Clean Coal Technology

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Week-02
Lecture-10

Hi, I, Professor Barun Kumar Nandi, welcome you on NPTEL online certification course on Clean Coal Technology. We are discussing on Module 2, on topic coal cleaning. So, in this module, we have already discussed cleaning of coal, pre-combustion cleaning coal, washability analysis and we are continuing with discussions on variations of coal properties with density of coal particles. So, in lecture 5 on coal cleaning, we will be discussing on variations of coal properties with density of coal particles. In this class, we will be discussing on surface morphology and ash properties variations with specific gravity of coal.

As with increase in particle density, we can see from a SEM image whatever taken from density of coal particles here so from this image we can see is that that surface structure or surface morphology of different density coal particles are entirely different. In some of the coal particle we can see here that some cracks are here. Here some surface are entirely different in this structure. Here surface is almost one porous structure is there and in this density particles surfaces porosity is less it has some porosity but porosity less in this particle density. Here also porosity is less and some moderate porosity in these structures. So, what we can understand from all this SEM image is that The surface structure or surface area, pore size, pore size distribution, they all are different for different specific gravity coal particles. So, if surface area and surface, if surface area, pore size distribution, pore size, all are varied with specific gravity of coal particle, so their reaction kinetics will also get changed as in during combustion or gasification or any other chemical reactions when we perform with coal this surface area plays an important role like any other solid gas chemical reactions. So, in solid gas chemical reaction surface area is used to absorb the gaseous particles and it helps to react it helps in chemical reaction. So as all this density coal particle has different amount of surface area available. So, their reaction kinetics will always get different like coal surface structure it is varied widely with the density of coal particle so that means if density if 1.3 specific gravity coal particles have higher surface area, they will highly reactive and they will easily react with the oxygen, carbon dioxide, whatever reactant we do during utilization of coal. Similarly, if 2.0 coal particles are having less surface area or they have some cracks, so their kinetics will always get different. As surface characteristics changes with the particle density, so oxygen adsorption characteristics and CO2 desorption characteristics, this is during the combustion. Similarly, in case of gasification, other reactions, other gases will also get adsorbed and desorbed. Similarly, produced hydrocarbons, their moisture, etc., their entire characteristics will also get varied. with this particle density. So overall what we can get it that this reaction kinetics will be different for different density of coal particles. As this reaction kinetics are different, different density coal particle will take different residence time to complete their particular chemical reactions. As their kinetic rates are different, so they are even their rate of heat release which is most important during the combustion of coal like during combustion of coal what we understand is that the rate of chemical reaction is most important to release the energy or calorific value. So, any coal particle can have good amount of calorific value, maybe 3000 kilocalorie per kg. But if rate of reaction is slow, so this entire 3000 kilocalorie amount of energy will be released in a longer span of time so if rate of reaction is slow so it may release only 300 kilocalorie per minute but if rate of reaction is fast it can release maybe 600 kilocalorie per minute. So, rate of heat release rate of reaction, everything will get different as the rate of reactions are different. Similarly, in case of gasification, this rate of gasification will also get different at the steam or carbon dioxide, carbon monoxide reacts with the coal particles.

So, there also rate of gasification will also get different or also get affected due to these variations in the surface morphology of coal. And as all these density coal particles having different surface morphology. So, if we compare coal with 30 percent ash. Suppose we compare coal with the 30 percent ash which corresponding to coal of 1.5 SG (specific gravity) and another coal which have same ash percentage but it is like an ROM coal run of mines coal. So, in the both the cases although their ash percentage and other percentage may be same. As their surface structure is different because it comes from 1.5 SG coal and another coal is the fresh coal having all the specific gravities So, in both the cases, the ROM coal properties with similar GCV and ash, it will certainly be different compared to the washed coal of similar gross calorific value or GCV.

So, this point shows that. This point infers that although coal can have similar properties, we mostly judge coal based on its gross calorific value, ash percentage, volatile material percentage, etc. So, although their basic characterization information indicates that the coal has similar values, similar parameters, and perhaps their pricing is also in the same price band, But their reaction kinetics will differ, as any particular coal, like 1.5 or 1.6 specific gravity, has distinct surface structure, surface area, pore volume, etc. It is different from that of any ROM coal. And this is the most important points to consider when we utilize coal or select coal for any particular application. As their coal properties and surface characteristics differ, pore sizes vary, and depending on the pore size—as we know— during physical adsorption, oxygen gas, carbon dioxide gas, and nitrogen gas all adsorb onto the surface or within the pore volume inside these coal particles. So, if some coal has smaller pore sizes or micropores, it will easily absorb oxygen and react quickly, whereas if other coal particles have macropores or mesopores, their rate of oxygen absorption will differ, and consequently, their entire chemical reaction will vary. Now, this is another property assessed for different specific gravity coal particles.

This is the ash composition or mineral matter composition. This mineral matter composition is determined after burning coal to create ash, which is then analyzed using X-ray fluorescence analysis, also known as XRF analysis. This XRF analysis provides information about the chemical composition or inorganic materials present in the form of oxides. So, if we examine the chemical composition of these coals with varying specific gravities—such as 1.25, 1.275, 1.325, and 1.75—we can extend this as needed. From this analysis, we observe that as the specific gravity of coal increases or changes, the silicon percentage also rises.

So, it is increasing from 46% to 49% and even at 59% and somewhere reaches up to 62% and again around 58%. So, this information gives that each and every specific gravity fraction of coal has different mineral matter composition that means mineral matter present in different density fractions coal are different as their mineral matter composition is changing. Obviously they are ash composition it is changing and the role of this mineral matter or ash during combustion it will affect the entire combustion process like if some coal has 24% alumina, another coal has 27% alumina.

Now any impact by alumina or Al2O3 or alumina salts during reaction as this alumina percentage or alumina percentage is changing, if alumina has any positive impact or if it has any negative impact, this impact will be seen during their chemical reaction. Like if I see, like that suppose calcium oxide has some catalytic activity. If we assume that calcium oxide has some catalytic activity, now in this 1.255 percent, 2.5 density coal, calcium percentage is 2.56, whereas in 1.75 percent, aluminium calcium percentage is 0.7. So, if calcium has any positive impact, if it has any catalytic activity, This 1.25 density coal will highly be reactive, whereas 1.75 coal will not be reactive.

Similarly, if iron has some negative impact, suppose in any combustion or gasification reaction, iron is not favorable, it does not react. the chemical reaction. So, as this percentage is here 6.78

percent whereas in this fraction it is 2.62 percent. So, negative impact will be less in this mass fraction and this density fraction pool whereas negative impact will be more in this fraction. So, what this information tells us is that as this ash composition is changing and even there is so many different numbers of mineral matters or inorganic compounds present inorganic salts present like SIO2, AL2O3, magnesium, iron, titanium, manganese, calcium, sodium, potassium, phosphorus, chromium and so many there are also some trace compounds present in all these coals so as they are Percentage is changing in each of this density fraction. So obviously whatever the role of all these inorganic compounds plays during any of the chemical reaction. So that will be seen during the entire chemical reactions of individual specific gravity of coal. That means if the hydrocarbon structure or other structures are, even if they are same, but due to only variations of this ash composition, the rate of chemical reactions will be different. Like if all these 1.25 coal of different sources, even if we see that they are hydrocarbon structures, they are double bond, single bond, if we assume that they all are same, but as they have different mineral matter composition, their rate of reactions will be different. As maybe some compound is playing some positive role, another inorganic oxides may play some negative role, another material may have improved the heat transfer coefficient, another oxides may reduce the heat transfer coefficient, another compound may easily or helping to absorb oxygen gas Other oxides may help during the desorption of oxygen gas. Someone making them homogeneous or someone making them very hard compound or difficult to grind.

All these parameters are playing there. So as throughout this density or different density coal particles, as their ash composition is changing with time, Ash composition is changing with the specific gravity of coal, their rate of chemical reactions will certainly be different. Another important is that their slagging and fouling characteristics. And this is most important when we consider the ash fusion temperature of coal.

Ash fusion temperature is of coal is at that temperature where the ash started melting or has started fusing. So, this ash fusion occurs based on the presence of individual oxides like if SiO_2 has higher melting temperature. So, then coal will not melt or coal will not fuse. But if sodium oxide, potassium oxides, phosphorus oxides are there, typically they melt or their fusion temperature is much lower. Around 1100, 1200 degree centigrade temperature, they started fusing.

Whereas, the silica, alumina, they started fusing even at higher temperature. So, as their percentage of sodium, potassium, Phosphorus, chromium, calcium, etc. is changing. Each and individual density fraction coal will have different ash fusion temperature. Accordingly, with change in the ash fusion temperature, their slagging characteristics, like if they melt, they will create deposit over the boiler tubes and other. Those characteristics are called the slagging and how much they are creating fouling, they are creating deposit, reducing the heat transfer coefficient. So, all these characteristics will also be different for individual density fractions of this coal. So, maybe this density fraction coal is good but this density fraction coal may not be good and if you are using this density fraction of coal in any particular thermal power plant. So, this density fraction of coal will create slagging and fouling inside the boiler but maybe similar GCV coal.

As a ROM coal, that coal may not create any fouling. So, although their gross calorific value and other parameters may be the same, due to their change in ash composition, their ash fusion, slagging, and fouling characteristics will all get different or will get modified. So, overall, what we can see is that as ash composition changes with the density of coal particles, all properties of coal related to the ash will change. Ash will also vary. Like ash fusion temperature, abrasion index, HGI, all will vary with changes in the ash fusion temperature and changes in the density of coal particles, as SiO_2, Al_2O_3, etc., also increase. So, the heat transfer coefficient during combustion for mineral matter and ash will also vary, as heat transfer coefficients differ. Ignition combustion characteristics, their activation energy parameters, will also vary. Some metal oxides may also have catalytic or opposite behavior or a negative impact during their combustion or gasification in some cases.

It has been observed that some rare earth metals or some toxic metals like mercury, lead, and cadmium are also found in particular density fractions of coal. So, sometimes it is also found in some coals, which are very toxic and environmentally polluting materials. So, this is also observed in some of the particular specific gravities of coal. So, if we finally try to conclude what the different parameters are or what information we are getting from the washability analysis or the variations of coal properties with density fractions of coal, what we get is that: The first point we get is that washability analysis is done for different feed sizes of coal.

So, for different feed sizes like 5 mm or 10 mm coal particles, their washability characteristics will be different. So, to identify the best possible feed size of coal for different coal mines, for each and every individual source coal, washability analysis is done at different particle sizes like 5 mm, 10 mm, or 25 mm, etc. Washability characteristics vary widely with different If we change the coal particle size, as the distribution of mineral matter and hydrocarbon is different and as it is an extremely heterogeneous material. So, washability characteristics vary widely for different sizes of coal.

And finally, it is a techno-economical decision. Why is it a techno-economical decision? Because if we reduce the particle size of coal, the cost of washing it increases. As with an increase in ash, we go for a much smaller particle size, which requires more crushing and size reduction equipment, increasing costs. It also creates a lot of coal fines. These fines must be processed differently. Overall, it is a technical decision whether reducing the size to 5 mm or 2 mm impacts the final yield of the coal and its market price. Coal fines, like particles less than 0.5 mm or about 1 mm in size, are also generated during size reduction, transportation, etc. They take a long time to settle in a sink-float analysis. So, in real-time analysis, a coal washery must process them differently, not the same way as larger coal particles. Larger coal particles settle easily as clean coal or refuse.

But these coal fines take much longer to settle; their settling time may be around 12 hours, 18 hours, or even 24 hours. So, they will take a lot of time. They are typically processed in a different circuit, through a separate channel, to handle these fines. During washability analysis, coal fines must be washed separately, as their settling characteristics differ. And they need different equipment or maybe they need different methods for beneficiation. Both clean coal and refuse or reject coal and ROM coal are priced at the same grading level. This is important because their grading is done based on either the GCV values for non-coking coal or the ash percentage values for coking coal. As they are marketed, they are priced on the same grading scale. Like even if we clean the coal after spending a lot of money, their market value will be judged based only on their ash percentage. So based on their grading difference, like from grade 1 to grade 2 or grade 2 to grade 3, if there is only a difference in market price of maybe 500 rupees per ton. So, we should not spend more than 500 rupees per ton to beneficiate the coal because it is market-dependent in price. So, this entire market pricing is based on the GCV or ash percentage coking properties of coal.

They have to compete with the same quality ROM coal. So, the cost of washing, crushing, grinding, beneficiation—everything should not be on a higher scale as they are graded based on their coal properties only, not considering whether they are beneficiated or non-beneficiated coal. And there may be a need for multiple coal washing equipment for better results. During coal washing, maybe that one circuit or one equipment may not be able to finally separate the good coal, higher ash coal, low ash coal, etc. So, there may be a requirement that they may need two or three consecutive pieces of equipment in series or parallel for better washing. So, these are the typical flow circuits or Process flow diagram used during coal washing. This is only one model.

In real time, the equipment to be used depends on the coal properties and the properties of clean coal. We want and the properties of refuse coal we want. So based on that and the properties of coal, ROM coal or raw coal, there were pretty characteristics. This circuit is changed, varied, or finally designed based on all these properties we want. So, this is only a model flow circuit typically used. So what are the different steps in coal cleaning? First, we have to reduce the coal size by crushing and grinding to make it suitable where we will reach the final size where we can easily separate high ash coal and low ash coal. That means we will reach the liberation size of that individual coal particle. So first, we do the crushing and grinding of coal. So that circuit is seen here like raw feed coal. It is first screened, then secondarily screened before going to the first circuit. So, this is the purpose of these first two, corresponding to the crushing, grinding, and screening of this coal, which is for beneficiation of bigger coal particles and second for beneficiation of finer coal particles. So, these circuits correspond to the beneficiation of bigger coal particles, that is, the coarser refuse size, and this corresponds to the beneficiation of finer coal particles. Then, the collection of clean coal and the collection of refuse coal after this circuit is offered. We will get the clean coal here, and we will get both from the coarser coal particle size as well as from the finer coal particle size. So, they will get mixed though, which means we will get clean coal from two different circuits: one will come from the bigger coal particle or coarser coal particle size, and another will come from the fine coal processing size, like froth processing and other units. The secondary processing of refuse coal is further done, like whatever we get the refuse coal here, whatever the refuse coal is here, maybe it has about 45 percent ash. Suppose from the clean coal, we are getting maybe 18 percent ash, and maybe this refuse coal we are getting 45 percent ash. Now, at this 45 percent ash coal particle, it still has some combustible material; it still has some calorific value, etc. So, we cannot just dump this 45 percent ash coal somewhere. Further processing is done to make it into another coal of 35 percent and another coal of maybe 60 to 70 percent. So, further recovery of this first from the first circuit, whatever the refuse coal is there. So, from that refuse coal, further recovery of some valuable useful coal is done in a secondary circuit to extract some more amount, but their calorific value may be less. However, to extract some more energy or some more valuable coal, as it is a precious fossil fuel, it has a limited reserve.

So, any coal above 60 to 70 percent which has which is not graded or which has very little market value, typically these coals are used for domestic purposes where we only need a minor quantity or small quantity of energy. Whereas this amount of 35 percent coal can also be used in some thermal power plants or any other cement plants or any other application. And whatever water is used during the coal washing, we also need to process the slurry and the water used in this coal washery. Like in this coal washery, typically water is used as a medium or fluid medium to wash the coal along with other chemicals. So, whatever water is used, that also needs to be treated, that also needs to be processed before discharging it into the environment. So, there is a separate circuit like from the transportation circuit, whatever water is used, that water is also treated or recycled to reduce the environmental impact. So, if we come to summarize this entire module 2, from coal washability analysis, coal cleaning to the variations of coal properties with the density of coal particles, what we can finally conclude is that for efficient coal cleaning, coal should be crushed at the lowest possible size. If we want to extract some more amount of coal or if we want to improve the efficiency of coal cleaning, we should try to clean the coal at the lowest possible size, the lowest possible techno-economical size. Identification of the distribution of mineral matter and hydrocarbons is essential. We have to identify how the mineral matter and hydrocarbons are distributed across the coal and accordingly, we should crush the coal and select the suitable process for coal washing. Different source coals need to be washed at different sizes. As the coal properties, their distribution of mineral matter and hydrocarbons are different across different coal mines, across different seams of the same coal mines.

So, different source coal has to be washed based on their individual washability characteristics. So, they may have to be washed at different sizes. Or different processes, through different equipment based on their individual coal characteristics. Mineral matter-rich coal typically shrinks as their density or specific gravity is on the higher side, whereas the hydrocarbon-rich coal particles are of the lower density coal particles; they will typically float, and selection of suitable cut density is essential for coal washing. We have to identify at what cut density we should wash the coal so that the entire clean coal meets the desired requirement or desired market price, and the refuse coal, whatever is there, does not contain a significant amount of combustible or calorific value. And this cut density will vary for different source coal. So, as coal properties vary with the source and others, as well as the size of coal, this cut density may be 1.5, 1.6, or 1.45. This will vary for different source coal, and that is the most important task or most important parameter to be controlled in an actual coal washery. In an actual coal washery, if it is a bigger size coal washery receiving coal from multiple coal mines—like in a particular area, there can be 10 or 15 coal mines of similar properties, but some variations are there—each and every individual coal mine will have different coal properties. Their distribution of mineral matter and hydrocarbons is different. So, the cut density to wash the coal at particularly 18% ash, 20% ash, or 35% ash will be different. So, it has to be continuously monitored in the coal washery. On a regular basis or continuously, that cut density or whatever the density to be used to separate that coal has to be monitored every time or on an online basis, and it has to be changed.

Washability analysis is very essential to identify the characteristics of clean coal. Without doing any type of washability analysis, we will not be able to judge what the properties of clean coal will be, what the properties of reject coal will be, what cut density we should use, or what type of beneficiation process we should use. So, all these aspects are identified through the coal washability analysis. That's why this sink-float analysis is very important in mineral processing as well as in coal preparation or coal cleaning. So, this washability analysis plot gives all the information about the variations of coal properties with the density or specific gravity of coal. So, it is the most important part, the theoretical part, for laboratory-based analysis to be done on a regular basis, maybe on a daily basis or maybe on an online basis, to identify the probable properties of clean coal and identify the cut density of coal and depending on the composition of mineral matter and hydrocarbons, these entire washability characteristics will vary. So, whatever final points we can get from this entire discussion or this entire Module 2 are that: First of all, washability analysis has to be done. Washability analysis must be done for each source coal. This is an important aspect of coal washing.

Secondly, coal properties vary in all aspects with different densities of coal particles. If we change the density of coal particles, their hydrocarbon structure changes, as does the mineral matter composition. Also, other physical characteristics like density, surface area, pore size, and porosity all vary with the different densities of coal particles. So, when we utilize coal in any coal-fired utilities or other utilities, we must keep in mind that when we change the specific gravity or density of coal, we are certainly not using the same amount or composition of hydrocarbons we are trying to burn, and this is significantly different from any liquid or gaseous fuel. In the case of liquid fuel, the distribution of different hydrocarbons is somewhat more uniform, and in gaseous fuels, they are almost uniform due to Brownian motion. However, coal is not the same, as there is no Brownian motion, and it is an extremely heterogeneous material. The distribution of mineral matter and hydrocarbons varies throughout the coal. So, even if we crush coal to a very fine size, there will still be differences in the distribution. That's why we must reach almost the liberation size for coal washing. And even at that size, there are some variations in the mineral matter composition.

There can be the same mineral matter percentage in terms of percentage, maybe 20% mineral matter. But within this 20%, the distribution of silica, alumina, iron, and others is different. Similarly, on the hydrocarbon side, although it can have 30% volatile material and 40% fixed carbon, the hydrocarbon composition varies or is different across the different 30% volatile material coal or different 40% volatile material coal. So, when we utilize coal of different densities, different sources, or from different mines, we have to understand that there will be some variations, and every time we have to do some fine-tuning in the process, whether during combustion or gasification, wherever we utilize coal. We always have to do the fine-tuning and monitor the composition of coal and the composition of the product gases we obtain. We always have to monitor them and finally decide how we should use the coal. If we consider all these parameters, we will certainly be able to utilize coal with minimal environmental impact.

Thank you.