very higher side. So these are called the unstable combustion. That means rate of combustion is varied widely. Sometimes varied 2 mass percentage per minute and next time may be happening 20 mass percentage per minute. This is an unstable combustion. which may exceed the design temperature of the combustor and may damage many of the combustion equipments, their refractory valve, boiler tube, their welding, etc. It can damage everything. And as it releases rapid heat release for few moments, so it can get some excess temperature which can cause overheating of tube, refractory damage and it also creates difficulty in maintaining the fireball temperature. If volatile material is very high for any of the fuel, as we know, VM plus FC plus ash, this broadly, plus moisture, they makes it 100%. So if volatile material is very high, obviously the fixed carbon contribution will get very less. So whatever the impact of fixed carbon is there, so that will be also seen if volatile material is excessive like if we see the petrol

and diesel like if we do the proximate analysis theoretically it will have entirely 100 percent volatile material. So in such case your coal will act like a liquid fuel. So its combustion characteristics will not be like a coal but its combustion characteristics will be nearby to that of any of the liquid fuel whereas that combustor is not designed for that liquid fuel so whatever the consequences and other impacts will be there that will be visible if volatile material is excessively high like if we see the biomass different type of biomass, their biomass Volatile material is always more than 50%, 60%, 70%. We all have seen that biomass burns very rapidly. Entire biomass burns within very few minutes or very few seconds. So, if any coal has similar characteristics, it will be difficult to utilize in conventional thermal power plant or coal-fired utilities. See their TGA-DTG curves. We can see that these TGA-DTG curves will be much more sharp and ignition temperature and burnout temperature, they will be very low. Like if we see their TGA-DTG curve, if volatile material is very high, we can see their sharpness profile or we may see profile like it is coming here and immediately it is finishing. So, within a very shorter time period of maybe 300 degree centigrade or whatever, their DTG max value will be very high. And all their ignition and peak temperature will be very much on lower side. So, that we can see if volatile material of coal is on higher side. So, analysis of TGA-DTG curve, we can identify that ignition temperature will be very low and if we see the TGA curves particularly it will be like sharp curve not a continuous curve here. So this curve will be seen if VM is high whereas this curve we can see if VM is on the lower side. So if we analyze the TGA DTG curve also we can get some informations about the type of volatile material presence and amount of volatile material present. If VM content is high, we can get this sharp curve means entire fuel is burning very rapidly within short span of time. Whereas if volatile material is very low, it will burn in this way that ignition, it will take lot of time. So ignition will happen at much more higher temperature and it is burn out will also happens at much higher temperature.

And if we discuss about the effect of fixed carbon. Typically fixed carbon represents the high molecular weight hydrocarbons present in coal. So typically they are the carbon rich hydro compounds or sometimes almost pure carbon. So that means this one theoretically they are the residual carbon when we heat the coal and 925 degree after 7 minutes. So whatever the volatile material is there after releasing all those material whatever the hydrocarbons are left. Those are called the fixed carbon. So effectively they are high or they are rich in carbon content and their hydrogen content will be very less. So most of the hydrogen oxygen and other elements present in coal. They are released along with the volatile material only smaller amount of hydrogen

can be present as part of complex hydrocarbon structure. So, theoretically, it is not the 100% carbon.

So, fixed carbon and carbon we obtain from the ultimate analysis, they are different, but their values can be similar. But theoretically, they are not the same amount of carbon. So, proximate analysis fixed carbon and ultimate analysis carbon content are different. As its content very less or negligible amount of Hydrogen its ignition is difficult. So if fixed carbon content is on the higher side such coal will have very difficulty in ignition as it doesn't have any hydrogen. So by heating it will not release higher quantity of hydrocarbons which will create volatile material or which will ignite the coal. So if any coal has extremely higher amount of fixed carbon its ignition will be very much difficult. It will take lot of time to ignite but once fixed carbon is ignited it will burn very much steadily once it is ignited it will burn steadily continuously by maintaining its fixed heat release rate that we call it like a stable heat release rate what is required in the thermal power plant application. So in thermal power plant we need that heat release from the fuel should be consistent. So that we can maintain the desirable temperature and we can maintain the desirable steam temperature steam quality other product quality whatever for which that coal is getting burned. So main advantage of this fixed carbon is that if fixed carbon content is high Only difficulty it will face is that during the ignition. If we can ignite this fixed carbon rich coal, it will burn very steadily, very smoothly, and it can maintain the desirable heat release rate.

So if we see that for the fixed carbon combustion, if we see the DTG curve, if DTG curve, it will cause like in this way, much more flat curve will be there. It is not like that volatile material rich means this curve we will get in the DTG. But if fixed carbon is there, they will burn in this way. Not like a very higher heat release rate but it will maintain a steady heat release rate. So in general if we see that if fixed carbon contains more amount of calorific value or more amount of energy than the volatile material.

So this is the in general principle that energy available from the fixed carbon as well as volatile material both are released during the combustion or both represents the calorific value of the coal. but in general if we see what is the contribution or what percentage of energy is available from the volatile material and what percentage of energy is available from the fixed carbon. In general volatile material energy content is less and energy content or GCV available from the fixed carbon is on the higher side but it may not be in all the cases that is in general there can have some exception Where volatile material provides maximum amount of energy and fixed

carbon provide less amount of energy. But those are some of the exceptional cases in some of the coal or some of the solid fuel we can get it. Fixed carbon gives much more amount of energy than volatile material.

So if fixed carbon content is on the higher side, we can assume that its calorific value or gross calorific value will be on the higher side. If volatile material is higher side, fixed carbon is less. In such case, such will have lower amount of calorific value. that's why by measuring the proximate analysis we can roughly estimate the theoretically estimate amount of gross calorific value without doing actual measurement of gross calorific value. So by measuring the proximate analysis, there are different theoretical formulas are available which gives amount of GCV that can be available or we can predict that amount.

So, if you see all those formulas, typically the contribution from fixed carbon is on the higher side, and the contribution from volatile material is on the lower side. So, if we combine or summarize the combined contribution of fixed carbon and volatile material, it is required that coal should have a higher amount of fixed carbon for stable combustion or a stable heat release rate in the boiler. As in combustion utilities, we need stable combustion. So, it is desirable that the fixed carbon content of this coal should be on the higher side. And if the fixed carbon content of the coal is on the higher side, the TGA DTG curve will be more flat.

It will be like this way or that way if the fixed carbon content is on the higher side. So, in such cases, the ignition temperature and burnout temperature will also be on the higher side for high fixed-carbon-rich coal. And if we see, there needs to be a suitable balance between fixed carbon and volatile material. We also need volatile material for ignition; otherwise, coal will not ignite at all, whereas fixed carbon is required for stable combustion. So, what we need is that there should be some suitable balance between the fixed carbon and volatile material in that coal. Neither fixed carbon should be extremely high nor volatile material should be on the extremely higher side. So, this ratio—volatile material by fixed carbon, or you can say fixed carbon by volatile material ratio—known as the fuel ratio, is important. So, for very good and stable combustion, it is required that their value should be near 0.8 to 1.25 or 1.3 in this range. Both there is a balance between volatile material and fixed carbon.

As a minimum, 20% VM is required; we can have like 40% FC there. In such cases, ignition will be there, but it will have difficulty in combustion. So, if it is like 25 plus 35, it makes a good balance. Similarly, it can have 30 plus 40; it makes a good balance.

Not like it is like. 15 and 40 or it is like 40 percent VM plus 15 FC. So these ratios are not desirable what desirable ratios is like in this way that their value should be nearby ratio should be around 0.8 to 1.25. If it is exceeds 2 that means if fixed carbon value is extremely high like in such case In particularly in this case, if this ratio exceeds 2, more than value of 2, in such case it will have difficulty in ignition. If it is like this value, where VM% is extremely high, it will create unstable combustion, which is typically seen in case of lignite. But in most of the bituminous and anthracite type of coal, they should have value nearby this.

So, final judgment to be done based on also other parameter. As other parameters like mineral matter composition, porosity, surface area, they also played an important role. So, that will give us the final judgment whether that coal should be suitable or it is useful or not. Overall, if we summarize or if we see is there some minimum quantity of Volatile material is required for ignition. It may be around 20% or 22% that is the lower side of volatile material should be present in any of coal to make it suitable for or make it suitable or selected for thermal power plant application.

If it is less than 20% volatile material we should add some alternate fuel like biomass or other things to make that coal combustible and if it is more than that like if it is crossing more than 35 percent it is not desirable at it may creates unstable combustion whereas if we see the fixed carbon side if it is extremely higher side although that coal can have higher amount of GCV but it may not ignites properly or it may not burn or release energy at the desired location. It will have delayed combustion and in real time burner it may not have that amount of length or dimensions available for combustion. So mostly all these fixed carbon will remain unburned and it will be part of bottom ash or fly ash where we can see some unburned carbon particles are there. So there needs a very good balance between fixed carbon and volatile material. Some minimum percentage is around 20 percent volatile material is look at but overall their ratio should be maintained in an well proximate like 0.8 to 1.25. Thank you