Clean Coal Technology

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Lecture-09

Hi, I, Professor Barun Kumar Nandi, welcome you in NPTEL online certification course on clean coal technology. We are discussing on module 2. Topic of coal cleaning. So, in lecture 9, I will be discussing variations of coal properties with density of coal particle. From the previous lecture, We have seen that we can segregate coal based on their specific gravity during the coal washing, which is known as the coal washability analysis. Here, specific gravity of coal is contributed both by combustible as well as the mineral matter. Typically, combustible represents different types of hydrocarbons present in coal. These hydrocarbons can be aliphatic, aromatic, cyclic or they can be single bond, double bond, triple bond, aromatic bond etc and along with all these hydrocarbons , they are can have different type of other elements presents like Halogen including chlorine, bromine, iodine, it can have sulphur, it can have phosphorus, it can have higher amount of nitrogen, oxygen, and maybe some of the metal elements like sodium, potassium, sometimes also part of organic hydrocarbons. So, they can also be part of different type of hydrocarbons present in coal.

Overall, this specific gravity of hydrocarbons, it comes from the different types of molecules present in coal. So, if we see the any particular specific gravity of hydrocarbon if it has attached some sodium compound. or it has attached some potassium compounds, its specific gravity will change as the molecular weight of sodium, potassium, even calcium are different. Similarly, if it has attached some compound of sulphur or some compounds of nitrogen, Its specific gravity will change. Although the hydrocarbon characteristics may be same or similar, but its specific gravity will change as it has different types of elements present like sulphur, nitrogen, even in chlorine, even in bromine or even in iodine. So, depending on the types of materials present or elements present in all these hydrocarbons, hydrocarbon specific gravity will change and accordingly due to presence of these different types of elements, hydrocarbons characteristics or its behaviour will also change. So, overall specific gravity of hydrocarbons comes from different types of molecules present in coal. Some mineral matters like sodium, potassium, etc. are also tightly bonded along with hydrocarbon and they cannot be isolated during the coal washing. As these mineral matters are very much attached to the coal, maybe in the nano range or maybe in the 1 to 2 micron range, they cannot be separated during the coal washing or washability analysis. So, what we can get from this analysis that even the hydrocarbons it can always contains some amount of mineral matter which is difficult to separate. Typically, it is observed that specific gravity of pure hydrocarbon rich coal like if it is a zero percent mineral matter. Although such coal is not available, but it is like and from theoretical plot if we have extended it to the zero percent mineral matter or if we have extended to the hundred percent mineral matter. We can get such concept which is known as this imaginary concept. So typically, if coal has zero percent mineral matter, its specific gravity typically happens between 1.2 to 1.25. And if it is the specific gravity of the mineral matter is controlled, like if it is 100% mineral matter. Their specific gravity is about 2.6 to 2.7. So, this is also an imaginary concept. If we extend it to the 2.6, we will get almost 100% mineral matter. That if we extend the washability curve versus that ash percentage versus specific gravity of coal curve in the washability analysis. So, these are only the theoretical concept in real time.

Neither can we get 0% ash coal, nor can we get 100% ash coal. The exact specific gravity of mineral matter depends on the composition of the mineral matter. For example, if it has silicon or aluminium oxides, their specific gravity will be high. If it has calcium, sodium, etc., their specific gravity will be lower. Coal particle specific gravity can vary roughly between 1.25 to 2.6. So, if we can change this percentage, like if we get coal of 1.25, it will have almost 0% ash. In reality, it can have 5% or 3% ash. Similarly, if we extend it to 2.6, we can theoretically get 100% ash. But in reality, we can get 95% or 97% ash. So, the further information we can gather is that high specific gravity coal means it will have a higher ash percentage.

As it has a higher ash percentage and a lower amount of combustible material, its gross calorific value will always be on the lower side. Similarly, low SG coal means if the specific gravity is less, the ash percentage is less or the hydrocarbon contribution is much more. We can expect that it will have a higher gross calorific value. On the other hand, if we see higher particle density coal, it means high ash coal with lower GCV. However, there can be some exceptions in this, as some hydrocarbons can have higher density. Some of the hydrocarbons that we have discussed in the previous class, some of the hydrocarbons which may be more compact or where the number of carbon atoms is much higher compared to the others. So, their specific gravity may be on the higher side. Hence, in such coal, we can get higher GCV compared to coal from other sources where hydrocarbons are of different types, but they can have similar specific gravity.

Similarly, the different source coals have different origins. Coal from particular mines and coal from other locations, like coal from BCCL in Dhanbad or coal from SCCL in Bilaspur or Raipur, their origin is entirely different. As their hydrocarbon compositions are different, their clay characteristics are different. Their hydrocarbon composition, mineral matter, everything is different. Washability analysis for individual coal will be different. So, we have to analyse their washability for each mine's coal and even in each seam of coal, if there is a major difference in the seam characteristics observed. So, washability analysis data needs constant monitoring because this data In a particular coal mine, there is no guarantee that coal is always extracted from the same mine. Sometimes identification of different seams is also difficult.

So, during mining multiple same coal are mined at the same time and during transportation may be coal from different mines are mixed and loaded in a same wagon or same trucks. There will be always variations of coal properties even we are getting it from any particular source or any particular subsidiaries of coal India. So, washability data always needs constant monitoring at the plant level. We have to regularly and continuously measure this washability data, so that we will not lose any of the combustible materials in the reject coal. That's why online monitoring is required even at plant level for better coal cleaning to identify what coal characteristics is there, what should be the cut density for coal and what should be the other equipment parameters to be set in the coal washing equipment. So it needs online monitoring. Now, these are some data how we can see their variations of coal properties with density of coal properties. So, typically if you see like this is from any particular source coal. If we change the source of coal, this data table will be changed. completely different like this is for one particular coal sample where at 1.24 we can see the carbon content is extremely high whereas 1.275 carbon content is decreasing. So typically, with increase in the specific gravity of coal what we can see is that their carbon content always get decreased and maybe at 1.65 or 1.7 we can get 32% or 32.71% of carbon content is there. So, what we can get is that with increase in the specific gravity of coal, typically carbon percentage decreases. Why these carbon percentages are decreasing? Because the amount of combustible materials present in this particular specific gravity or specific gravity fractions of coal is decreasing. So typically, this carbon percentage always get decreased with increase in the specific gravity of coal.

Similarly, hydrogen percentage if we see from 5.59% it decreases even up to 3.2% and even at density of 2 it is around 1.41% which is very less percentage and if we see The sulphur percentage, it also varies along with the specific gravity of coal like 0.59, 0.55, 0.5, 0.46, 0.44 and it decreases even up to 0.13 percentage. So, this information gives us that if we increase the specific gravity of that coal or if the density of the coal particles are increased, their combustible material percentage gets decreased. So, in actual plant practice, we have to identify up to what extent we can accept or plant can accept their particular specific gravity coal. So maybe at 1.65 or 1.75, they have to wash the coal to get it. Another important information from these plots, what we get is that if we burn 1.32 coal and if we, in another burner, if we burn 1.65 specific gravity coal, if you select like these two coal, what we can get is that their carbon percentage, their hydrogen percentage, their sulphur percentage is different. So, as they are all these percentage are different, their gross calorific value will be different , other parameters will be different as well as their reaction kinetics will be different like if it has 60 percent carbon another coal has 36 percent carbon that means there are different types of hydrocarbon present in these different density coal particles. So, as their hydrocarbon types are different. So their reaction kinetics how they will react with oxygen during combustion or how they will react with steam and other media during gasification or how they will react using their pyrolysis how they will react in a blast furnace using reduction of iron ore their entire reaction kinetics will change if we change the specific gravity of coal and that is the main reason why the coal from different coal mines that can have similar ash percentage but they can have the different properties their reaction kinetics their utilization everything will get impacted based on this specific gravity of coal because we only measured the ash percentage as an reference but if we see not only as percentage it is also changing the carbon percentage in the coal so if carbon percentage is different its reaction kinetics will be different as this 60 percent carbon or higher or different amount of carbon it can have different type of hydrocarbon presence maybe lowering lower molecular hydrocarbon can have the aliphatic compounds and other compounds

Other hydrocarbon can have the aromatic compounds. So, if aliphatic compounds are there and aliphatic compounds are there, their reaction kinetics will be different. So, we change in the specific gravity or density of coal particle, their entire utilization kinetics, their reaction kinetics will get different. So, when we utilize coal in any of the plants for combustion purpose, gasification purpose or other purpose, Their utilization efficiency or their reaction methods, reaction kinetics, resistance time, everything will get changed. Another most important part is changing their sulphur percentage. So, as we can see with the specific gravity of coal, this sulphur percentage is changing. Now, this percentage of sulphur changing also depends on the types of sulphur present. If I can see that in this particular type of coal, the sulphur percent is decreasing. Sulphur percentage here is decreasing, meaning sulphur is attached to the hydrocarbon part of the coal. That's why we see a decrease in the hydrocarbon part. Or, in the combustible part of the coal, sulphur percentage is decreasing. So, in this particular coal, what we can understand is that this coal has mostly organic sulphur present. That is why organic sulphur is present. So, this sulphur percentage is decreasing as we reduce the combustible part in the coal. So, their sulphur percentage is always decreasing. If it was some inorganic sulphur, like sulphate sulphur or pyritic sulphur, it would not decrease; it would be constant or may increase. So, whether it is organic sulphur or inorganic sulphur like pyritic or sulphate sulphur, that also impacts the total amount of sulphur present in their percentage. So, this information is also required. Because we may wash the coal at this particular density and maybe we can see that for the other coal at this particular density, sulphur percentage exceeds 1%. Maybe in some of the cases. In certain cases, that cut density we cannot use for coal washing.

So overall we can see variation of ultimate analysis parameters is always there with specific gravity of coal. Similarly other parameters also varied and they varied based on the origin of coal. This is one of the plots we can see from different source coal like coal A, coal B, coal C, coal D and coal E. Five coal is taken from different source like from different coal mines. One may be from eastern part of India; another may be from western part of India. Third coal may be from the central part of India like this. So, if we analyse five different coal from five different coal mines across the different broad origin, what we can find is that their ash percentage, how it is varying with the average relative density or average specific gravity of coal. This is basically the relative density of liquid used or the specific gravity of coal. What we can see, what we are discussing that if we can extend this plot, like at 1.25, their ash percentage is 0.25, like 0.2 or 3 percent so if we extend this part maybe here density will be around 1.1 or whatever if we extend this curve so at 0 percent as what we can get similarly we can get it like extend this like this that's why we got these parameters like this one that it is about

1.2 to 1.25. This varies from source to source but approximately if we get coal like 1.2 or 1.25 it will have almost 0 percent mineral matter, so that thing we can see from this type of plot and this is this varies with source to source not that all will have like particular this green curve if we see it is increasing here and here you can see it is in different way here increasing means here Mineral matter, their specific gravity is very less. There are some mineral matter where specific gravity is less. That's why their ash percentage is on higher side. So, this depends on the coal from source to source. Not all that always means that lower specific gravity means like hydrocarbon is there. If there can have some mineral matter, that's why it is showing some higher ash percentage. But those mineral matters are of low specific gravity. so if we see from all these five different coal broadly it increased like if we increase the specific gravity of coal this ash percentage increase but even at the same specific gravity level here we can see these five plots are different and here we can see at any particular specific gravity of 1.9 it can have higher ash percent of 60 whereas these can have higher ash percentage of about 45 so there is a variation from 45 percentage to 60 percentage although their specific gravity is around 1.9 This shows that these plots change from source to source. Not all coal will have in general trend that this will increase. But what will be the exact ash percentage at individual cut density we have to identify. What it indirectly infer is that when we utilize coal. for this coal of this coal E, it will have always high ash percentage for this ash coal. This E coal we will get around 60 to 65 percent ash for 1.9 whether as for other coal it can have 45 percent ash, so this 45 percent ash can have good GCV whereas this coal can have inferior GCV. So even at 1.9 their coal properties will be different and this Always impact their utilization in combustion, gasification and everywhere. Similarly, if we see the variations of volatile material. What is the role of volatile material? Typically, volatile materials have seen good ignition characteristics of coal. If volatile material is good, coal will easily get ignited and it will easily get burnt.

What we can see is that with increase in the average relative density or specific gravity of coal, their volatile percentage is decreasing. Volatile percentage is decreasing because coal have much more amount of mineral matter at higher specific gravity and at lower specific gravity mineral matter is less and hydrocarbon is more. So, what we can get is that if we wash the coal at 1.3 Maybe that is the suitable GCV we are getting, but 1.3 means it will have extremely higher volatile material, maybe of 37%. And this 37% volatile material may not be the selection criteria for any type of or any particular type of equipment in their combustion. So, if they want to good coal they having intermediate volatile material may be at 25% if their desired prior parameter is like 25% they should wash the coal at this particular And that density may not be their desirable corresponding ash percentage. So, all these parameters needs to be considered. Not only that, only ash percentage to be considered. If we see even at 1.65, their volatile material is good. But if we take very low density coal or low specific gravity coal, their volatile material is on the higher side. And this particular in terms of volatile material, it may not match the equipment design criteria. Whereas in terms of higher specific gravity, it may match the selection criteria. Also, if we see across the five different coal, like this coal, it has volatile material is higher side. But if we see this curve, this volatile material is only 15%. So from coal E and coal D, if we see these two curves, this coal D is this blue curve, this has very low volatile material. So, for that, we should get the desired volatile material at 1.4 or 1.45, but for this coal E, we can get even good volatile material at this. So, if we see that with a change in the density or specific gravity of coal particles, their coal property varies very widely. So, They can have ash plots; ash percentage plots are okay. They are very much nearby. There is not very much variation here. But if we see their volatile material, their variation is too much, and that may not need or that may exceed or that may not meet the design criteria. Maybe their value is on the lower side. As this volatile material varies with the specific gravity of coal, so their entire combustion, gasification, all these parameters, their impact will be there when we utilize this coal in real-time combustion or other. Similarly, if we see the fixed carbon content, fixed carbon means higher monochloride hydrocarbons or mostly the carbon-rich hydrocarbons. Even that varies widely.

This curve you can see, fixed carbon, where is that fixed carbon? That value is around 25%, whereas these curves, their value is around 40%. So even at the same density of 1.75 specific gravity, their fixed carbon percentage is changed, and this part, they all these four are similar at 1.75. But they are different at this lower density, at this lower density of 1.4 or 1.3, there is a wide variation. But at this point, their variation is less, and even in this case, if we can see that it has at 2.0 volatile that Fixed carbon content is very less. So, this means at 2.0, it will have a very less amount of GCV. But at this red curve or this green curve, it will have a very good amount of GCV even at 2.0. So, if we generally consider that 2.0 coal means it is bad coal. It may be a well prediction for this coal, but it is not a very good prediction for this coal. This blue curve and green curve. That means coal, this coal C and this black curve coal A. For them, it is not the well theory applicable that higher specific gravity means it is not a good quality of coal. Similarly, if we see the elemental carbon percentage, what we get from the ultimate analysis. Here also we can see that carbon percentage is continuously decreasing, as we have seen in the previous table. So, it is decreasing and even it varies with the different types of coal or different origin coal. So, for this coal E, carbon percentage is there is half decrease, but in case of this green curve or black curve like coal A and coal C. Still at the same specific gravity layer level, their carbon percentage is here 40, whereas these parts it is around 57 or 58. So this coal properties is also varying, that means their ultimate analysis parameter is also varying with specific gravity or relative density of coal. So, as this carbon percentage is varying, we can see their fixed carbon percentage is varying, their volatile material percentage is varying, but maybe their ash percentage is not varying too much. So, in the washability analysis, we give much more stress on only ash percentage with the specific gravity and others, but this is only some parameters, not exactly the final parameters to decide the coal properties. If we see only the ash percentage, it is not varying so much because ash percentage, entire washability analysis or coal washing is based on the specific gravity. So, with increasing mineral matter, ash percentage is increasing and their variation is not too much, but if we see their hydrocarbons composition variation. Variation in volatile material is there, variation of fixed carbon is there, and variation of carbon percentage is there. So overall, if we see the distribution of hydrocarbons across different specific gravity is very much higher side. So, there is no straight curve formula that with increase in the higher specific gravity of coal, you will always get it is general that they will be decreasing, but from mine to mine, this hydrocarbon composition is varied. Although their ash percentage variation may not be there, but their hydrocarbon composition, as we analyse by carbon, ultimate analysis in carbon or volatile material and fixed carbon in proximate analysis, they are varying widely.

As they vary widely, their reaction kinetics vary on the higher side. For example, the reaction kinetics of coal E and coal A will be completely different. So even if we wash the coal at any particular specific gravity, say 1.6, their combustion characteristics, gasification, carbonization, reduction behaviour—everything will be different as we increase it, since their hydrocarbon composition varies. Why are these variations present? Because some coal may contain aliphatic hydrocarbons, while other coal may contain aromatic hydrocarbons. This coal may be of low maturity. Another coal may have a higher maturity level. This coal may originate from a particular type of tree. Another coal may originate from a different type or species of tree. That's why all these parameters vary, and the same can be observed in hydrogen percentage variations.

Hydrogen percentages also vary. Because hydrogen in coal indicates the presence of hydrocarbons, and hydrogen-rich hydrocarbons typically consist of low-molecular-weight compounds where hydrogen content is high while carbon content is low. So, you can see that hydrogen percentages also vary widely. Observe these three curves—how much variation exists between the black curve and the green curve. They are in widely different positions, but in the higher-density section, their variation is not as significant. At lower specific gravity or density levels, hydrogen percentage variation is much higher. We can see that all these parameters vary. Whether we check proximate analysis, ultimate analysis, or gross calorific value analysis, all these parameters vary significantly, as seen in the gross calorific value variation. Similarly, even at 1.7, this red curve has a gross calorific value of 3,500, whereas this curve has a gross calorific value around 4,500. Similarly, at this level, around 1.35, this can go up to 8,200, whereas this coal can have a variation of 6,500. So, the variation of coal properties is with Coal particle density is always there, and it varies greatly with the origin source, types of hydrocarbons, and everything present in coal. So, whenever we utilize coal, we have to measure each individual coal to determine its properties. Generally, equipment is designed based on particular criteria, but once we change the source of coal, these entire characteristics change, and that coal utilization may not be suitable. So, coal may not burn at all, or maybe coal is burning at a higher rate, coal is burning at a slower rate, coal is giving too much amount of temperature, which may not, which may actually damage the boiler and other components. So, this has to be done or this has to be measured for each and every source. If we do not consider this variation when we utilize coal, we will always get some problem, some unburned carbon, some higher temperature, which will result in some environmental efficiency loss and others. And if we do the FTIR analysis, we typically analyse the different types of functional groups present in coal. In this FTIR analysis, a typical analysis is done from 4000 wave number to 500 wave number, and we can see that at each individual specific gravity of coal, not all the functional groups are present in all the hydrocarbons. Like these functional groups are present in this 1.42 and 1.47 coal, but they are not present in this coal of 1.25 specific gravity. These particular functional groups are in very small amounts in 1.25, but they are present in much greater quantity here. Similarly, in such cases, there are some functional groups corresponding to this 3397 wave number, but these functional groups are very few in this particular wave number. So, What is inferred from that? That means coal hydrocarbon composition is different. The same thing we can see in the higher specific gravity also, in 1.55. These groups' contribution is much more. Here you can see these functional groups are present in a higher quantity. But in this coal, these functional groups are not present at all.

Similarly, these functional groups are present in higher quantity here. But they are very small in quantity or a very small quantity of functional groups is present in this. So, with each and every specific gravity of coal, the functional groups are changing. These functional groups changing means this confirms that all these different specific gravity coals have different types of hydrocarbons present. Their hydrocarbon types, like aliphatic, aromatic, single-bond compounds, C-C single bonds, or C-C double bonds, C-C triple bonds. It shows that everything is changing, and some of the compounds may represent the presence of maybe chlorine, bromine, or some metallic elements like sodium, potassium, etc. So, all these are available in this FTIR analysis, and even if we do the NMR analysis, we also get similar types of data, which confirms that each and every individual density of coal is unique, and this is only available for some particular coal sources, like Coal E. This plot is for Coal E. So, even if we see the plot for Coal A, these entire characteristics will change.

As their entire characteristics are changing, and they vary with the density of coal particles. So, their hydrocarbon composition, their hydrocarbon types, and their hydrocarbon percentages are changing with the specific gravity or density of coal particles. So, what we can conclude is that if we change the density of coal particles, apart from other changes, there will certainly be a major change in their reaction kinetics. So, if we change the source of coal or the cut density of coal, their hydrocarbon composition will change significantly, which will impact their utilization behaviour, and we may not get the desirable conversion of coal, even if we use the same cut density during coal washing. Or simply, if we change the source of coal from Coal Mine A to Coal Mine B, their hydrocarbon composition will change. So, their reaction kinetics will be modified; they will change. So, we cannot always follow a straight-cut rule that this equipment is designed for coal of specific gravity 1.4 or that this equipment will work well with 30% ash coal. A 30% ash coal may work well only if we see the ash percentage of coal, as there is not so much variation. But as their combustible percentage, their volatile material, their fixed carbon percentage, their carbon percentage, and their hydrogen percentage are changing. As the reaction happens at the molecular level, the individual bond level, if the hydrogen percentage changes, if their carbon percentage changes. their reaction kinetics will change. For example, if a compound has C-C double bonds and C-C single bonds, their reaction kinetics, their activation energy, everything will change when it reacts with either oxygen, carbon dioxide, or nitrogen, wherever we want to utilize this coal. So, their reaction kinetics will change. So, in terms of their utilization behaviour, it will change with the individual source of coal and the individual specific gravity of coal.

So, when we utilize coal in industrial boilers or any industrial utilities, we have to keep in mind all these parameters. So there always needs to be some fine-tuning of the parameters to adjust any variation in the coal properties so that the product quality, reaction kinetics can be maintained, or we can achieve desirable coal properties, heat release, or other gasification products. They always need constant monitoring of the input coal parameters as well as the final product parameters.

Thank you.