Clean Coal Technology

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Week-05

Lecture-22

Hi, Professor Barun Kumar Nandi, welcome to the NPTEL online certification course on clean coal technology. We are in module 5, discussing the effects of coal properties on their combustion characteristics. So in the previous class, we discussed the effect of volatile matter and fixed carbon on their combustion characteristics. So in this class, I will discuss the effect of mineral matter and moisture on their combustion characteristics. So if we have seen the characterization of coal in our previous chapters, we have seen that some amount of moisture is always present in coal.

So some amount of moisture is always present in coal. So irrespective of coal types or coal maturity, we will always find some amount of moisture there. So this amount of moisture indirectly represents the maturity of coal. As when coal starts from its origin, like actual trees or plants, it has a higher amount of moisture content, maybe 50 to 60% moisture. As this coalification process goes, so the moisture content from this coal is slowly reduced as other hydrocarbons are also leaving the structure of this coal. So in this way, the starting part of this coalification process or the very beginning of the coalification process, the coal we get is peat coal, which we can say is almost like the structure of the original trees or plants. It will always have a very high amount of moisture, maybe around 35 to 40% moisture content is available in the peat. Whereas its next part in this rank of coal, that is lignite, will also still have a higher amount of moisture, like 25 to 30%, sometimes 35%. So all these coals will always have more than 15% moisture. Similarly, in the next series of coalification, like bituminous coal, it will have a lower amount of moisture, approximately around 15% or less than that. And in the final stage of anthracite, it will have a very low quantity of moisture, maybe 1%, 2%, or 5% moisture. So, overall, if we see the amount of moisture present in coal, it represents the maturity of coal or the status of the coalification process at which the coal currently exists. So if any coal has a higher amount of moisture, that means it has not undergone the complete coalification process.

So its hydrocarbon structures are not completely converted to coal. It is in an intermediate state. So the amount of moisture present indirectly hints or gives us an indication about the types of hydrocarbons present, their maturity, and other factors. So if any coal has a higher amount of moisture, that means there will always be a higher amount of hydrogen content and a lower amount of carbon content, and its volatile material will be on the higher side, whereas the fixed carbon will be on the lower side. So by measuring the moisture content present in coal, we can get some information or an idea about what type of hydrocarbons may be present in such coal. So during this heating, what happens is all the moisture is released or escapes from the coal structure. As we heat the coal to around 100 degrees centigrade or 105 degrees centigrade, whatever moisture is present in this coal will be released or escape from that coal structure. So whatever the location or whatever space is occupied by this moisture, those spaces will become vacant, and as a result, the entire coal will have a porous structure. So this moisture leaving the coal creates some porous structure, and later, as these pores are present, it improves the overall pore size surface area which is required and which is very much important for gas solid chemical reaction. Any gas solid chemical reaction, there is a major role of higher surface area and higher amount of porosity pore size etc. So as these moistures are living from the coal structure there will be some vacant pores And those pores and higher surface area available, they will improve the chemical reaction between oxygen as well as the hydrocarbons or coal or even in case of gasification also, they will accordingly do the chemical reaction. So in those pores oxygen can be absorbed. So in case of oxygen in this force oxygen can be absorbed in case of gasification related gases, they can be absorbed in case of pyrolysis nitrogen or other gases whatever is there. They can be absorbed in that force and they will help in doing the chemical reaction whatever type of chemical reaction we want to do with the coal and We can get this information as that some minor gain in the TGA-DTG curve, we have already seen in our previous classes, that around 200 to 250 degree centigrade or maybe up to 300 degree centigrade in TGA curves or DTG curves, there is some minor mass gain can be observed for some of the coal, not all type of coal. Some of the coal, if it shows some mass gain, that means this mass gain is due to the adsorption of reacting or reacted gases, which is getting adsorbed in the structure of this coal.

So they increase mass percentage by one or two mass percentage due to this adsorption. So due to that adsorption of gases, coal will react easily. and it will react at much higher rate. So heat release rate or the rate of chemical reaction or the DTG max rate everything all these values will be on higher side for the high moisture coal. So if any coal has higher amount of moisture we can see there is some higher amount of mass gain also and their reactivity will be typically on the higher side and if there is some low moisture coal. So typically as there is no surface area available for reaction additional surface area available for reaction as the porosity is less only from the external surface chemical reactions will occur. So it will have difficulty in ignition. So mostly we can find it that it will have higher ignition temperature Like it will not ignite easily, it will only ignite at much higher temperature and it will be the also combined impact what we can say that coal maturity as well as the surface area . Coal has less amount of porosity that means coal is indirectly we can say that coal is and the high maturity coal may be bituminous or anthracite rank of coal. So in those coal coal has higher maturity hydrogen content is less carbon content is more. So obviously for such coal reactivity is little bit on the lower side at the same time as they are mature coal their moisture content is less so there will be less porosity. So their surface area will be less and their rate of reactions will be on lower side. So if we see all these aspects particularly with the moisture of coal and if we see the reactivity or chemical reactivity chemical utilization potential of any of the coal as we have all known Typically peat is not used in most of the cases in high end application. Some domestic applications only peat can be used as it has higher amount of moisture and it has higher amount of volatile material. So during ignition it always release higher amount of flue gases, some smoke, everything is created.

So peat is not used in large-scale applications. Only some minor small-scale applications use peat. Lignites are used. but not in a wide range, in the case of thermal power plant applications, where some low-end applications exist, peat is used.

And most thermal power plants use bituminous coal. So both thermal power plants as well as coke-making industries or steel plants prefer to use bituminous rank coal. But if coal becomes anthracite or if the coal rank is at the top level of anthracite, its ignition characteristics are extremely difficult. So, it will not ignite very easily. So typically, if we send anthracite coal to a thermal power plant, they face lots of difficulties as it has a very low amount of moisture and its reactivity is very low.

So for thermal power plant utilization or most coal utilization, bituminous coal is always preferred over anthracite coal. Anthracite coal is good if it has good reactivity or if it is ground to a much finer size so that it can react easily with the reacting gases. So, this moisture content present in any of the coals by analyzing this moisture content, we can indirectly guess the maturity of coal and its reactivity, how it can react with oxygen gas or other gases when we want to utilize it.

And if we analyze the mineral matter or ash content, typically mineral matter represents inorganic salts of different elements as well as phosphorus, sulfur, chlorine, etc. So, during heating, mineral matter oxidizes and is converted to individual oxides, but it may not always happen. In most cases, they are converted to oxides, depending on the exact reaction temperature and the type of salt present. If they reach the corresponding reaction condition, they will react; if not, they will not. As mineral matter in combustibles, they are tightly bonded, even at the very small size corresponding to their liberation size. So, during combustion, mineral matter also plays a role—some positive and some negative. Some roles we have already discussed in our previous classes, like if ash melts when coal is burned at higher temperatures, as in pulverized coal combustion in thermal power plants, where coal is burned at around 1300 to 1400 degrees Celsius. So, if ash melts at that temperature, it corresponds to each individual ash melting point or the melting point of the individual oxides. This is what we call the ash fusion temperature. So, this ash fusion parameter—temperature parameter—because in ash fusion, temperature is a detailed profile: at what temperature it starts melting, at what temperature it almost becomes a liquid phase. A detailed profile is there when we analyze the ash fusion temperature profile. So, it entirely depends on the mineral matter composition. If mineral matter has a higher amount of silica, a higher amount of alumina, or a higher amount of alkali oxides, etc., all these impacts the ash fusion temperature. So even when we use blended fuel—blended coal, or coal and biomass blends— their ash fusion characteristics—whether ash will fuse, to what extent it can become a liquid phase—all depend on the mineral matter composition. So, the ash fusion characteristics of coal entirely depend on the mineral matter composition and its origin. Some coals may fuse inside the combustor, and some may not fuse inside the combustor. Overall, this ash-fusion characteristic is a very bad situation for thermal power plants, as the liquid phase sticks or attaches to the refractory wall. So, if ash is getting fused and there is highly turbulent flow—high velocity, high-pressure air, and coal particles mixed—all the ash gets stuck to the surface area of the boiler's refractory materials and other surfaces. So, which sometimes, it blocks the air valve. If it blocks or precipitates over the openings of the air valve, in such cases, the air flow rate—that means the entry of primary air, secondary air, as well as the exit of flue gas—those gas valves may get affected. So, flue gas may also contain some of the liquid-phase ash, and they may also stick to the different exit points of the flue gas. It can also deposit on the bottom side, etc. There are a lot of consequences, particularly the bad impact if there is some ash or mineral matter in the coal, and that entirely depends on the ash and mineral matter composition. Particularly, if any ash fusion takes place—that is, a phase change of ash—typically, whenever coal is burned, ash is in the solid phase.

So, from the solid phase, if it has to fuse, it has to get the latent heat for the conversion of phase from solid to liquid. So, for the conversion of solid phase to liquid phase, it needs the latent heat. And if we see the values of sensible heat and latent heat, sensible heat means the heat required to increase the temperature of any material by 1 degree. So, typically, the sensible heat value for any material is on the lower side. But the latent heat value for the phase change is significantly higher. So, if any ash fusion takes place, it will take the latent heat for phase change from the combustor itself. That means whatever heat has been released by the burning of coal, some amount of heat will be used for the phase change of this mineral matter. So, as a result, the overall heat available for utilization—for the main purpose for which coal is getting burned or being burned—will be less. So, overall, it will reduce the thermal efficiency of the boiler. So, if the thermal efficiency of the boiler is less due to the fusion of ash—as it becomes a liquid phase—it has a major negative impact.

As it will create problems in all this aspect where it will clog the pores opening, refractory wall damage, everything is there as well as it will reduce the thermal efficiency. So, from both the side ash will create problems. as well as if any ash particles either in the solid phase or in the liquid phase if they deposit over the boiler surface where heat is used to convert that water to steam. So it will stick to the boiler surface boiler tube surface area, so there it will reduce the heat transfer coefficient whatever the radiation heat transfer as well as the conduction heat transfer is there they all will get reduced as it creates an additional layer or insulating layer and sometimes due to difference in their thermal conductivity of the metallic or stainless steel tubes as well as the refracted this ash material there is some thermal stress is generated as thermal conductivity is different the temperature profile will be different. So, due to that after certain time sometimes boiler tube breaks there are some cracks are formed. So effectively if any ash is there or ash is there it will create the heat transfer coefficient also it will reduce the lifespan of the boiler tube. So very frequently we have to do the maintenance work repairing cleaning of this boiler tube if coal has higher amount of ash

As well as it also depends on the thermal conductivity of the ash material which is linked to the composition of the mineral matter. So, such condition is extremely undesirable. condition but in some of the cases we cannot avoid this phenomena always so in some cases we can reduce this impact of as fusion and others by reducing the boiler temperature if we burn coal at 1100 degree centigrade or 1000 degree centigrade we can avoid this ash fusion phenomena but it may not be always possible because we are utilizing coal for thermal power plants And for thermal power plant, there are different types of thermal power plants available like normal power plant, super thermal power plant. Then upper category is also there where we increase in the boiler temperature.

So, it increases the overall efficiency of the Rankine cycle in the thermal power plant where it is required that coal should be burned at much higher temperature like 1300 degree centigrade or 1400 degree centigrade. So, we cannot always avoid that coal will be burned only at below 100 degree or below 1000 degree or below 1100 degree centigrade. So, we always have to go along with the mineral matter. That means we have to accept that mineral matter will be present in this coal. It will create some ash fusion and we have to be ready with the consequences of ash fusion. So, all these negative points are additional along with their impact on the combustion characteristics. Like if ash is there, it will create the diffusion difficulty for diffusion of oxygen as carbon dioxide gases as we have seen in the shrinking core model. So, all these impacts are additional along with the effect on the combustion characteristics. And also, along with the coal handling problems.

So, if we see the coal handling problems for with the high ash coal, like if coal has some 30 or 40% ash, so that Part of this coal does not contribute to any calorific value or energy content. But we unnecessarily transport this mineral matter from long distance, maybe 500 kilometers or 1000 kilometers, as its location of thermal power plants may be far away from the actual coal mines. So, all these negative points are additional. Apart from their negative impact on combustion as well as the coal handling.

Similarly, if mineral metal contains some quartz type material or silica rich material, their abrasion characteristics will be on higher side. Their HGI value will be on higher side. So, they all create problem in the coal handling section as well as in the combustion as well as in the combustion utilities. And we have to remember that coal of different sources has different ash composition. This is another aspect.

Typically, many times we ignore this part. Like, we only consider that this coal has 30% ash or this coal has 40% ash. So, we think that this ash will have no impact on other aspects, but it actually depends on the origin or source of this coal. What is the composition of that ash, and how will it impact all these aspects? Because some coal may have a lower amount of ash, but it can create many or major problems, whereas other coal can have a higher amount of ash.

But their impact will be on the lower side in all this combustion and other aspects. So, what we know is that we have to think about the ash composition, which is also varied. So, the plant needs regular monitoring of this ash composition. It is not that they only monitor the ash percentage of the coal. They should also monitor the ash concentration.

The composition of that coal—what is the composition of ash? Typically, this ash composition is analyzed through XRF analysis (X-ray fluorescence analysis) as well as XRD analysis (X-ray diffraction analysis). So, mostly these two analyses or any individual analysis are used to identify the ash composition. Although, to some extent, through the FESEM-EDAX analysis, the EDAX analysis also gives the composition of the mineral matter. But always, this XRF analysis is preferred, and in some laboratories, sometimes these analyses are done through some chemical leaching methods. So, anyhow, we have to understand or we have to identify what the composition of this ash is. Typically, if we see this ash composition, it mostly contains silica and alumina. In the case of Indian coal, their combined effect—this silica and alumina—is around 90 percent in most Indian coals, although it varies. But in major cases, it is around 90 percent. We can get, like here, 61 percent and 31 percent. Other coals can have 45-45. Or 55-35 like this. So, in the Indian case, mostly it is around 90 percent silica and alumina, and there are some other minor elements like iron, titanium, calcium, sodium, potassium, magnesium, and even we can get some phosphorus, manganese, or sulfate (SO_3) contents in this mineral matter. So, this— All this distribution—and this is not only limited to this—some of the other elements like mercury, selenium, lead can also be available, but overall, their percentage is less. So, in the case of XRF analysis, we make it like a column like— Like make and others. Others are traces, maybe less than 1% or less than 0.5%.

So, this ash composition varies from source to source. Some coals can have a higher amount of silica, whereas some can have a higher amount of iron or sodium. So, if any coal has a higher amount of silica— Then whatever the impact of silica is there during the chemical reaction, that will be visible during the utilization of coal. Similarly, if any coal has a higher amount of potassium or magnesium. Whatever the impact of sodium, potassium, or magnesium is there—whether their impact is on the positive side or negative side, whether ash fusion temperature, magnesium oxides, or potassium oxides are lower or higher, and up to what extent—if they are 0.5%, 0.1%, or 2%, depending on their individual percentage of their— Contribution, the ash characteristics will be different, and as a result, the entire coal utilization behavior will be different. So, if we consider only that ash is 30%, it gives only some information, but not the detailed information. Detailed information we can get if we analyze the entire characteristics.

And some of the theoretical formulas are also available in different textbooks as well as international journal literature, where from all these compositions we can analyze the ash fusion characteristics and their fouling characteristics in the boiler. There are various theories or formulas available, which are typically used to predict the actual slagging and fouling characteristics present in coal. And if we see the composition of coal as well as different types of biomasses. So, if we see their biomass, biomass may contain some amount of silica and alumina overall. But there are significant differences in the alkali metal. Like alkali materials such as calcium, sodium, potassium, and magnesium, their percentage in the biomass is always on the higher side.

So, this also has some other aspects, which are nowadays considered during the utilization of biomass. When we try to co-fire or blend coal and biomass for thermal power plants, their ash composition must also be kept in mind. Why? The major difference is that in the case of coal, we can broadly get around 85% to 90% as the combined contribution of silica and alumina. Whereas in the case of biomass, depending on their source—such as mustard husk, wheat straw, flaxseed residue, and others—their alkali oxide composition changes based on origin and type.

For example, here we can see calcium oxide percentage is on the higher side, whereas in this field, calcium oxide percentage is lower, but still much higher than that of coal. Similarly, in this case, wheat straw potassium oxides are much higher, whereas in this case, their contribution is lower, and here potassium oxide is higher. So, this alkali material composition also has a major impact on the biomass ash composition. So, whenever we blend coal and biomass or two different sources of coal, we must also keep in mind their ash composition—what is the composition of their mineral matter? Recent studies show that if alkali materials present in biomass or even coal are in higher percentages, these alkali materials at high temperatures in the boiler They react with stainless steel or the boiler tubes. So, in such cases, the lifespan of the boiler tubes may differ or may be reduced. Because these boiler tubes are typically designed for the coal. So, in coal, their alkali material percentage is on the lower side. So, as their alkali material percentage is on the lower side, their stainless-steel material has been designed accordingly. But if we use other sourced coal, like we change the source of coal for which the alkali composition is on the higher side. Or if we are using coal and biomass blends, their alkali material percentage is on the higher side or maybe in other case, there can have sulfur content is on the higher side or phosphorus content is on higher side. And in some cases, chlorine is also there so they may react at higher temperature of 1100 degree or 1200 degree so all these materials may be highly reactive and they can directly react with the stainless steel material or the boiler tube material whatever metal is being used there so we have to always be careful about what ash composition is there as it can easily reduce the lifespan of the boiler tubes or entire thermal power plant we may have to go for frequent repairing and shutdown of the thermal power plant. So typically, if we summarize, coal has higher amount of silica and alumina about 85 to 95%. There are minor quantities of all these gases. Whereas there is biomass, they have higher amount of alkali oxides. So recent study confirms that the alkali oxides, they can corrode the boiler tube much more compared to the other materials. And these things, this part we have already discussed in the previous section like if the ash composition and other properties changes, how it affects the coal combustion during the shrinking core model. So overall, if we summarize, ash layer formed during the combustion control the combustion mechanism.

O2 and CO2 has to diffuse through this ash layer like here O2 has to diffuse through this ash layer forms and CO2 also has to back diffuse from the ash layer form and so there will also be a gas film containing all these gases and it has to pass. so this selectivity affinity or reactions among the ash and these gases they can alter the reaction mechanism like if this has some calcium compounds some magnesium compounds if they have any particular selectivity or they absorb oxygen or any sulfur or any other for any particular chemical reaction so that may change the reaction kinetics during the coal combustion with increase in the ash layer thickness typically gas fusion rate slows down make it difficult or take long time to complete the reaction hence combustion rate of high ash coal is always less Ash layer thickness will be much more. For high ash coal, this will be always less.

It will cause also lower heat release rate and may not be suitable for high temperature application but may be suitable for domestic application. And in the other side, if we increase the ash percentage of coal, obviously combustible percentage also get reduced which will finally impact the gross calorific value of the coal. So, if we see the other aspect, if we see the high ash coal, we also have to go for the solid waste generated from the thermal power plants or utilities because if high ash percentage is more, the overall ash percentage, either bottom ash or fly ash, it will be on the higher side. And particularly if the fly ash content is getting higher side, if the mineral matter composition is that there are present some lighter material content lighter mineral matter. Like if there is a higher amount of sodium and potassium oxides, they are typically lighter compared to alumina and others. So those will mostly report to the fly ash. So fly ash handling units, they are ESP, cyclone separator, all will have to do lot of work so there will be some higher amount of energy consumption and other aspect will be there and similarly if the high as coal is there the crushing grinding will also be difficult They become abrasive in nature, they become very hard and sometimes it is very difficult to make them even up to 75 micron which is required for the pulverizing combustion units.

So for efficient combustion, high ash coal should be reduced to much more finer size as with increase in the high ash percentage, their ash layer thickness increased so they may have to burn even at much more smaller size like 50 micron so they may have to reduce like 50 micron or 30 micron because if their size is on bigger side their diffusion layer will be much more and they may take lot of time to get burnt so they may have to grind at much smaller size but sometimes it is not techno-economically feasible so that we should grind the coal high ash coal where calorific value is less its energy content is less but its handling cost is on the other side and as particle deposits over the boiler tube reduce the heat transfer as well as the tube failure may occurs If coal has higher amount of sulfur, higher amount of ash percentage. And particularly if we see about this point, like for efficient combustion, coal ash should be at this level and particularly if we see this point, as we have seen in the laboratory analysis, laboratory analysis that if we do the proximate analysis of coal, when we are doing the proximate analysis of coal, typically one gram of coal is taken of sulfur. 72 mesh or 200 square microns so we take one gram of coal of 208-micron coal. So this is the standard procedure but if we want to do the proximate analysis of coal having 40 percent or 45 percent or 50 percent or beyond that in such case even we can see that in the ash crucible even after keeping it for one hour it may not completely burn that means for high ash coal like 45% ash 50% ash coal our standard procedure for ash determination that sometimes it fails that fails only due to the higher ash percentage of coal in such case Even if we keep the coal for two hours, due to the thick ash layer formation over the coal particles, we cannot get the complete combustion. And our results of proximate analysis for the ash percentage is sometimes erroneous.

So, to avoid that, it is observed that we may have to take 0.8 gram of coal or 0.7 gram of coal particles there. Particularly if coal has higher amount of ash percentage or in case of bomb calorimeter when we do the GCV analysis of coal, we may have to add other combustible material. So that this coal gets completely burned and we get the proper calorific value after deducting calorific value contributed by the other combustible material. material so for high ash coal like if a 45 percent or 50 percent conventional coal analysis method in the proximate analysis as well as the gross calorific value analysis it will not work we have to modify the method by adding some other fuel other coal or other organic compounds or other liquid fuel whatever and makes necessary corrections for the energy contribution but the by the secondary or other fuel we add or other as percentage we add so this is the sometimes we face difficulty so when and that originates from the highest content and their mineral matter of the coal present. So overall if we summarize always some moisture content will be present in coal but sometimes this presence of moisture, as it reduces the gross calorific value of the coal, it sometimes helps in combustion or the reaction kinetics of the coal. So, to some extent, moisture is good but not on the higher side. If it is on the higher side, the overall calorific value and heat loss will be much more during combustion. But two to three percent moisture, or up to five percent, is required to make the coal porous. To make the coal reactive so that it can burn properly during utilization. In the case of mineral matter, we have to consider both the mineral matter percentage as well as the mineral matter composition. If the mineral matter percentage is on the higher side, in most cases, combustion becomes difficult as it may not burn properly. It takes a lot of time for burning, and we may have to grind the coal to a much finer size than the actual pulverizing size. It can also create problems in ash fusion and other aspects, as well as difficulties in coal utilization.

Thank you.