Clean Coal Technology

Prof. Barun Kumar Nandi

Department of Fuel, Minerals and Metallurgical Engineering

IIT ISM Dhanbad

Week-04

Lecture-19

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are discussing coal combustion fundamentals in module 4. So, in this lecture 4 on coal combustion, I will be discussing different types of TGA and DTG curves according to the variations in coal properties and their significance. As in the previous lecture, I discussed the theoretical aspects of thermogravimetric analysis, TGA curves, and DTG curves.

So now I will describe how these TGA and DTG curves vary with variations in coal properties, like the variation of ash percentage, volatile matter, fixed carbon, and how these TGA and DTG curves actually look in the case of coal blends. As in real-time thermal power plants, they receive coal from multiple sources. So, although thermal power plants are designed for a particular coal or coal from a single mine, at present, they receive coal from multiple mines. These mines can be from nearby locations or different locations, like if we say BCCL coal is available in Dhanbad. So, if any company makes a contract with a particular BCCL, CCL, or ECL, they send coal from multiple coal mines in a particular railway wagon, and all that coal is received at a thermal power plant.

So thermal power plants actually receive coal from multiple coal mines across multiple coal seams, which have some differences in their coal properties. Although the calorific value of the coal as well as the ash percentage may be in a similar range, there are wide variations in other coal properties, such as volatile matter, fixed carbon, ash composition, FTIR properties, and other factors, which vary on a day-to-day basis. So maybe the next day, the same power plant receives coal from other subsidiaries like CCL, ECL, or any other locations. That coal will also have significant variations, as in India, coal is traded based on calorific value, which is linked to the grading of coal. So Thermal power plants, based on the calorific value of coal, purchase or receive coal from multiple mines. As well as, this scenario sometimes becomes very bad when there is a scarcity or shortage of coal supply, particularly during the summer.

So, in those times, some thermal plant has to force to use coal from imported coal or other type of coal. So overall if we see getting a single coal or particular type of coal is very difficult for thermal power plants. So, they always have to go for blending of coal or they always have to use mixture of coal which are directly sent to the combustor. Now as this coal have some differences in their properties. combustor will have difficulty in maintaining the heat release rate, desired temperature, etc.

So, in this lecture, I will be discussing how we can avoid or how we can efficiently utilize mixture of coal or coal blends. Like if we see in this picture, like from this table, if we see here, like this coal A, this coal A, it is from particular source. It has ash percentage of 12% as well as this is their combustible percentage. And in case of coal B, it is their combustible percentage. So, these two coal has different properties. Now, if we see their TGA curves, particularly for this coal A. As this coal A has less amount of ash, what difference we can see is that this residual ash percentage here, it will be around 12 to 15%. There are some variations in the end point can be seen because We are taking small quantity of coal here. So here in proximate analysis, we are getting around 13%. In TGA analysis, we may get around 15-16% or like that. So this much of variation is observed in all types of coal. So here we can see this is the curve for coal A, whereas this is the highest coal curve around 45% ash per coal B. If we see the coal A, its initial moisture loss part is significantly on higher side, whereas in coal B, this moisture part loss is on the lower value. That is because that coal A has around 14% moisture, so it will have around 14% moisture loss here, whereas coal B have only 6% moisture, it will have less quantity of moisture. And further what we can see is that around 250 degrees centigrade, there is some minor mass gain is observed. There can have 2 to 3% mass gain, which we can see particularly from this DTG curve. Like from this percentage, it has increased, again like it has decreased from this value, again increase in mass percentage from 1 to 2% or 3%. So, maybe 2 to 3% mass gain is there. Mass gain. Now this is a very much general question why in the TGA curves or in the DTG curves some mass gain characteristics is observed. As in DTG or TGA analysis we always heat the coal, we expect that there will be always some mass loss as some materials are releasing from the coal surface. Some amount of mass gain is observed. Around 200 to 250 degrees centigrade, maybe around 300 degrees centigrade depending on the coal, this mass gain is due to the adsorption of oxygen gas on the surface or pore structure of the coal. As coal has some amount of moisture present—14 percent for coal A and six percent for coal B—once these moistures are released around 100 degrees centigrade or 105 degrees centigrade, there will be some pores available in the coal structure. As we increase the temperature, all the moisture gets removed, and coal will have some vacant pores inside its structure. Since we are continuously sending combustion gases like air or oxygen, those gases will get trapped or adsorbed on the coal surface. As oxygen is getting adsorbed, it is being stored inside the coal structure. The mass gain corresponds to the mass of oxygen gas, resulting in some increase. This increase is actually helpful in further combustion with oxygen. If this mass gain is on the higher side, that means coal is absorbing more oxygen, even at the inner pore and micro-pore levels. When it reaches the combustion level, it will burn very easily due to better oxygen mixing within the coal. Later, we can see that coal A has a sharp decrease in combustibility, whereas in the case of coal B, the plot shows a different trend.

If we analyze it in terms of the DTG curve, we can see that, particularly from this curve, it is sometimes difficult to determine what is actually happening with temperature. That is why DTG analysis is further conducted to identify the rate of mass loss. We can see that in the case of coal A, there are multiple DTG peaks. This means there are two peaks corresponding to the DTG max values. That means one peak at this particular temperature and the second peak at another temperature. So these are we call like DTG max 1, DTG max 2 because it's showing is that combustion is happening at two different stages. So, at first lower temperature around here maybe 375 degree some mass loss is there. So, some of the hydrocarbons are burning at lower temperature whereas some of the hydrocarbons are burning around 475 degrees centigrade at higher temperature. This is a two-stage combustion is occurring. So, this two-stage combustion is due to the combustion happening based on the different type of hydrocarbon. So, some of the hydrocarbons are getting ignited, they are getting burned at lower temperature. Some other hydrocarbons are there; their activation energy is on the higher side. So, there can have multiple peaks, which shows that coal burning will not be very much smooth. Initially it will release some of the energy, then after some time remaining energy it will get released.

So, some coal or some fuel can have single DTG profile, single DTG max values like what we have seen for the coal B or they can have multiple peaks like coal A. So, this is very common and particularly with the coal that is not so much matured like if it is in between lignite and bituminous stage. So, in such case conversion or coalification process is not entirely completed. So, in such case we can see such type of DTG curves. And around this particular temperature coal combustion is almost finished which is around 550 degrees centigrade and if we see the coal B, that red curve here, and its behavior is something different. Like in case of coal B, it is DTG peak. coal burning happening at even at very much smaller temperature zone and suddenly its value is significantly on higher side like 14%, whereas the peak rate for coal is around 4% and 3%. On the other side, for coal B, this value is significantly high. That means once this coal B gets ignited, Entire coal will burn within short span of time. So, whatever the calorific value, whatever the energy stored in this coal, that entire energy will be released within very short span of time. What will be its significance? If it releases entire energy in short span of time, typically we call it like an unstable combustion. Like entire energy it is releasing within very few milliseconds in real time boiler.

So particularly in that zone, it will have significantly higher temperature. Like if it is releasing heating, continuously so it is continuously releasing heat so it will maintain the desirable temperature whatever we want to maintain that temperature it can be used to get some constant temperature which we call like a smooth combustion but in this case what will happen at any particular zone where this DTG max is happening. So, in that zone, suddenly it will resist very higher amount of energy, which we typically call like an explosion, not like it is a combustion.

So, if any fuel has this type of curve, so in such case, it will at some particular zone it will have significantly higher temperature which may exceeds the design temperature whereas the other zone it will not have desirable temperature so this type of fuel or this type of coal is not good not desirable for the thermal power plant. So, if we see their individual ignition temperature peak temperature and burnout temperature Like ignition temperature for coal A is around 248 degrees centigrade whereas for ignition temperature of coal B is 260 degrees centigrade. And peak temperature for coal A at this if we consider this highest value as the peak one its value is 483 and for coal B it is 406. and it can if sometimes we may write some other temperature also if it has multiple peaks of similar values. So, whereas in the burnout temperature we can see it is finishing burning at 467 degrees centigrade for coal B whereas for coal A it is finishing burning at 520 degrees centigrade. So although their ignition starting point there is only 12 degree difference whereas in the peak temperature or burning end point there is difference of about 50 degree centigrade so these two differences shows that these two coal cannot or these two coal have significant difference in their burning profile what we can already we are seeing it in this case so if we feed this coal A which has been designed for coal A, it will perform okay. But if we feed coal B in a combustor which is designed for coal A, so there will be some uneven temperature distribution as well as it may not get the desirable distance or it may exceed or it may overheat the combustor. So, if we see further, like the burning profile analysis for coal and coal blends.

Burning profile for each coal or even nowadays as we are burning biomass also as a part of fuel in thermal power plant. So, burning profile for each coal and biomass is different. Each coal from individual coal mines, individual coal seam, their burning profile will be different. And this will also be different significantly for the biomass. boiler design such as dimensions of the boiler that length and width depth of this boiler that all these dimensions of the boiler and their temperature profile that at which section of this boiler will have 1400-degree centigrade which section it will have 1200 degree centigrade. So, this entire temperature profile which is typically called the fireball. This fireball actually is the temperature profile inside the combustor what we see in a computer display in a control room of thermal power plant. So basically, this fireball means it is the temperature profile inside the boiler. So, if this temperature profile is shifting towards left side or right side that means that coal is not burning properly. It may be burning early or it may have delayed combustion. So, this fireball typically analysis is done that represents the temperature profile of the boiler. So, it is designed or its temperature profile is maintained as per the design of boiler. So that boiler tube at this particular section whether it is an economizer, whether it is an evaporator or it has the super heater, all these zones get the desirable temperature that is made based on the burning profile of coal and for blended fuel like if we blend two different coal or three different coal or if you are blending coal and biomass any variations in the burning profile parameters results in deviation of fireball and emission characteristics of the plant. So, whenever we use a blended coal we have to keep in mind that our final burning profile that means or final this TGA DTG curve what is for this blend. Like if it is like any thermal power plant is designed for coal A having this type of TGA curves and this type of DTG curve. We have to ensure that the blended fuel will have same type or same temperature distribution like it should have same temperature. All these values should be same or nearby values.

So, this coal B, it will be 12. So, if we see that when this we use a blended fuel. We have to ensure that blended fuel will have TGA DTG curve that match with the design coal like if it is designed for coal A whatever the ignition temperature peak temperature burning temperature is there. So blended fuel will should have same peak temperature burning temperature ignition temperature all these temperatures should be same that is coal properties for blended coal any variations in the burning profile parameter results in deviation of fireball and emission characteristics of this plant and coal properties varies even in mine on daily basis from source to source for best performance we should match the TGA profile. Typically, when we use coal from other sources, we generally match their proximate analysis as well as GCV analysis. That way their calorific value is same and their broadly ash percentage is same. But that is a very much rough decision, not the exact decision. Exactly if we want to go for the finest tuning or for the best performance, we should verify their TGA, DTG curves. If the TGA, DTG curves are matching with the original coal, then only we can burn them in the same boiler. If there are some significant variations in the TGA, DTG profile from original coal or the designed coal with the blended coal, there will always have some differences in the properties.

That's why any variations in the properties of coal Results in problems in boiler and it will create lot of other issues like we can have unburned carbon. Why we can have unburned carbon? Because the dimension for the boiler that is designed for coal A or coal B, where it is expected that it should finish burning by that temperature. But if the blended coal takes some more time for burning, it may not have some adequate length or adequate dimension, adequate air flow rate in the burner. So that part of coal will not get burned. and it will become either bottom ash as well as the fly ash whatever or if it is releasing temperature at undesirable location it can have excess temperature which can causes melting of ash because typically this ash fusion temperature of the coal is around 1300 degree centigrade to 1400 degree centigrade. So, if any coal at any particular zone temperature exceeded 1400 degree centigrade all the ash will get fused. So as melting will occur that will have other consequences. So, we should always match their TGA, DTG profile to verify whether it is matching because we are utilizing in a combustor. We should match their combustion properties, not their ash percentage, not their GCV percentage. We should always consider the properties which are used in the combustor. In the combustor, the combustor profile is important. The reaction behavior of the coal particles is important, not their ash percentage. So, ash percentage will give some indication but not the full-proof indication we can derive from ash percentage. So always we should match the suitable properties which are representing or which are actually happening inside the combustor. As the same coal from the same mine is not really possible. We cannot get the same design coal for any particular coal source or any particular thermal power plant throughout the lifespan of the coal-based thermal power plant. Typically, a thermal power plant's lifespan is around 25 to 30 years. So, when a thermal power plant is designed, at that time whatever coal was available that coal may be available for nearby one or two years or maybe up to five years. That same coal will never be available after 15 years.

But we have to run this thermal power plant. So, as the same coal is not available or really not possible in reality to obtain throughout this 30-year lifespan of the thermal power plant. We should always match their TGA and DTG profiles and we should observe their variations in their blended coal. And these variations should be minimal. Like it should vary within plus or minus 5 degrees centigrade or plus or minus 10 degrees centigrade or whatever. These variations should not be significantly high, and DTG max should also be within nearby values. For example, if we see, this is the curve for the burning profile of coal and biomass blends. Now biomass is also being blended in thermal power plants due to the shortage of coal as well as the excess biomass available. We want to recycle this biomass to gain some carbon credits, etc. So always some biomass blends are mixed along with coal in the combustor.

So, if we see the coal and biomass blends curves, particularly this is the TGA curve. Like this is the wheat straw (WS means wheat straw), which means here is wheat husk. These are the two fuels available in different parts of India. So, on a laboratory scale, we have analyzed this part. If we see these two curves like This is the curve for the wheat straw. This is the curve for the wheat husk. Even we can see that although they are from the same biomass, wheat straw has different properties, whereas wheat husk has different properties. Their blended fuel always has some different TGA-DTG profile. So, their char combustion rate where fixed carbon burning occurs, their volatilization temperature during which their ignition characteristics are important. All these profiles are entirely different for both wheat husk as well as wheat straw. Similarly, if we see it in the DTG curve, what we can observe is that Otherwise, we are getting two-stage combustion even in the blends.

As a pure coal black curve, it has only a single DTG curve. But whenever we see any biomass, in most cases for biomass, we get multiple DTG curves. These multiple DTG curves are due to the presence of different types of hydrocarbons. Like one peak is for the burning of lignin cellulose, another peak may be due to the burning of hemicellulose and other compounds. So, always if we use biomass, it will have two-stage or multi-stage combustion. That means some part of that biomass burns at a lower temperature, another part burns at a higher temperature. And if we blend them in a very small ratio, like only 5% biomass is blended.

So, in such case, we can retain the burning profile of coal. Whatever the burning profile of coal is there, those temperature will almost there be retaining. But if we use biomass more than 10% or even up to 20%, in such case, we cannot retain the burning profile of coal there. There will have significant difference or significant changes in the burning profile of coal. That's why when we use a blended coal or blended coal and biomass, if we use blend up to 5% or 10%, we can use that blend. even without doing any of the TGA-DTG analysis as this analysis is not available at the plant site. But if we want to use two coal blends in the 50-50 ratio or 60-30 ratio, in such case it is desirable that always we do TGA-DTG analysis to get their exact burning profile like if we see here whenever we are using wheat straw and wheat husk there is some differences in the ignition temperature which is significantly different from that of coal typically for coal temperature is always above 300 degree centigrade and within 300 to 400 degree centigrade some coal ignites at lower temperature if their volatile material is on the higher side whereas some coal can ignite at later around 400 degree centigrade temperature whereas biomass they always ignite at much lower temperature in most of the cases below 300 degree centigrade and they will have always two peak temperature one is at 281 another is at 400 degree centigrade for this it is 299 and 419 degrees centigrade. Similarly their burnout temperature for coal is 509 degree centigrade whereas for biomass it is 436 and 490 degree centigrade and even if you see their DTG max values for coal value is around 4 whereas for biomass values is almost double first peak is at eight percent, second peak is very minor around two percent and when we blend the coal at different ratio like this is for 10 ratio this is for 20 ratio at 10 ratio we can see We value it is 383 and 227 in between at 287 degree centigrade whereas 20% blend ratio we can get it like 250 degree centigrade as biomass concentration is higher it reduces the Ignition temperature significantly. Similarly, its burnout temperature even if we see here it is 509 that almost retaining the burnout temperature for biomass coal whereas in both the cases it is almost there but it is reducing to some extent but we can get their significant change in the peak temperature it has shifted. like from 281 it has shifted to 295 and 287 degrees centigrade. Similarly 400 degree peak is at happening at later at 449 degree centigrade similarly for wheat husk it is 269 and 264 and here this burnout temperature is almost same but it is modifying the peak temperature and ignition temperature also their peak combustion rate is also getting modified so what we can get or what we can understand from this analysis is that if we use biomass smaller quantity of biomass like five percent and ten percent we can easily add to the system without changing any significant parameters or any significant temperature profile inside the boiler but if we go for a higher ratio like 20 percent 30 percent 50 percent it will have significant effect on the ignition characteristics as well as the peak temperature characteristics or peak combustion characteristics so what we can understand from this analysis is that if you are using blending of coal or coal and biomass blends we always have to ensure that the burning profile parameters their temperature differences and their burning profile temperature peak temperature burnout temperature and their peak combustion rate they all they matches with the design there can have some minor differences in their burning profile parameters which is always there. So there these variations would be on the lower side may be on the 5 to 10 percent side of 5 to 10 degree centigrade. So that it does not impact the temperature profile inside the boiler. If there is a significant change in the temperature profile. It will always create some unburned carbon overheating etc. which will result in failure of boiler as well as melting of ash or ash fusion.

Thank you