Technologies for Clean and Renewable Energy Production
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Lecture 02
Coal as a Source of Energy

Hi friends, now we will discuss on the topic coal as a source of energy, as discussed in the previous module, it is clear to us that coal is mostly used in India for the production of electricity, around 60% electricity is produced from the coal. Now, you will see why the coal as energy resource, what are the properties and what are the composition of it, what is the availability and how the coal is formed, all those things will discuss in this module.

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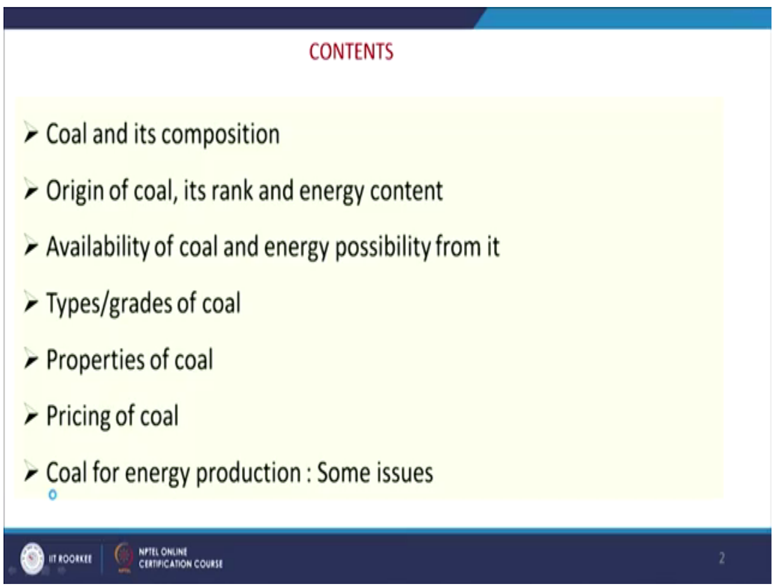

And the contents of this module are; coal and its composition, origin of coal, its rank and energy content, availability of coal and energy possibility from it, types or grades of coal, properties of coal, coal pricing and coal for energy production, some issues in India. Let us see what the coal is? As you know that it is a solid fossil fuel, which is available under the earth crust and it has been originated from plant bodies.

So, partially the plant body was decomposed and which has been converted to coal to geological actions at high temperature and pressure for millions of years long reactions. This is a black or brown brownish sedimentary rock normally occurring in rock strata in layers, which is called coal bed or coal seam.

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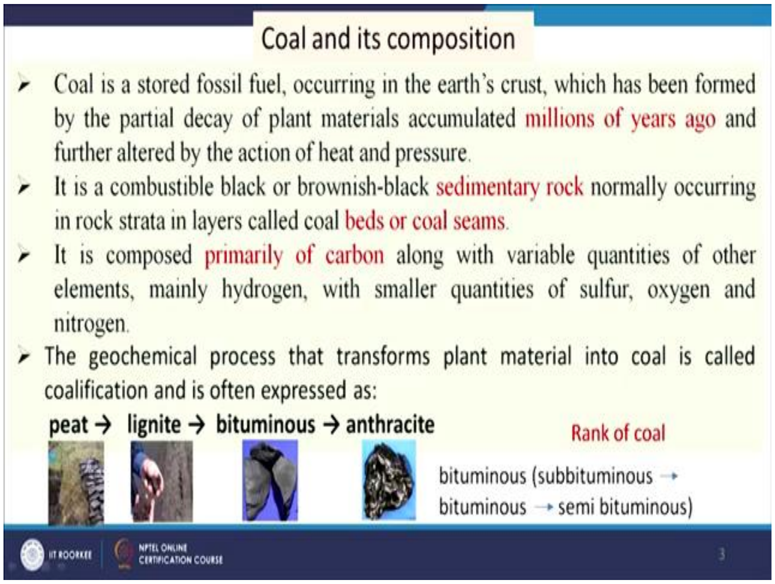

It is composed of carbon along with hydrogen and some amount of other elements like nitrogen, sulphur, etc. So, from plant body to coal formation, this has taken place to different stages. So, we can get different type of coal. Let see Peat, which is not considered as coal the first stage of coalification process, then lignite, then we get bituminous and then higher quality is anthracite. So, this process through which the plant biomass has been converted to coal is called coalification process.

And different types are lignite, bituminous and anthracite; these are also called as the rank of coal. And the bituminous category, this is also divided into sub bituminous and semi bituminous, if we see the compositions and the properties, then we see that carbon content is different from one and to other rank and higher the carbon content we get higher the heating value, which is desirable for energy production. So, in short, we can classify the coal in high rank coal and low rank coal.

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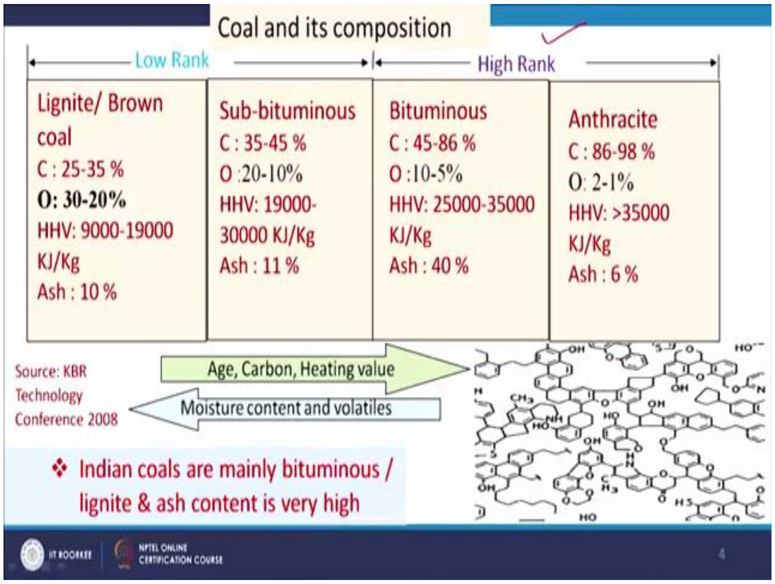

High rank coal includes bituminous and the anthracite whereas low rank coal includes lignite and sub bituminous. If we see here, this figure if we consider, it is very clear to us that in coal number of aromatic rings are available. So, it is a complex structure having large number of aromatic rings. And finally, ketonic and nitrogen containing compounds are available in it. If we go to higher rank, or more the age of formation of the coal, will get more carbon, more heating value.

But if we go to the lower age or the low rank coal, then we see that moisture content and volatiles are higher so it follows to have more volatiles and more moisture. So, virtually this reduces with the higher rank of coal. Here for lignite, we have carbon content 25 to 35% for sub bituminous it is 35 to 45 and bituminous 45 to 86% and anthracite 86 to 98%. This is a typical example of the coal composition.

Similarly, oxygen is starting to 20% for lignite and 20 to 10% for sub bituminous 10 to 5% for bituminous and two to 1% for anthracite and we see the heating value; anthracite is having the highest heating value more than 35,000 kilo joule per kg whereas the lignite the lowest one 9000 to 19,000 kilo joule per kg and ash content is also different, there is very interesting to see here the bituminous coal available in India is having very high ash content.

And that is a major issue we have to consider and we have to develop some techniques indigenously for the utilization of Indian coal. But in India, coals are mainly bituminous or lignite and ash content is very high. Now, we will see what are the theories available on the production of coal from the plant biomass.

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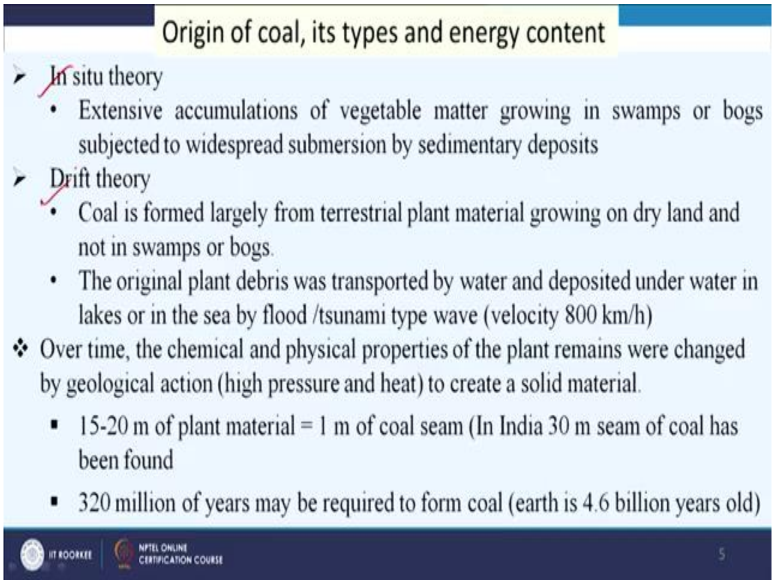

There are two theories; one is In-situ theory and another is drift theory. So, In-situ theory supports that the coal is produced from the plant biomass which are grown in swamps or bogs and subject to widespread submersion of the huge amount of these plant biomass, the sedimentary deposits took place and it converted to coal. And drift theory says that coal is formed largely from the terrestrial plant materials growing on dry land not in swamps or bogs.

And the original plant debris was transported by water body and deposited under water in lakes or in sea by flood or tsunami like situation with very high wind speed or the high velocity that is your 800 kilometer per hour. And over time, the chemical and physical property of the plant remains widely changed by geological action. And it has been reported that 15 to 20 meter of plant depth is converted to one meter of coal seam.

But in India, we have 30-meter seam. So, it is expected that around 600-meter plant biomass layer was formed at the starting of this coal and the coalification time is as high as far 220 million years which is required and the earth is 4.6 billion years old. So, this is that different theory on the production of coal. Now, with the increasing the rank of the coal, what we can see that carbon content is increased.

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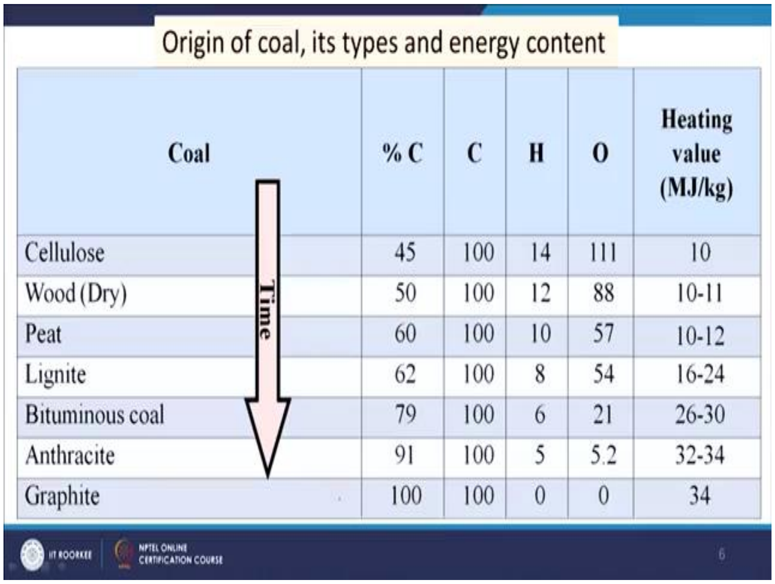
Origin of coal, its types and energy content

Coal	% C	C	H	O	Heating value (MJ/kg)
Cellulose	45	100	14	111	10
Wood (Dry)	50	100	12	88	10-11
Peat	60	100	10	57	10-12
Lignite	62	100	8	54	16-24
Bituminous coal	79	100	6	21	26-30
Anthracite	91	100	5	5.2	32-34
Graphite	100	100	0	0	34

This table shows us the carbon content is increased from cellulose to graphite, graphite is completely carbon 100% carbon and anthracite is 91%. And if we see the relative amount of carbon, hydrogen, oxygen, then also we see that hydrogen and oxygen gradually decrease as you go from cellulose to anthracite, as a result, the heating value increases. So, if we want to produce energy, obviously, will be preferring the high heating value containing coal. So, price will also be different for different types, of coal, so, we will discuss this later on.

Now, we will see the availability of the coal. Is the coal available everywhere equally across the globe? or not? This table gives us that information. It is very clear that coal is available in higher amount in specific regions. In some in some countries, as mentioned here:

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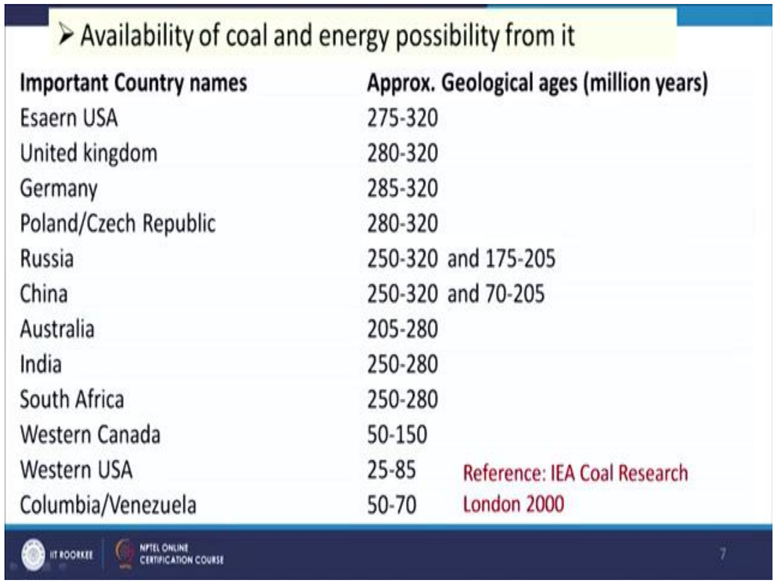

Important countries are Eastern USA, United Kingdom, Germany, Poland, Russia, China, Australia, India, South Africa, Western Canada, Western USA, and Colombia. So, these are the different geological age that 25 to 320, some odd cites 50 to 70, somewhere 50 to 150 is available. So, in India, we are having 250 to 280, as per this report, the age of the coal is 250 to 280 for India. But another report says that we have some less moisture coal also. I will give you that information.

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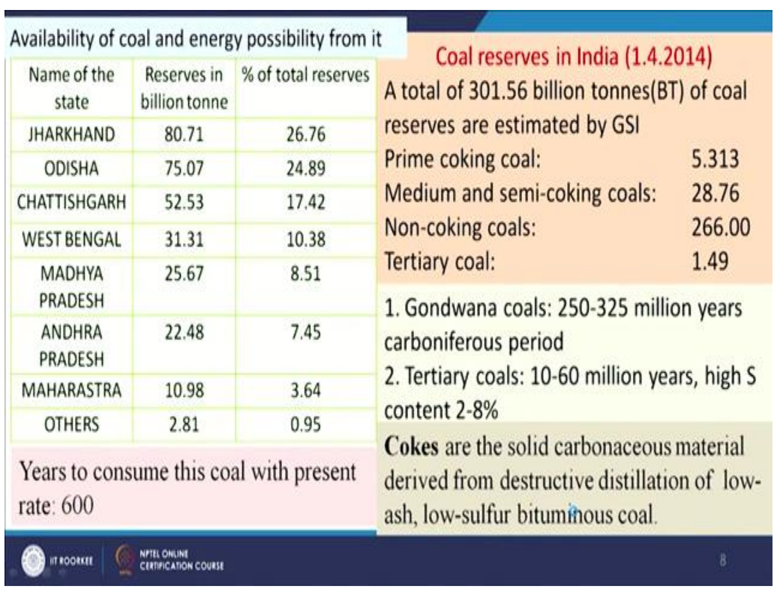

Here we will see the availability of coal in India as per 2014 report, which is devoted by Geological Survey of India, GSI. India has 3001.56 billion tons coal and out of this coal we have different types that is prime coking coal 5.313 billion tonnes, medium and semi coking 28.76

tonnes, coking 266 and Tertiary coal 1.49, this tertiary coal has ages less. And when the coal is available in India? These are the states where it is available.

See if we see this table, it is very clear that Jharkhand, Orissa, Chhattisgarh, West Bengal within these states most of the coal is available in the country, other states where it is available that is Madhya Pradesh, Andhra Pradesh , Maharashtra and the amount of quality available in the country that can serve electricity for 600 years. And this coal if we see in India, one is 250 to 325 million years old that is called Gondwana coal and another is tertiary coal that is 10 to 16 million years.

And we will be using the coal, we need one reactor system for the utilization of coal, for its converts into energy we need a specific particular size and we need its mechanical strength, but coal does not have much mechanical strength and it can be broken down into small dust and particles. So, for its use in furnace coal is converted to coke in some applications. So, that coke are the solid carbonaceous materials derived from destructive distillation of low ash, low Sulphur, and bituminous coal.

So, why from bituminous coal or not from others, because it contains the bituminous contents, bitumen type material which helps to bind and give strength to the coke. if we classify the coal then you can classify it on the base of rank that I have already discussed. Apart from that, we can classify based on coking properties, whether it has coking property or not, whether we can produce coke from the coal or not, or semi coking, it may be coking it may be semi coking or it may be non-coking.

And on the based on age also just we have discussed that is Gondwana and tertiary. Apart from these, some coals are there around the world, which are not conventional coal, for these the seam is very limited. Where scattered and less amount of coal is available. And that is also not very high quality. So this is an unconventional coal.

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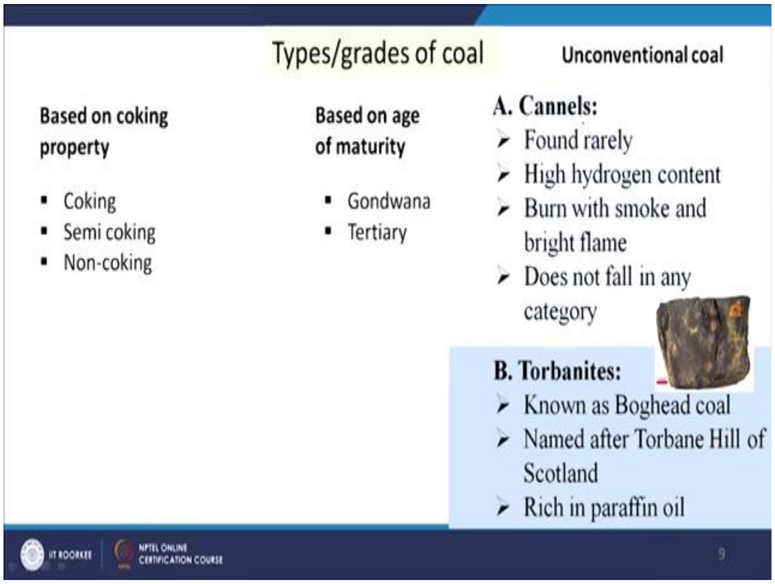

One is Cannels and another is Torbanites. cannels are found rarely. And the high hydrogen content it has and burns with smoke and bright flame and does not fall in any category. And the Torbanites, this is known as Boghead coal also, it is named after Torbane Hill of Scotland and this is rich in paraffin oil. Now, how can you create the coal we need coal for different applications? We may use it for simple energy productions in thermal power plant or we may use it for steel production in steel industries.

So, when we are interested to use it, in steel industry, then it requires more strength, more density and we can we can classify steel grade one and steel grade two.

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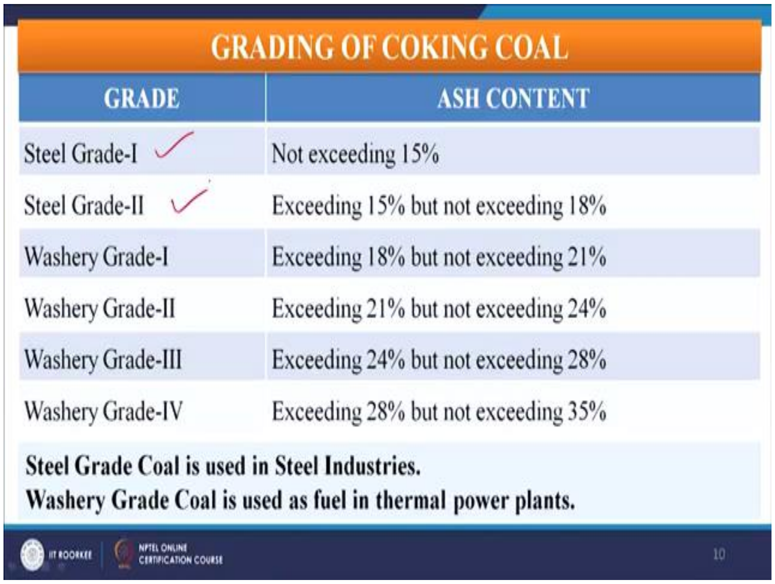

GRADING OF COKING COAL

GRADE	ASH CONTENT
Steel Grade-I	Not exceeding 15%
Steel Grade-II	Exceeding 15% but not exceeding 18%
Washery Grade-I	Exceeding 18% but not exceeding 21%
Washery Grade-II	Exceeding 21% but not exceeding 24%
Washery Grade-III	Exceeding 24% but not exceeding 28%
Washery Grade-IV	Exceeding 28% but not exceeding 35%

Steel Grade Coal is used in Steel Industries.
Washery Grade Coal is used as fuel in thermal power plants.

And that classification is based on ash content if the ash content is less than equal to 15% then it is steel grade 1. If it is 15 to 18%, then it is steel grade 2 and washery grade which is used for the energy production in thermal power plant, then we can get grade 1, grade 2, grade 3 and grade 4. and grade 1, we have 18 to 21% of ash in the grade 2 we have 21 to 24% of ash grade 3 we have 24 to 28% of ash and grade 4 we have 28 to 35% of ash.

Now grading of non coking coal; so, non coking coal grading is done not only basis of ash, it also consideres the moisture content. And this moisture content is determined at 60% relative humidity and 40 degrees centigrade as per BIS standard.

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GRADING OF NON-COKING COAL

Grade	Ash% + Moisture % (at 60% RH & 40° C)	Useful Heat Value (UHV) (in kcal/kg) UHV= 8900-138(Ash% + Moisture %)
A	Not exceeding 19.5	Exceeding 6200
B	19.6 to 23.8	Exceeding 5600 but not exceeding 6200
C	23.9 to 28.6	Exceeding 4940 but not exceeding 5600
D	28.7 to 34.0	Exceeding 4200 but not exceeding 4940
E	34.1 to 40.0	Exceeding 3360 but not exceeding 4200
F	40.1 to 47.0	Exceeding 2400 but not exceeding 3360
G	47.1 to 55.0	Exceeding 1300 but not exceeding 2400

So we can classify non coking coal into grade A, grade B, grade C, grade D, grade E, grade F and grade G, and ash and moisture content total will not exceed in 19.5 for A category, which is having heating value around 6200 kilo calorie per kg and for B category the ash and moisture falls in 19.6 to 23.8. And its heating value falls between 5600 to 6200 kilocalories per kg. For C category the ash and moisture content is 23.9 to 28.6%.

Similarly, the energy the heating value is 49 40 to 5600, and D category the ash and moisture content 28.7 to 34% whereas the heating value is 4200 to 4940 kilocalories per kg. For category E the ash and moisture content is 34.1 to 40% and then heating value 3360 to 4200 kilocalories per kg. So, F category its ash and moisture content is 41.1 to 47% whereas, the heating value is

2400 to 3360 kilocalories per kg and for G category the ash and moisture content is 47.1 to 55% and useful heating value 1300 to 2400 kilocalorie per kg.

So, in this case, if we go down, then heating values decreasing and we see here the moisture and ash is also increasing. So, this will be having different applications and different price.

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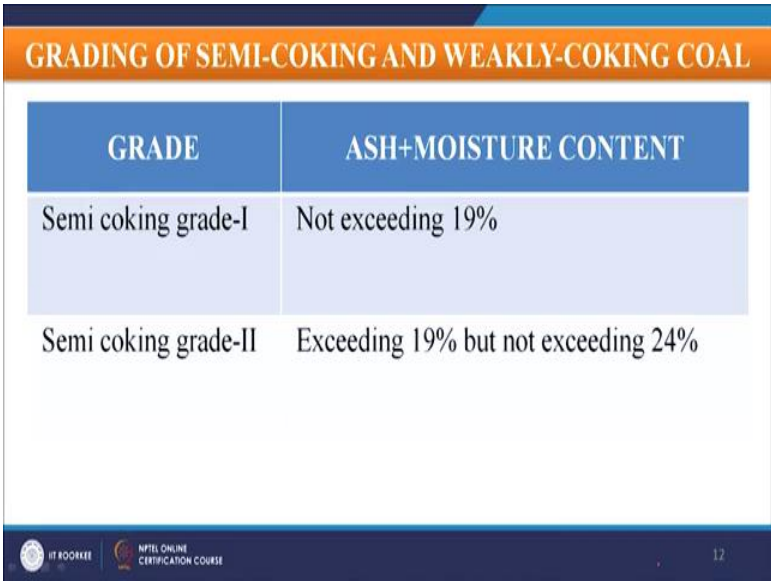

GRADING OF SEMI-COKING AND WEAKLY-COKING COAL

GRADE	ASH+MOISTURE CONTENT
Semi coking grade-I	Not exceeding 19%
Semi coking grade-II	Exceeding 19% but not exceeding 24%

Now, grading of semi coking and weekly coking coal, we can have grade 1 one and grade 2 that is also on the basis of ash and moisture content. So, if the moisture content is not exceeding 19% grade 1 and if it is 19 to 24%, it is grade 2.

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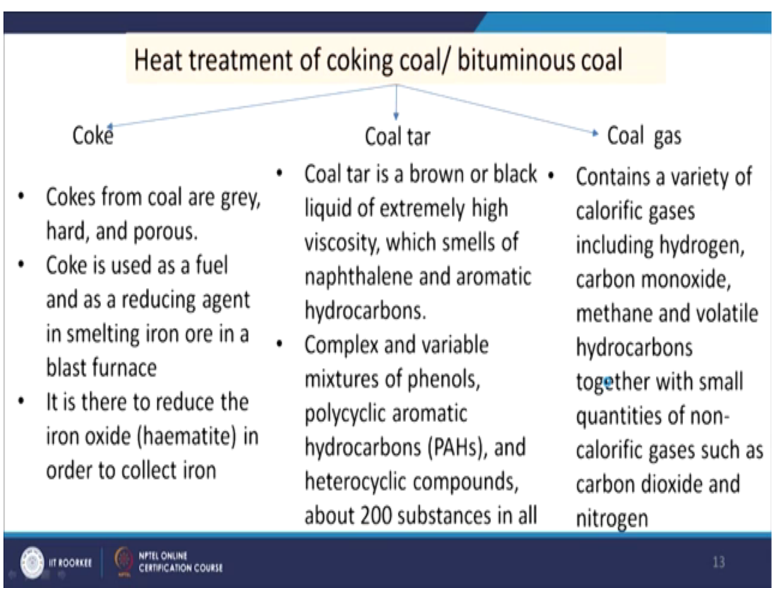

Now in thermal power plant we produce flue gas by the combustion of coal in presence of air, but if we do not apply air, just heat it in absence of air, then coal will be converted to three products, one is your coke and others coal tar that is liquid and another coal gas. So, solid liquid and gas will be getting, this coke which is produced here that will be having superior quality with respect to coal and can be used for steel production.

And this coke is a grey, hard and porous material and it is used as a fuel and reducing agent in smelting iron ore in a blast furnace. iron oxide is converted to iron, metallic iron here , and coal tar ; it is a liquid product which is produced by heat application on coal in absence of oxygen. And here the liquid product contains different types of organic compounds variable mixtures of phenols, polycyclic aromatic hydrocarbons PAHS and hetero cyclic compounds.

There are around 200 substances in case of coal tar and it is a black liquid an extremely highly viscous and it smells naphthenic and aromatic hydrocarbons. Then coal gas contains some combustible gas and non combustible gas; it may include hydrogen, carbon monoxide, metal and volatile hydrocarbons also. So, this way we can get different product from coal and which can be used for different application.

We can also use it in thermal power plant through combustion or we can also use it through gasification to producer gas. So, for the application of coal in different routes, we need to understand the quality of the coal which I know be suitable for which applications so, different types of properties are tested and the values are compared and the coal is selected.

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So, the properties of coal; I mentioned here that is caking and coking properties, heating value that is very important for energy application, moisture content, volatile matter content, fixed carbon, mineral metal or ash content and the chemical compositions that is elemental analysis CHONS oxygen sulphur phosphorus iron and etcetera, particle size and porosity, caking index, swelling index and petrographic analysis.

As I mentioned that particular sizes and porosity is important for the operation in reactor system. Now we will see the caking and coking. What is caking and what is the coking? If we apply heat to coal in absence of oxygen it swells some of the coal soils and it leaves coherent residue this property of the coal is called a caking property and in some caking coal the remaining residue is coherent. And it has middle cluster as well as all properties of the commercial coke.

And that coal is called coking coal. So caking coal and coking coal if we compare all coking coals are caking coal, but all caking coals are not coking coal, necessarily, some of the caking coals will produce coke. So, all coking coals are caking but the reverse is not always true. Now, we will discuss on heating value. So, if we use coal and combust it to release heat that will be used for any heat application.

Now amount of energy will be in usable form from unit amount of coal is it heating value. So, what is happening if we think about the electricity production? we are combusting coal, then coal flue gas is produced then flue gas is used to produce steam from the water and then steam is again used for the electricity production in steam turbine. So, what is my available energy, available energy in terms of electricity? in terms of heat here?

So, when the steam is pumped, that steam may be at higher temperature, that steam may be at lower temperature at ambient condition. So, when the steam is converted to ambient temperature, the water will condense and the usable energy which we are able to extract from the steam will be higher and the maximum and that is called higher rating value or gross heating value. But net heating value in which condition we are using it the net amount of energy we are getting from it that is called low heating value.

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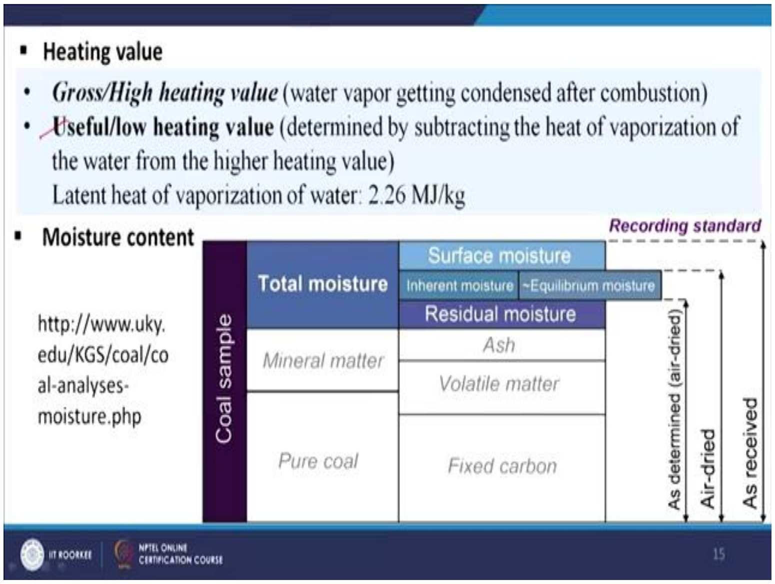

So, how can we consider and make the relationship between high heating and low heating value? Obviously, the latent heat of vaporization of water is playing role. If we reduce this one from the high heating value, we can get the low heating value of the coal. We will make more discussion in next chapter, our next lecture how to determine the heating value.

Then we have mineral matter that is converted to ash and fuel coal is having volatile matter and fixed carbon and it also have some moisture that is total moisture. So moisture may be available at the surface of the coal or it may be available in pores inside it that is general property of this or it may be available in microstructure of it.

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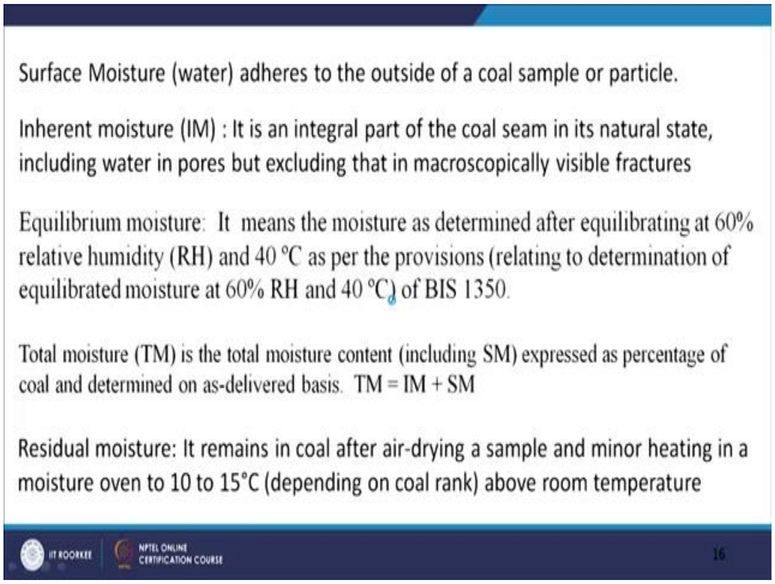

So, we can get different types of moisture, surface moisture, which is available at the surface of the coal is called surface moisture. And Indian coals are having more surface moisture because the inherent moisture, which is available inside the coal and which is an integral part of coal seam in its natural state, that includes the water in pores but excludes that in macroscopic visible fractures.

This inherent moisture in Indian coal is less and surface moistures is high because water is added for its transportation and storage. And then another equilibrium moisture; equilibrium moisture is determined as per BIS standard 1350 and we have to heat the coal sample at 40 degrees centigrade under 65% relative humidity and moisture content is determined is called equilibrium measure. So total moisture TM is equal to inherent moisture plus surface moisture, we get another is your equilibrium moisture.

So 3 types of moisture so I've got surface moisture, inherent moisture and equilibrium moisture and residual moisture in term, it remains in coal after air drying a sample and minor heating in a moisture oven to 10 to 15 degree centigrade above the ambient temperature. What are the basis for reporting coal properties, data and their combustion? that we are going to discuss now. So, coal which we have got from the coal seam, it has come to the laboratory, we are analyzing it and we are getting the compositions and that is as received basis.

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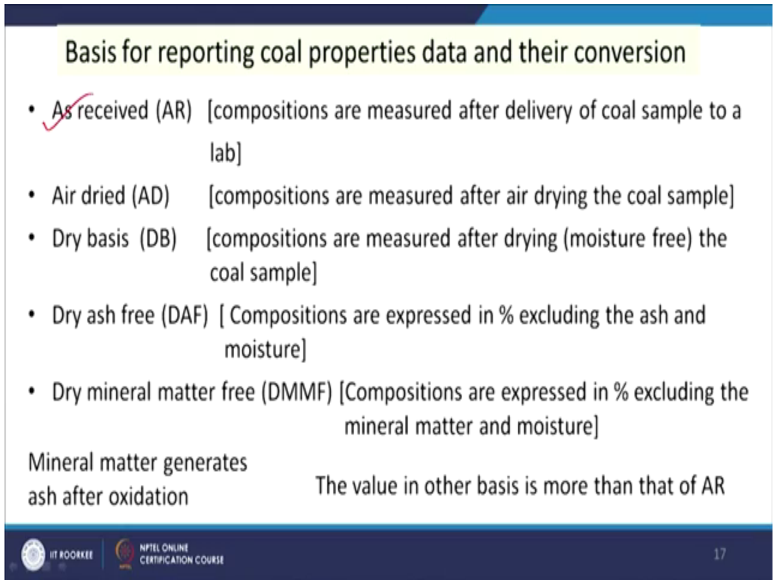

But we can air dry, measure the composition's again, we will get air dried basis and dry basis; this compositions are measured after drying the coal sample at specific condition, and then dry an ash free basis; it will be dried and then ash had to be removed from it during the calculation of the percentage composition, and dry and mineral matter free basis, compositions are expressed in percentage excluding the mineral matter and moisture. So, the value of any compositions in as received basis is lesser than any other basis.

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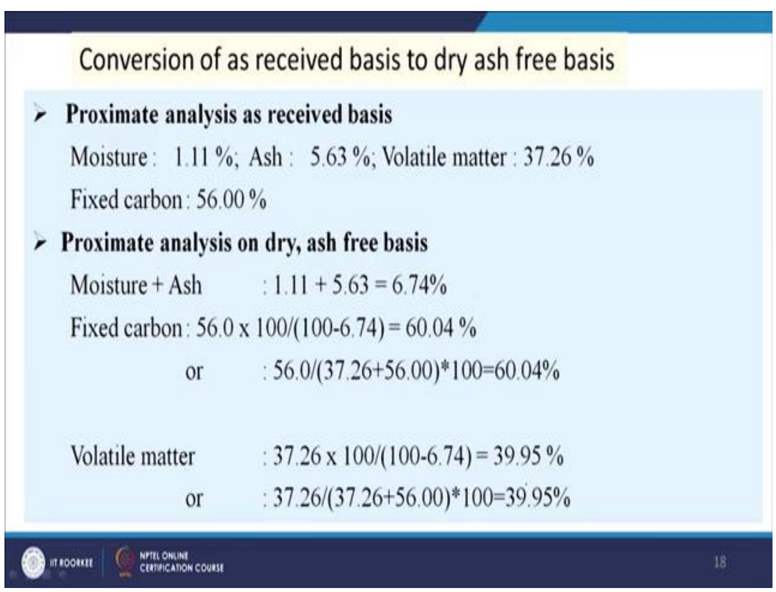

Here some example is shown here. So, we have a coal with proximate analysis Moisture is 1.1% ash 5.63% volatile matter is 37.26% and fixed carbon 56%. So, we want to convert it into dry and ash free basis. So, here in this case, we see moisture and ash we are having 1.11% + 5.63 so

6.74% we are having moisture and ash, so we have to reduce it, we have to leave it, since if we leave it, so remaining will be having fixed carbon and volatile matter. so 56 divided by these volatile plus fixed carbon we are getting 60.04% , we can also get it by these 56.0 into 100 divided by 100 minus this 2 moisture and ash that is 6.74. So, that is also welcoming 60.04% and similarly the volatile matter content is getting 39.95 and 39.95%.

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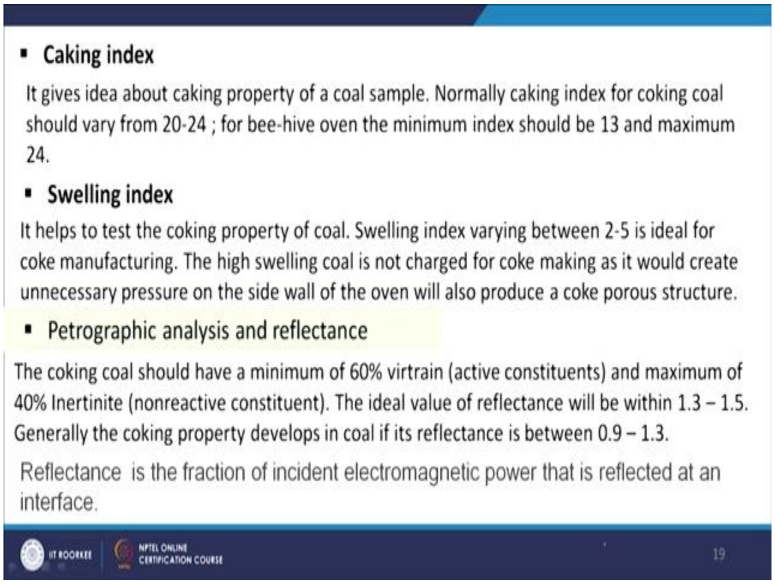

Other properties caking index. So caking indexes keeps an indications how suitable the coal is for caking, really we say 20-24 and minimum index should be 13 and maximum should be 24. And under property swelling index, it also gives some indications the how suitability for coke formation. So, swelling index 2 to 5 is ideal one and the high swelling index value is not desirable, it will create problem during operation.

Petrographic analysis and reflectance; this is one property which indicates how the coal will be able to produce coke. Coking coal should have 60% of the virtrain which contributes on the coke formation and 40% is a non reactive constituent. And this will 1.3 to 1.5 of these petrographic analysis reflectance values is suitable and it and coking poverty develops in coal when this value is .9 to 1.3.

And pricing of coal; Pricing is very important and depends on the quality. So pricing is done on the basis of equilibrium moisture. So that moisture is considered.

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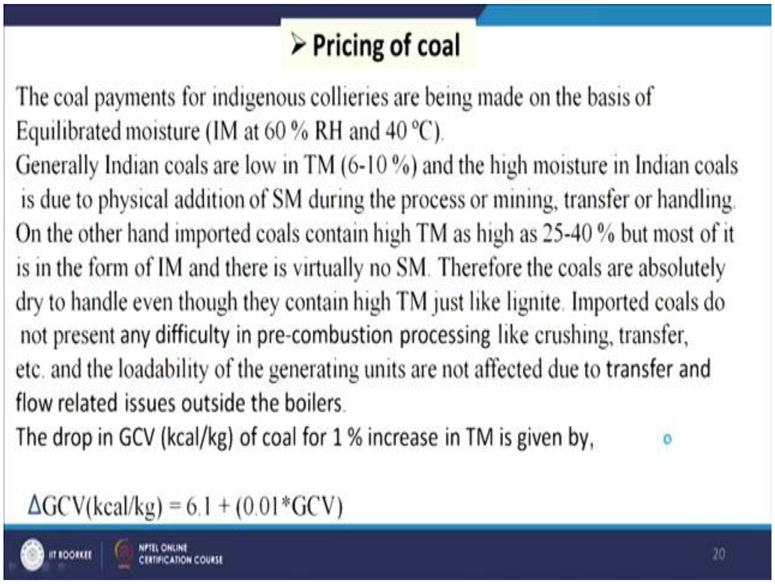

And with the increase of more moisture the price decreases because the gross calorific value decreases with moisture content, this is the empirical relationship which shows that with 1% increase in TM total moisture the ΔGCV, the changes in gross calorific value, is 6.1 + 0.01 into gross calorific value.

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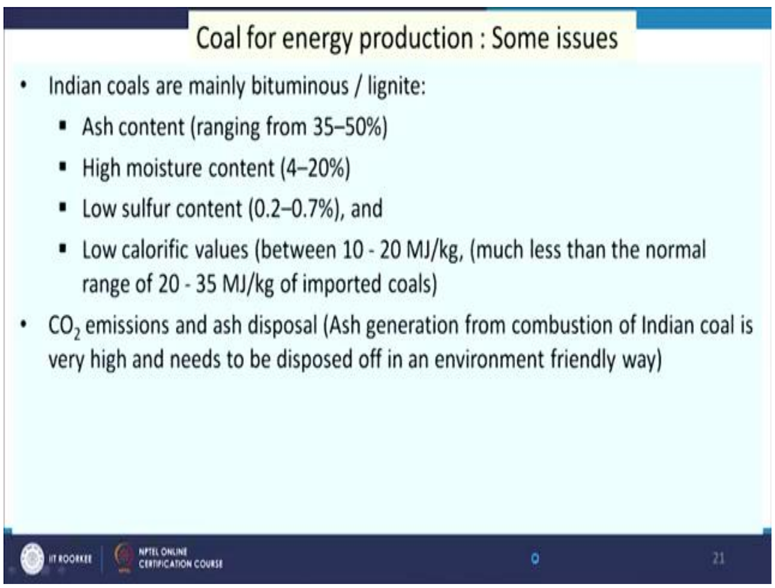

Now, we are coming to some issues for the coal use in India. So, Indian coals are mainly bituminous lignite type it has, high ash content and high moisture content high surface moisture, but low inherent moisture. So, these are the basic problems for Indian coal less inherent moisture makes it difficult to operations, imported coals are having high inherent moisture, and they are not having surface moisture.

So, this is easy to transport it is easy to operate, but Indian coals are having difficulty with respect of moisture as well as ash content. So, we need our own technology for its application. And it has some contamination also mercury contamination 0.1 ppm, arsenic 1.4 to 71 ppm, selenium 3 ppm in coal. So, these are the drawbacks of Indian coal. We need our own technology for its application.

Apart from these we also have groundwater and surface water contamination issues from the coal. So all those things we have to take into consideration for developing any new technology or application of Indian coal in cleaner technology routes. Thank you very much.