

**Clean Coal Technology**  
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**Week-01**  
**Lecture-03**

Hi, I Professor Barun Kumar Nandi. Welcome you to the NPTEL online certification course on clean coal technology module 1. After the previous two classes, I will be discussing on coal properties and their details in this class. So, if we want to identify or characterize coal, depending on their properties, these are the different properties, we use to characterize or identify the coal for their different utilization behavior. First characterization is their proximate analysis. In the proximate analysis, this is the easiest way and almost everywhere or easily we can install this equipment required for this analysis. So, in this analysis, we measured the moisture content, volatile material, ash or mineral matter and fixed carbon of the coal. So entire coal properties, they are divided in four different ways in this analysis. In the moisture analysis, we first prepare the coal samples for this proximate analysis and others.

So, each of these analysis needs different size of this coal. So, for proximate analysis, we need coal of 72 mesh or approximately 212-micron size coal particles or coal fines. So, for this purpose, entire coal is initially crushed to smaller size, then further grinded to the required size of 72 micron. In this analysis, entire coal is initially crushed and then grinded to 72 mesh size and in the 72-mesh size coal. For moisture analysis, one gram of coal sample is taken in a glass or glass plates. One gram of coal sample is taken in a glass plate of particular design. So, this coal sample is kept in a hot air oven for approximately one hour. So, during this one hour from coal surface, moisture will be going out as both the moisture internal moisture and external moisture. They will be removed from the coal surface. So, after this analysis, we measure the mass loss from the coal surface and the mass loss from the coal surface that percentage will be converted to the moisture percentage. So, we measure the initial weight  $w_1$  That is the initial weight part. We take the  $w_2$  that is the mass of the coal after heating and we also measured amount of coal taken that is approximately 1 gram. So approximately 1 gram of coal we take and we take their difference in their weight which will be converted like  $w_1$  minus  $w_2$  by the exact mass of coal taken.  $m_1$  so that percentage will be converted and multiplied to 100 that will be known as the moisture content. Now this moisture content, we can analyze in different basis. Actually, in proximate analysis, we can analyze all these parameters in different basis

like as received basis, whatever coal we received from the mines, if we analyze it, we call it as the as received basis or ARB. If we dry the sample at sunlight for some time to remove some of the external moisture, we call them as the sun-dried basis or air-dried basis. Another basis is also used that is the equivalent moisture condition.

In this proximate analysis, we analyze the coal sample for the moisture at different basis. One is the as received basis and second is the air-dried basis and third one is the equilibrated basis. In the equilibrated basis, we keep the coal sample at particular condition which can be similar or replicated every location. as the location or nearby atmospheric condition can change the moisture content of the coal. That's why in the equilibrated analysis, we analyze them at 40 degrees centigrade with 16 relative humidity condition, which can be synthesized at the laboratory condition. So, this condition can be analyzed in every location. So that we can get same proximate analysis for the coal sample if we change the location Because the location at each city or each country has different temperature as well as the different atmospheric moisture or relative humidity.

Any city nearby coastal area like Kolkata, Chennai that can have higher moisture content available. Whether any city inside the India like Madhya Pradesh, Chhattisgarh and other they are relatively dry locations where relative humidity is less. To get the accurate result, that's why this equilibrated analysis is also reported in some of the cases. So overall proximate analysis is reported in three bases. One is on the as received basis, ARB.

Second is the sun-dried basis or dry basis, air dry basis. And third is the equilibrated basis. In these three bases, analysis is done. So, in the moisture analysis, we measure the amount of mass loss around 100-degree centigrade heating. So, this moisture is typically around 4 to 5 percent for the anthracite and bituminous coal, whereas for the peat and lignite, it can be more than 15 to 20 percent. Second analysis is the volatile matter. In this analysis, we measure the percentage of low molecular rate hydrocarbons present in the coal. So, coal sample is heated at 925 degrees centigrade for 7 minutes in the absence of air and the mass loss is measured. What is the amount of mass loss? And this mass loss will be total mass loss constituent from moisture as well as the volatile metal. So total mass loss will be the volatile material and it will be actual volatile material plus moisture. So, in case of actual volatile material, this moisture will be removed or it will be minus from the total amount of volatile material available. Third analysis is the ash or mineral matter content in this analysis coal sample is heated in the presence of oxygen or air at 800 degrees centigrade and keep there for about one hour. So, by this one hour this coal sample will get burned. All the hydrocarbon will get burned and only the residue will be there, where mineral

matter will be converted to their individual oxides or ash. So, we measured the residual mass present in the course we measure the residual mass present in the coal sample that is known ash. The ash, so after analysis of all this moisture, volatile material and ash, remaining part will be considered as the fixed carbon. So fixed carbon, it will be 100 percent minus moisture Plus volatile material plus ash. So, this will be the percentage of fixed carbon. So fixed carbon is measured by difference not by the any other method and second analysis here is the ultimate analysis of the coal. In this ultimate analysis, we measure the elemental composition of different hydrocarbons present like carbon, hydrogen, nitrogen, sulfur and oxygen. so, at present days equipment's are available, where we can measure all the five elements or five hydrocarbon compounds. All the five elements present in coal like carbon, hydrogen, nitrogen, sulfur and oxygen. But for fuel analysis typically oxygen analysis is not directly done. So, it is measured like C H N S are measured and oxygen is measured by difference.

So, here to measure the oxygen content, we have to also consider the amount of mineral matter and moisture present in the coal. So, in this oxygen content, it will be the residual part. Sometimes we measure directly if equipment is available and if equipment is not available or equipment does not have this configuration, we measure the CHNS and oxygen by Balance. Carbon content. This carbon content is actually the carbon present in the coal that mostly originates from the hydrocarbon. So, this carbon comes from both volatile material as well as the fixed carbon of the coal. And maybe some trace amount of carbonate salt if it is present, they can also contribute to this carbon content. But generally, that is not considered. So, any carbon content is assumed to be originate from the volatile material as well as the fixed carbon of the coal.

If carbon content is high, it is assumed that coal will have very good gross-calorific value and very higher utilization potential. If carbon content is less, that means coal will have lower utilization potential. With increase in the maturity of the coal from peat, lignite, bituminous, anthracite, carbon content of the coal is increased. So higher carbon coal means, it is of the higher rank coal. second part is the hydrogen part of the coal. So, hydrogen part is part of the hydrocarbon structure present in the coal. Typically, hydrogen present in as part of hydrocarbon which can be of aliphatic aromatic or any cyclic compound around four to five percent hydrogen present in coal is very common and it is observed presence of hydrogen is good as hydrogen gives the

gross calorific value or energy content present in the coal. So, in any coal, Overall energy content is available from hydrogen part as well as the carbon containing part present in the

coal both carbon and hydrogen contributes to the calorific value but difference is that if hydrogen is higher that means coal can have low molecular weight hydrocarbons that means coal will have volatile matter rich hydrocarbons present. So, if coal volatile material is higher than typically hydrogen content is high. If in the coal fixed carbon is on the higher side then hydrogen percentage will be on the lower side and same thing with the carbon content if carbon content is high typically fixed carbon is high and volatile material is linked with the hydrogen part. Other two parameters, nitrogen is always present in the coal as part of different hydrocarbon. As in organic compounds, they always contain some nitrogen rich compounds. So, this nitrogen is also part of coal structure and typically one to two percent, maximum to three percentage of nitrogen is sometimes present in different coal. Nitrogen doesn't take part in any of the coal utilization aspects. So, nitrogen does not react during the coal utilization. This assumed that so nitrogen content does not bother about the presence of nitrogen there or not. So around two to three percent nitrogen can be seen in different type of coal. Fourth parameter is the sulfur content which is always present in some of the coal. So, this sulfur present can have some from different origins like it can have from the hydrocarbon part of the coal as well as it can comes from the mineral matter part of the coal. Accordingly different types of sulfurs are there. So, we will be discussing this presence of sulfur or types of sulfur in next class. So overall if sulfur is present in coal, it creates

Sulfur dioxide during combustion and it is a toxic material or environmental polluting material which is not desirable part of this coal. And oxygen it is also part of different type of hydrocarbon present in coal. So, some amount of oxygen is always available in coal around 5 to 6% or up to 8% oxygen is very common. As it is measured by difference. In most of the cases may be value may be up to 10% is also same. So, this is all about the ultimate analysis.

So, this analysis is done in an ultimate analysis equipment. made of different brands. So here very fine size coal is taken as only 4 mg to 10 mg, 15 mg coal sample is taken for this analysis. So, in this analysis, very fine coal particle of 72 micron or less 72-micron size or less or it is known as the 200-mesh size in case of size analysis. So very fine particles of coal sample of 4 to 5 mg or maybe up to 10 mg, 15 mg depending on the equipment type is taken in this ultimate analysis. so, this ultimate analysis is used to identify the different type of gases to be released or predicting the calorific value of the coal. Third point is the gross calorific value of the coal. So, this calorific value is measured in units like kilocalorie per kg of coal like amount of heat released

per unit mass of coal. So, it is measured as kilo calorie per gram, calorie per gram or in kilo joule per kg or mega joule per kg or similar units. Gross calorific value is the most important parameter which affects its utilization in thermal power plants. If gross calorific value on the higher side that means from that particular coal we will get more amount of energy available. So, this more amount of energy is measured using the bomb calorimeter equipment.

Typically, coal contains calorific value above 6000 is very good. and in most of the cases, calorific value for coal is 3000 calorie or 3000 kilocalorie per kg it is very common. If calorific value is less than 3000 kilocalorie per kg. It has less utilization potential or mostly it is used in the domestic applications. Now fourth parameter is the hardness of the coal measured as the Hardgrove Grindability index or HGI values. This is then parameter to decide or to identify the how much hard is coal to grind because most of the utilization in thermal power plant very fine powder coal size is used. So, during making of this very fine coal from the bigger size coal, different type of coal mill, ball mill or grinder is used.

Now if coal is very hard then grinder will take lot of energy consumed for grinding the coal as well as the it will take lot of time to grind the coal. So, in this Hardgrove Grindability Index, we measured how difficult or how easy to grind the coal. So, in this analysis coal is grinded to 72-micron size using a particular equipment and we measured how much out of 50 gram of coal sample taken, how easily coal can be grinded to make it 75 microns. If coal takes less time or very easily, most of the coal is grinded, then coal is known as the soft coal.

And if there is minor quantity or smaller quantity of fine coal is available, then we call it as a hard coal. If coal is soft then in the coal handling section of the plant or in the coal mill, Energy consumption will be less and coal will be grinded within a smaller time span of time. But if coal is hard or it is difficult to grind. Then we need high power capacity grinder or motor to grind the coal as well as it will more time to grind the coal.

So, in such case, we have to use many numbers of coal mills to get the required coal grinding. So, this is one of the most important parameters in case of thermal power plant. If coal is very soft, then we can easily meet the coal grinding or coal feeding requirement in the boiler so that coal mill can easily make the coal powder and burn it, but if coal is hard then it needs special arrangement in the coal handling section to grind the hard coal. Typically, this HGI value is measured around 40 to 60 is known as overall hard or medium

hard coal and any value above 60 or 70 it is known as the soft coal. Another parameter which affects coal utilization is their abrasion index.

Abrasion index is the abrasive nature of the coal. In the coal, there are different types of mineral matter present. They are the inorganic compounds. As well as if coal, their hydrocarbons are very strong and if they are hard, they will have very abrasive nature and they will damage the different type of coal handling equipment like coal crusher, coal screen, as well as the conveyor belt and coal mill, etc. So, depending on how much difficult in handling the coal and how much damage the coal will make to the coal handling section, this abrasiveness is measured. Typically, any quartz or silica type of materials are present in coal. They are responsible for the abrasiveness of the coal. If coal is highly abrasive, then all these conveyor belt, crusher, screen, they need frequent maintenance and frequent replacement in the thermal power plant or in any other plant. This abrasiveness is an important parameter which affects the plant life or coal handling section. This is measured in unit of mg per kg of coal like if we handle one kg of coal, how much mg of mass loss will be happening to the particular conveyor belt or coal handling or any crusher or any screen that measured is the abrasiveness index. If coal is highly abrasive, lifespan will be less. And this indirectly shows that coal has quartz type of material or silica type of material is present. Other characterization is related to the caking index or segregation of coal based on their caking value like coking coal and non-coking coal. If coal has the caking characteristics there, then it is called the caking index.

Similarly, it is the similar analysis there, free swelling index, sometimes also known as the crucible swelling number or CSN index. and more sophisticated analysis is the plasticity or fluidity properties if how much plastic properties or how much swelling is happening when we heat the coal that measurement is the plasticity or fluidity. We can also have the low temperature gray king analysis or LTGK analysis. So, this, all these analyses are related to the caking and non-caking characteristics or identifying coal based on the coking or non-coking coal. Any of these two parameters or one parameter or all the parameters are measured depending on their utilization. Another important aspect for coal is their ash composition. Ash composition means what are the composition of the mineral matter. Whether coal is rich in alumina, silica, iron, calcium, sodium, potassium and their oxides. What is their composition? Because this all this as composition played an important role during their utilization. If coal has silica rich compounds or SiO<sub>2</sub> content is higher, then obviously there is abrasive index or AI will be higher side. It will be hardness will be high.

So, its HGI value will be on lower side. So, coal will be very difficult to grind because of presence of mineral matter. Coal will be hard. Similarly, if coal has some alkali compounds like sodium, potassium, magnesium, calcium and their oxides. So, these alkali compounds, their behavior is sometimes different compared to their conventional silica and alumina compounds. So this ash composition also played an important role. It impacts their entire coal utilization practice. Then FTIR and NMR analysis is also done to identify what type of hydrocarbons are present in coal. Typically coal utilization that impacts we know that their fixed carbon and volatile materials are present. So, this fixed carbon volatile material characterization is based on their thermal properties whether they are releasing or not.

They are releasing hydrocarbon at 925 degrees centigrade or not. So that is a rough or an approximate characterization of the coal but actual coal properties depend on those types of hydrocarbons present whether the compounds are of aromatic compounds, aliphatic compounds, cyclic compound. What type of hydrocarbon bonds are there. Whether they are the single bond compounds, double bond compounds, triple bond compounds are there. So, all they are analyzed based on their FTIR analysis as well as in the NMR analysis. So, these two analyses as well as similar more analysis are available nowadays and more analysis is getting invented day by day.

So, this analysis gives about the types of bonds, hydrocarbon bonds present in the coal and which has very important role in their coal utilization. And another analysis is there; it is the petrographic analysis. It is one of the microscopic observations of the coal. Using a special type of microscope, we can identify what type of picture that microscope is showing so by microscopic observation we can identify different type of hydrocarbon by their physical color. So any gray color type of material means coal has gone for under tremendous modification and it has mostly carbon rich compounds. So similarly, there are different images are there which identify different type of hydrocarbons, different type of mineral matter, which is a part of detailed part of petrographic analysis which is done based on the petrographic analysis in most of the cases the geological department. They analyze this type of analysis now if we want to analyze their coal characterization based on their coking coal. What is their fundamental difference between the coking coal and non-coking coal? If we see the coking coal if we heat the coal in the absence of air like in any solid material if we heat the coal it comes to liquid, then goes to other phases. So, in case of coal, some of the coal will come to intermediate liquid phase or plastic phase, we call them as a plastic phase where we can it will be almost a liquid or semi-liquid phase, where we can see some viscosity or viscous properties there we call it as a plastic phase if coal

shows these properties then it is known as the coking coal. So, for coking coal that coal after heating, it will come to an intermediate liquid phase and then again it will re-solidify. So, such coal is called the coking coal if coal doesn't re-solidify or if coal doesn't have these properties this coal is called the non-coking coal so during heating in the absence of air. Due to chemical reaction or thermal cracking reactions of coal, goes an intermediate plastic phase or fluidic phase and later re-solidify as hard solid, we call it and coal.

We call it a hard solid coke. And during this process, VM released from the coal surface. And typically, low ash coal, around ash content below 18%, This shows high plastic properties like very good or higher amount of free swelling index, crucible swelling number or taking index properties. And they are used for the coke making. If their properties do not have all these high good plastic properties, they are not the coking coal, they are called as the non-coking coal. So non-coking coal doesn't show any of such properties or they will show very minor or very less values of all these parameters. So, for non-coking coal, they will not have any such values irrespective of their ash content. So, for non-coking coal, hydrocarbon structures are different. Hydrocarbon present in the coal are different. So, they will not show any plastic properties. So, it is irrespective of the ash content. But for coking coal, typically low ash coal shows these properties. So, what most important is that for coking coal, swelling characteristics must be there along with the low ash content. These two properties are typically present in coking coal. So, for coking coal, low ash content is compulsory and swelling index is also compulsory. But for non-coking coal, it can have low ash content but may not have those coking properties. So, for non-coking coal, high ash content or ash content should be less. Higher ash, lower plastic properties is typically observed with increase in the ash content, typically that agglomeration properties or plastic properties reduces. So, higher ash means it will have lower plastic properties and it will make inferior coke and here ash or mineral matter acts as an impurity. So overall what we get is that coking coal means it will have low ash content and swelling properties. Coal can have their low ash content and still non-coking properties is there. So overall we find it that ash is always as impurities present in coal.

So, this is one of the impurities present in coal creates barrier in coal utilization. So, ash always acts or considered like an impurity. So non-coking coal swelling properties should not be there if swelling properties exist there. If coal becomes liquid or plastic during its utilization it creates problem in their utilization. So, for non-coking coal swelling properties should not be there irrespective of ash content and these are the picture what we get it from the free swelling index analysis. Like if we take 1 gram of coal and after heating in the

absence of oxygen at 800 degrees centigrade, it creates this type of structure and this image matches with this particular shape. If these values are doesn't change anything like 1.1.52. They are considered like a non-coking part, but if it swells creates like this picture is matches almost like this or this so they are called or they are known as the coking coal. So, with the picture when we get after we heat the coal in a free swelling index analysis, depending on the profile we get from this, we characterize whether this fixture matches with this profile or it matches with this profile. If their value is on lower side, like low FSI value, they are non-coking coal.

Intermediate values, they are known as the semi-coking or medium-coking coal. And pro-cup profile. And particularly for semi-coking or medium coking coal, it is observed that if we reduce the mineral matter or ash content from the coal, this coking property improves. That is why they are sometimes called semi-coking or medium coking. And their properties may improve if ash is reduced. And if it has a very good swelling characteristics, then they are called the coking coal. Now based on the Characteristics of this coking, whether it is coking or non-coking and to how much extent coking characteristics there, coal pricing is done. So, their coal is graded in different characteristics like at present as per Indian guideline. Coal should have very good swelling characteristics and apart from that, depending on the ash or mineral matter present, they are graded like steel grade 1 where ash content is less than 15%, they are very excellent or very superior quality of coal for making coke. If it is steel grade 2 where ash is more than 15% but less than 18%, then it can have the washery grade. Washery grade means if we wash the coal or if we beneficiate the coal to remove some of the mineral matter. This coal can be used for coking. So washery grade ones it is from 18 to 21 percent, so 18 to 21 percent ash with coking properties here most important is that it should have that coking properties must be there coking properties plus ash. If ash is on the lower side they will have the steel grade 1, steel grade 2. If ash is on the higher side, we can use this coal after some process of reducing the mineral matter or ash content, we grade them as washery grade 1, similarly washery grade 2, washery grade 3, washery grade 4, washery grade 5, washery grade 6 etc. and there can have semi coking grade 1 not exceeding 19 percent ash plus moisture, not exceeding 19 and within 19 to 24 percent semi coking grade 2. So, Government of India has graded. They have given guideline for grading of coal. So that their market value or actual cost can be considered or their actual cost can be identified based on this coal typically this steel grade 1 and steel grade 2 coal are directly used in the coke making. For making coke, so that those coke can be used in the steel plant. Whereas, the Washery grade 1, 2, 3, 4, 5, 6 allows the semi-coking grade 1 and 2. These coals are washed in coal washery

for reduction of mineral matter. As we have identified that ash is impurities present in coal. So, they are washed and they are graded. So, in the next class, we will be discussing these coal quality parameters.

Thank you.