

**Clean Coal Technology**  
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**Week-01**  
**Lecture-04**

Hi, I am Professor Barun Kumar Nandi. Welcome you in NPTEL online certification course on clean coal technology. We are continuing with the module 1 coal properties and in lecture 4. So, in the last class, we have discussed lots about the hydrocarbons present in the coal. Now apart from hydrocarbons, their main contribution in the coal is in their gross calorific value of the coal. Gross calorific value-it represents the total amount of energy available in coal. So, if coal has higher amount of energy available or if we can get higher amount of energy after combustion of coal, that coal will have higher amount of gross calorific value. Its unit is kilo calorie per kg of coal. That is, after burning unit mass of coal, how much energy we can get from that coal. Higher combustible and low ash are required to get good calorific value.

High ash coal has difficulty in combustion. It reduces the heat release rate in terms of kilocalorie heat release per unit time or minute time. Incomplete combustion also occurs if coal has high ash content. So, in these aspects, also ash or mineral matter is impurities present in coal. Now if we say the gross calorific value, gross calorific value or energy released from the coal is from their inherent different type of hydrocarbons present in coal. So, if coal has higher amount of combustible material, so by other reason its ash content will be reduced. Because total combustible, ash and moisture content will make it 100%. So, if coal has higher combustible, so it is expected that coal will have lower ash content and its gross calorific value will be on the higher side. In the opposite side, if coal has high ash content, so its combustible quantity will be on lower side and its calorific value will be on lower side.

So overall, if we find that high ash content means lower calorific value as well as it will be difficult in their burning because high ash content coal will have lower heat release rate in terms of kilocalorie per minute, it will also cause incomplete combustion. Other aspects of high ash are that high ash results in hardness of coal. If coal has higher mineral matter and that mineral matter contains different type of inorganic compounds, that coal will be difficult to grind. As during grinding, the hardness of mineral matter is on higher side, whereas the combustible or hydrocarbons are on the softer side. So, if coal has high mineral matter, it will be difficult in grinding as well as its abrasiveness will also be on higher side. So, if coal has higher ash, so mill performance or pulverize or ball mill performance during the grinding in pulverized coal combustion will be difficult. High ash also results in abrasiveness of coal as we discussed earlier. Coal contains quartz and other type of material. Those damages the entire coal handling section starting from conveyor belt, crusher, screen, mill, the storage in bunker

etc. Mostly quartz, alumina, silica type material causes regular damage and it also results in lower lifespan of the equipment and it needs regular maintenance. And particularly if coal have the high abrasiveness, we can see that there will be frequent start and stop and frequently it needs maintenance of the entire coal handling section. Conveyor belts are mostly made of cotton and synthetic material. So those material cannot withstand high abrasive material. So typically, their lifespan will be very less. An entire plant may have very frequent breakdown if coal has high ash content and high abrasiveness.

Ash composition also played an important role in deciding the ash fusion temperature. Ash fusion temperature is that temperature where the mineral matter or their converted part the ash which are the oxides from metal oxides. reach their boiling point. As a result, this mineral matter oxides reach their melting point, where they converted from solid phase to the liquid phase. So, as they reach the liquid phase ash, it is a mixture it is called the fusion temperature not the melting temperature. So, as fusion temperature reaches coal ash will form liquid ash and that damages the entire furnace boiler and other section because liquid ash or liquid metal oxides that will stick to the surface of the furnace wall, which are made of different type of refractory material. so, their refractory material, it will have an additional layer which will have different thermal conductivity and it will face different type of thermal action. As a result, its lifespan will be reduced similarly boiler tubes and other parts. if it sticks to the boiler tubes, boiler tube will also have different type of thermal conductivity. So as a result, entire boiler performance will reduce and individual metal oxides present in ash and their melting point are mostly responsible for this ash fusion. So, if any coal has mixture of five different oxides and any individual oxide is responsible. So, it is not an additive property. it is like a non-additive property. Properties of coal-like properties we cannot add when it is in as part, individual sodium oxide, potassium oxide, calcium oxide, etc. Individual oxides will have their melting point. So, if any of the oxides reaches its melting point, entire ash will become soft. As a result, ash fusion occurs. So individual metal oxides present in ash are responsible for the gas fusion and this factor is very much important when we see the coal from different coal mines or different coal sources because different coal mines are originated from the different type of clay material. So individual clay material can have different mineral matter composition. So, ash fusion temperature or ash melting temperature for different source coal will be different. So, although coal can have similar other properties. But if in the ash composition is different, they can melt or fused at much lower temperature and also in the mineral matter. Some of the toxic or harmful metal elements compounds also can be present in ash. Different type of toxic metal like lead, mercury and other toxic metals are also available as part of clay material and sometimes toxic elements like chlorine, fluorine. They can also present as part of coal so effectively. This coal has represented the nearby clay compound. It is also observed that in some cases. Some of the valuable metals like selenium is also available in the ash. So effectively the ash represents the nearby clay composition, which has mostly the negative

impact and which are mostly harmful and toxic element and they can have some toxic compound also present in ash and apart from these two aspects. For high ash coal, if we see, it has unnecessarily burden on the transport of coal.

Because we use coal for their calorific value or for their combustible material, which comes from the fixed carbon as well as the volatile material. So, if any coal has 50% ash content, that means it has 50% carbon. ash content and remaining 50% may be as part of combustible. So, this 50% combustible part is helpful whereas the remaining 50% ash part is not helpful. But when we transport coal from long distance, so we unnecessarily transport this additional 50% mass, which doesn't contribute to the calorific value, as well as it creates lots of other problems. And after combustion, its residue part ash, it also creates an ash disposal problem. And there are similar many other environmental issues which originates from the ash of the coal. So as a result, overall, we find that mineral matter or ash is the major impurities for both coking coal as well as the non-coking coal. For coking coal, if high ash content is there, its coking property reduces. So, we cannot make it like washey grade 1, washey grade 2, steel grade 1, steel grade 2, all will vary. And in case of non-coking coal, due to the presence of ash, it has so many environmental problems, ash fusion occurs, some toxic components may be there, it will be difficult in the combustion also. So, to reduce this mineral matter, the method is to reduce mineral matter or ash from coal, which is known as the coal cleaning or coal washing or sometimes known as the coal preparation plants. So, in these methods, we try to reduce mineral matter present in coal by different technologies. And apart from this, there can have sulfur, chlorine, phosphorus and other elements on their compounds are also problematic. If sulfur is present, it also creates sulfur dioxide emission or SO<sub>2</sub> emission in the environment. If chlorine is present during combustion, chlorine may create chlorine oxides and other harmful gases. Same thing with the phosphorus. It will release phosphorus and their oxides and finally phosphoric acids and similar toxic compounds to the environment. And sulfur is already part of coal analysis. We analyze it in the ultimate analysis, which is known as the CHNSO analysis.

Typically, sulfur is... measured in coal analysis as its percentage is on the higher side whereas the chlorine phosphorus and other elements are typically not analyzed if some problem or something is faced by industry so they are analyzed on demand on case-to-case basis. As a result, most of the equipment it will have the facilities to analyze CHNSO and sulfur, phosphorus, chlorine. it will have the most of the equipment, it has the facilities to analyze CHNSO and chlorine, phosphorus, and other elements are analyzed on demand on case-to-case basis. And in case of metallurgical coal, steel quality also deteriorates if coal contains sulfur, phosphorus, chlorine, etc. are present.

So, in these aspects also, apart from mineral matter, sulfur is also a problematic material which needs to be removed or reduced from the coal. At the present time, presence of chlorine, phosphorus and other impurities are not too much concerned. But in future case, maybe we

have to think about reduction of chlorine, phosphorus and other toxic elements from the coal. And if sulfur is present in combustion, it releases SO<sub>2</sub>, SO<sub>3</sub> gas and other toxic gases.

During coke making, as it is in the reducing environment, H<sub>2</sub>S gas and other sulfur-rich hydrocarbon gases are released. All these gases have some permissible limits in the air. So as per their environmental rules for every core consuming industry, some limits of sulfur are present. As we cannot completely remove sulfur from the coal. As sulfur is part of the inherent hydrocarbon structure. So, it is not possible to have zero percent sulfur in coal. So, there is some permissible limits of sulfur in coal below which coal can be used and if that limit is exceeded, coal cannot be used. So typically sulfur content in ultimate analysis should be less than 1%. That is the present environmental guideline. If it is less than 1% that sulfur can be used and that is can be used in both steel plants in metallurgical coal as well as in the thermal power plant for thermal coal. If it exceeds 1%, coal cannot be used. So, these quality parameters are very much similar to that of liquid fuel quality parameters. We know like BS4 and BS6 where the variations of sulfur in the petrol and diesel are there.

So, this sulfur percentage guideline is almost in line or in similar to the other fuels like gaseous fuel and liquid fuel. Any coal which is burned in industry, they should verify the sulfur content whether if it is below 1% or above 1%. And this sulfur measurement is as per the BIS guidelines in Indian context as well as in the international context ASTM guidelines. So, sulfur reduction from coal is very much necessary to make it suitable for industrial use. and typically, northeast coal it has very good calorific value good caking properties but it has very high sulfur content that's why it is not useful at all. So, such coal is extremely useless and there is very minimum use of such northeast coal due to presence of higher amount of sulfur. So, if we measure the gross calorific value, that gross calorific value is the amount of heat release during combustion of 1 kg of coal. Exact heat release from the gross calorific value, it is to be measured in this Bomb calorimeter. So, in the bomb calorimeter, exact heat release from the coal is measured and heat loss from the Sensible heat loss by participating oxygen gas, flue gases, and water vapor latent heat, all are considered during this process.

And other heat loss and gain in system are also considered. As in the bomb calorimeter, it is an electrically fired system. So, heat generated from the electricity, some cotton threads, and other mediums are also considered when we measure the GCV. And apart from this gross calorific value there is another parameter like net calorific value is also there, which excludes the heat loss due to the evaporation of water. Difference between the gross calorific value and net calorific value is that in the gross calorific value we measured overall heat available from the coal. But during combustion, some amount of moisture is also produced as coal contains hydrogen. So, those hydrogen will be converted to moisture and this moisture is released in the vapor form. And for this vaporization, it takes the latent heat as well as the sensible heat for vaporization and that amount of heat it takes from the heat released from the coal. So, this

amount of heat is actually not available for utilization. Gross calorific value is overall heat energy available, but not the entire heat energy can be used.

So, there is some amount of heat energy lost from the sensible and latent heat from the water vapor as well as whatever the flue gases are produced like carbon dioxide and others. They are also released in the atmosphere at higher temperature. So those heats are not considered. So those are not considered, then it is the exact net calorific value. So effectively NCV means GCV minus heat losses from the other gases. Bomb calorimeter is widely used for this measurement and thermal coal; they are priced in India based on the gross calorific value. If coal has good calorific value, it is placed in the higher price band. And gradation of coal and similarly lignite is also done by Coal India Limited. Here model is that high GCV, it is better price. And GCV originates from the internal energy or internal hydrocarbon bonds, which constitute carbon-hydrogen, carbon-oxygen carbon-carbon bonds and similar other bonds present in the hydrocarbon. So, if coal has different type of hydrocarbons present and their bonds are single bond, double bond, triple bond, aromatic bonds and other their internal energy will be different and during combustion those internal energy and bonds are broken and that energy is released and we get the energy. So, depending on the types of hydrocarbons present in coal, GCV will vary.

And that is most important that coal can have similar proximate analysis like hydrocarbon. If we see the hydrocarbon can have same percentage, but if their hydrocarbon bonds are of different type. Like coal can have 30% volatile material, 30% fixed carbon. But if their hydrocarbon bonds are different, so that can have different amount of energy stored in those bonds. So, GCV will vary. As a result, coal of similar characteristics can have different GCV. And that is the reason why each year coal pricing, coal gradation is done by government of India. So, this is a typical chart. We got it from the Ministry of Coal website. So typically, coals are priced based on their GCV and their grade. So high GCV means it is placed as the grade 1. Grade 2, Grade 3, Grade 4, Grade 5, Grade 6, Grade 7, Grade 8, Grade 9, Grade 10, etc. Which is a typically with a price difference of 300 kilocalories per kg. So, by difference of 300 kilocalories per kg, different type of price band has been made by government of India. So that coal can be graded and accordingly their market price is different. and if we see the volatile material, volatile material measures the non-water gases released from coal during heating at 925 degrees centigrade for seven minutes in an oxygen free environment. It excludes the moisture as moisture loss happens at 105 degrees centigrade. Most volatile material comes from the low molecular hydrocarbons either present or they are released by the thermal decomposition of high molecular weight hydrocarbons present in coal and some volatile material may also originate from the mineral matter. So, some of the mineral matter, they may decompose at lower temperature and their mass loss is also Part of mass loss when it occurs during the measurement of volatile material. So, it is not that entire volatile material may come

from the hydrocarbon. Some mass percentage may come from the mineral matter. If mineral matter decomposition occurs at lower temperature like 500 or 700 degrees centigrade.

Because volatile material measurement is done at 925 degrees centigrade. So, some mineral matter decomposition may or may not be part of volatile material. Volatile material, its main role is that it will easily catch fire during combustion. It helps to ignite the coal. Now once coal is ignited, remaining hydrocarbon present in coal, it will also get burned and gets the required activation energy for oxidation. So higher volatile material means better ignition characteristics of coal. Low volatile material means difficulty in ignition. And VM also contributes to the gross calorific value of the coal. Entire calorific value of the coal comes from combined contribution of volatile material as well as the fixed carbon of the coal. and some moistures are present in coal that should be on the lower side. High moisture coal can have higher porosity surface area for chemical reaction. As this moisture release at the lower temperature. So, after releasing moisture, there can have some vacant spaces or surface area, which is helpful in absorbing oxygen which is helpful during their chemical reaction.

Fixed carbon represents mostly the high molecular weight hydrocarbons or almost pure carbons present in coal. They are the residue after release of volatile material excluding ash. If fixed carbon content is high, coal is difficult to ignite and it will have higher activation energy for chemical reaction. And in comparison, if we compare from the volatile material and fixed carbon, fixed carbon is the major source of gross calorific value. Volatile material is a part of that also contributes to the gross calorific value, but most of the calorific value comes from the fixed carbon.

Fixed carbon is mostly rich in carbon and that carbon is used in the reduction of iron ore in the steel plant. So, if we can see that good amount of calorific value is obtained from the fixed carbon, whereas the volatile material helps in the ignition and combustion of coal. So, there should have a very good balance between volatile material and fixed carbon for their better combustion characteristics. If VM is reduced, Volatile material is reduced with rank of coal.

During coalification process, volatile material gets released from the coal surface and its percentage get reduced. As a result, overall combining to the 100 percentage, so fixed carbon percentage increases and this ratio or this gives an indication about the maturity of the coal. Ash fusion temperature should be high. So that no ash fusion occurs, no ash fusion related problems occur in the boiler. HGI should be soft so that Coal can be easily grinded.

So main purpose of this HGI value is that HGI value or coal should be on softer side. AI value should be on the lower side so that coal can be used without any abrasiveness or any damage to the coal circuits. And apart from that, XRF, X-ray fluorescence analysis is used to analyze the coal mineral matter composition. FTIR, petrography analysis is also important when we

analyze the coal or when we decide the coal's usability. So, if we summarize the coal characterization techniques, ultimate analysis, it represents the elemental composition of the coal or hydrocarbon.

This is used in the stoichiometric calculation to estimate the amount of CO<sub>2</sub>, SO<sub>2</sub>, steel, NO<sub>x</sub>, etc., which can be released during combustion. Higher carbon content represents better maturity of coal. And it represents higher fixed carbon. Higher hydrogen means it will have lower maturity and higher volatile material. It will have very good ignition characteristics but it will also result in heat loss due to moisture release. So, both carbon and hydrogen contribute to the gross calorific value. Some amount of nitrogen, oxygen, they are present as part of hydrocarbon. We cannot avoid them, including sulfur content. Sulfur also presents as an organic hydrocarbon, as well as part of inorganic salts, which are like some sulfates or sulfides as part of inorganic material also can be present. So, if we summarize it,

Thermal coal, it should have non-coking properties, it should have low ash content, low sulfur content, good amount of GCV and adequate volatile material for combustion purpose. Whereas the coking coal, it should have very good coking properties, low ash content to make it very good quality coke, it should have low sulfur content, it should have higher amount of fixed carbon and carbon. So, if we see there, this part that is hydrocarbon, CHNS, volatile material, fixed carbon, gross calorific value, they are the major part of this coal which are required part whether this mineral matter, moisture as well as the different inorganic materials present in coal, they are the impurities, they are non-desirable part of coal. So, in clean coal technology or coal cleaning, our purpose is to reduce the mineral matter or to reduce this part as well as to reduce this sulfur present in coal. So, at present, sulfur is considered as an impurity, but as we go on year by year, there can have other impurities also to be removed from the coal.

So, if we conclude from entire coal characterization studies or coal quality parameters, so origin of coal, that means here the actual plant converted to coal determines the types of hydrocarbons present in coal. If the actual plant is different, different type of hydrocarbon present and their composition will be different. actual type of or origin of the plant is most important to decide the types of hydrocarbons present in coal. Coalification process is also important to identify at which stage coal is present, so it is either peat, lignite, bituminous or anthracite because with change in rank other coal properties also varied and types of coal, types of hydrocarbons present in coal, like it is an aliphatic hydrocarbon, aromatic, cyclic, branch chain, etc.

They decide their coal properties, their reaction kinetics, caking properties, etc. Ash and sulfur are the major impurities and those are the major barriers in the coal utilization. So, main focus here is to reduce this ash and mineral matter and their impact on the environment because they are the major impurities. Impurities are their major barrier in coal utilization. If coal have any of this quantity exceeding their permissible limit, we cannot use that coal.

A coking coal should have low ash along with good plastic properties. So, if we need a coking coal, it should have good plastic properties. That is most important and it should have lower ash content. Whereas in a non-coking coal, it should have adequate volatile material and gross calorific value. So that coal, after burning of coal, we can get good amount of energy release. As hydrocarbon vary from source-to-source mines in each seam of the coal, coal properties and their utilization gets also varied. So same coal, or from one coal mines with change in the seam or change in the layer of coal at any particular mines, their hydrocarbon structure, their mineral matter composition can vary. As a result, in any particular coal mines, one particular seam can be useful. On the other way, the next seam may not be useful or may not match their design criteria for any particular plant.

Actual chemical composition of coal hydrocarbon is important. When we utilize their coal, their actual hydrocarbons are most important, not their exactly volatile material, fixed carbon, carbon, hydrogen. Volatile material, fixed carbon, carbon, hydrogen, we analyze to identify what type of, it is an outside interfacial analysis to guess what type of properties coal can give. exactly the hydrocarbons present they reacts during their utilization. So, their composition is much more important than volatile material. This says that two coals can have similar volatile material but if their hydrocarbon structure is different. They can show their different combustion characteristics or they can show different gross calorific value. They can show their different caking properties etc. So, it is the chemical reaction on individual hydrocarbon level in presence of other impurities like aluminum, silica, iron, etc.

So, when we utilize coal or when we burn coal, individual hydrocarbon reacts with oxygen in presence of mineral matter. So, that is most important. level reaction occurs whether we do it combustion, gasification or other utilization that individual level reaction is most important. Although we analyze them in terms of volatile material, fixed carbons or others and they represent only some particular, they represent some limitation not the entire characteristics of the coal. Mineral matter composition also plays important role

Because they can have some heat resistance material, they can have some thermal conductivity, thermal reactivity, some of they can have some catalytic activity etc. So mineral matter composition plays important role during the combustion. and coke making process particularly analysis of volatile material coke making. This is one type of chemical reaction and these are irreversible chemical reaction. So, they cannot be repeated for same coal like if we analyze the volatile material of coal. When we analyze the volatile material of coal. We heat the coal at 925 degrees centigrade and by this process, some chemical reaction occurs some compound released from the coal structure. So, if we want to analyze or repeat the test, we have to take some other coal not the same coal because it is only one time property it is an irreversible chemical reaction So, any analysis, repeated analysis for volatile material, fixed carbon, others, it has to be on an exactly different coal sample. That coal sample can have from same location,

but it is not the same coal sample we are using. We are using a different amount or different coal for analysis of volatile material and fixed carbon.

So, thank you.