Clean Coal Technology
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Week-02
Lecture-06

Hi, I am Professor Barun Kumar Nandi. Welcome to the NPTEL online certification course on Clean Coal Technology. This is module 2. We will be discussing different aspects of coal cleaning methods. So, in this module, we will be discussing the cleaning of coal, which consists of pre-combustion cleaning, coal washability analysis, and the variation of coal properties with the density of coal particles. Now, if we want to start with coal cleaning, we have to first accept that coal is an extremely heterogeneous material. Here, the distribution of mineral matter and hydrocarbons is complex and uneven. So, this distribution of mineral matter and hydrocarbons is most important. We can say that this distribution of mineral matter. Coal is heterogeneous to such an extent that we cannot get the same amount of mineral matter or the same amount of hydrocarbons at any section of coal. It is totally heterogeneous to what extent it can be possible and their distribution is very much complex and uneven. Like, if we can see this particular coal, and if we can see the nearby coal, although their color can be similar or they are, maybe they are extracted from the same coal mines, their coal properties and their distribution of mineral matter and hydrocarbons are entirely different. So, in this coal cleaning, we have to go to such an extent that we can separate their mineral matter and hydrocarbons to the final level wherever it is possible. So, a hundred percent separation of mineral matter and hydrocarbons is never possible. We cannot totally separate mineral matter-rich materials as well as hydrocarbon-rich materials. It is never possible; we can only separate them to such an extent where our technical feasibility is there. Mineral matter and hydrocarbons are mixed even at the nanostructure level. So, this is that all the mineral matter and hydrocarbons are mixed even at the nanostructure level. Like, if we take this coal particle and if we make it into a smaller coal particle, here also, we will have mineral matter and hydrocarbons, and even if we can make it like a 0.1 At that point also, there will be a distribution of mineral matter and hydrocarbons. So, they are mixed even at the nanostructure level.

So, if we want to separate this mineral matter and hydrocarbon, we have to crush or grind the coal to such a level, which may not be technically feasible. So, in coal cleaning, what do we do? We only separate or segregate the coal. as hydrocarbon-rich and mineral matter-rich coal particles. So, in this coal cleaning process, what we do is that we have maybe 100 molecules of coal particles. We only separate them so that these coal particles may have a good amount of hydrocarbons, whereas these coal particles have more amount of mineral matter. We only segregate them or separate them. as hydrocarbon-rich and mineral matter-rich coal. So, out of the total amount of coal, we only separate them so that some coal may be 30% or 40% rich in hydrocarbon, where the volatile material combustible part will be more, and the ash content will be less, and another part of coal or another section of coal where the mineral matter will be 60 to 70%, and the remaining 30 to 40% will be the combustible. So, in this case, size reduction is done to such an extent that coal particles are classified only as high mineral matter or high hydrocarbon-rich coal. Such a level is called the liberation size. And that is the techno-economical decision to what size we can crush or grind the coal. So, during this coal cleaning process, we crush or grind the coal, which is called size reduction, which reduces the size of the coal particle to such an extent that we can expose or at least separate mineral matter-rich coal in one part and hydrocarbon-rich coal in another section.

So, like if there is a bigger size of coal particle. Maybe this part of coal has a good amount of mineral matter, and this part of coal has a good amount of hydrocarbon. So, we crush them into different smaller sizes so that we can separate mineral matter-rich coal and hydrocarbon-rich coal. And to what size? That is to what size we can use the equipment. Where it is economically possible, economically viable, or technically possible because we cannot crush or grind the coal to a very small size. We cannot grind the coal below a certain size, like 75 microns. This 75-micron size is used most in the combustor. It is almost the finest level up to which we can grind the coal in industrial practice. So, if we want to grind all the coal to this 75-micron size, the grinding cost or size reduction cost will be extremely high. So, maybe that grinding cost or size reduction cost is higher than the actual cost of coal. And if we see that the overall cost of coal or the overall cost of coal as an energy source is very small. It is almost 20 to 30 times less than that of liquid fuel. So, if we see at present conditions, liquid fuel is costly, maybe around 100 rupees per liter, but in that context, if we see the price of coal, which is around three to five rupees per kg. So, there is a price difference of 20 to 25 to 30 times than that of liquid fuel. That means coal is not an expensive fuel. So, if we consider the cost of coal and if we consider the cost of size reduction of coal, we should not reduce the coal to a very small fine size where the cost of beneficiation or the cost of cleaning will be much more than the actual cost of coal as an energy source. The last one is sampling of coal is very important. Sampling is also an important parameter when we discuss coal because coal is an extremely heterogeneous material. So, it is very difficult to get a representative coal sample from the actual coal mines or the actual coal. Like if there is a 100 kg or 1000 kg of coal sample, we have to get a representative sample which represents the entire characteristics of the coal. So, as coal is an extremely heterogeneous material, we have to take the correct sample as per the BIS or the ASTM guidelines. So that we can get the actual coal properties which represent the entire coal sample. So here, sampling is also important. Otherwise, after cleaning the coal, we may take some coal samples where the mineral matter is very low. So, we can say that the coal is completely clean. But that is not what actually happened. Maybe the mineral matter percentage is lower at the nearby location, or it is of medium size. So, sampling of coal is always important in the case of coal cleaning.

So, what we actually do in the case of coal cleaning is categorize it either as physical coal cleaning or chemical coal cleaning, and there are some biochemical coal cleaning or other techniques also available. In the case of physical coal cleaning, we separate the coal particles using some differences in their properties, such as their hydrocarbon content as well as the mineral matter. We want physical coal cleaning to mean that we will not use any type of chemicals that will chemically react with the mineral matter or chemically react with the hydrocarbon. We may add some chemicals, but they will not react with the coal. So, in the physical coal cleaning process, we typically separate the coal using some of the differences in their properties, either their physical properties, their surface properties, their electrical charge, or any similar type of properties. We have to identify which are different in hydrocarbons and mineral matter, like hydrocarbons can be hydrophobic or hydrophilic, whereas mineral matter may have the opposite tendency. Maybe hydrocarbons are lighter in nature, and mineral matter is heavier in nature. Maybe some hydrocarbons have a tendency to react with particular liquids, whereas the mineral matter will not have such an affinity to some particular chemicals or liquids. So, we identify such differences in their properties. By which we can segregate or differentiate between the hydrocarbon-rich coal and the mineral matter-rich coal. So, such differences may be in their particle density, surface charge, different characteristics, or they may have some particular affinity to any particular chemical reagent, so that in the presence of some particular reagent, hydrocarbon-rich coal will come to one side, and mineral matter-rich coal will go to the other side. So, basically, if we see, if we have some feed coal with 45% ash, we can segregate some of the coal, which we may call clean coal, where we can have 15% ash with a mass of 30 kg. So, out of 100 kg of coal or 100.1 kg of coal, we can get about 30 kg of coal which will have a lesser quantity of ash. We call this clean coal, and there will be some residue coal. This residue coal will have a higher quantity of ash. So, if it is 30 kg, the residue coal will be more than 70 kg. As a result, 30 plus 70 will total around 100 kg of coal. By material balance, if 30 kg contains 15 percent ash, we can determine how much ash will be in the residue coal. In this way, we segregate the coal into two fractions or further segregate this coal as clean coal. And residue coal is like this. So, in this process, we segregate the coal based on their physical properties, chemical properties, or any similar properties. One part, where the amount of ash is typically less or the amount of pollutants like ash and sulfur content is less, we call clean coal, whereas the other part We typically call it residue coal, but depending on the coal properties, sometimes the nomenclature in the industry is either middling coal, reject coal, or tailing coal. Similar terminology is used for this fraction of coal.

So, in chemical coal cleaning, we use selective chemicals. These selective chemicals may react with either the hydrocarbon part, the mineral matter part, or the sulfur-rich compounds, etc. So, they selectively react with the coal, and as a result, those impurities or those parts will get dissolved in the water or the medium. So, either hydrocarbon or mineral matter, they can respond to this reaction. So, either hydrocarbon can react with this chemical, or maybe mineral matter or any sulfur-rich material can react with this material. As a result, after reacting, there will be some phase change or separation of phases. So, some parts will get dissolved, and some parts will remain undissolved. And as a result, we can separate them. Apart from this, there are also some biochemical coal cleaning methods, though their utilization or application is on a very minor scale. In this process, some microorganisms, bacteria, or similar materials are used to decompose or degrade some of the hydrocarbons because these microorganisms react with the hydrocarbon part. So, they can react with the hydrocarbon, and they can consume some of the sulfur, phosphorus, etc. Presents in the coal, and as a result, we can get some amount of clean coal which will have less sulfur, phosphorus, and similar other impurities. In the case of coal cleaning, we have to focus both on ash content or mineral matter as well as sulfur present in coal. So, when we clean the coal, we have to consider both these aspects because if coal has some sulfate sulfur or pyritic sulfur and we reduce only the organic content, maybe that after the cleaning Ash is less, but it can have some more amount of sulfur, pyritic sulfur, or organic sulfur.

So, we have to see both these aspects because it is not that only ash reduction is important. Also, we have to keep an eye on the sulfur percentage present in coal. If, in the clean coal, the sulfur percentage is high, that coal cannot again be used. That again needs to be purified or separately processed for the removal of sulfur. So, coal cleaning must be done considering both these impurities, sulfur as well as the mineral matter. So, in clean coal, there should be both within the permissible limit. Like ash content will be less, but sulfur should also be within the permissible limit. Then only we can say it is a desirable product, and there will be some residual product or we sometimes call them reject coal. And the final product coal should match with the desired quality market value of similar ROM coal. Now, after coal cleaning, but that means after doing all this coal beneficiation process, if we see the final price of the clean coal. So, the final price of the clean coal should match with the similar quality or similar GCV, ROM coal available in the market. Because there is no separate price in the market for clean coal as well as the ROM coal. Whatever the coal is there, that is marketed, they are priced based on their gross calorific value or their ash content as per the gradation done by the Government of India as we have discussed in previous classes. So, even after reducing mineral matter or reducing the sulfur content of this coal, the finer coal should match the price of nearby ROM coal, and that is the actual main challenge, as we have discussed in the previous class, like this one, that the overall cost of coal is much less.

It is not a very costly fuel, so we cannot go for a very costly beneficiation process by which we can remove some of the impurities present in coal. Whatever the cost of coal is there, its price level is based on its calorific value or mineral matter or whatever the properties it has, and it is not so much high. So, even after coal cleaning, whatever is there, that means that clean coal should match the nearby market value of the ROM coal. That means if there is a price of rupees 4000 per ton of your ROM coal, and after coal cleaning, you cannot expect too much that the clean coal cost is rupees 10000 per ton, not 20000 per ton. After cleaning, also, this market value will be in the same range as that of ROM coal. That is the main challenge, particularly for the coal cleaning or coal beneficiation process. And that's why this coal cleaning process or coal beneficiation process should not be too costly. And that's why we have told it that it is a techno-economical decision. We have to see both the technical part, and we have to see the economical part of this coal cleaning. Because by the beneficiation process, it should not be too expensive. And during this process, both material balance and species balance are followed. Like if we see the ash percentage, if ROM coal or feed coal has a higher amount of ash percentage, if clean coal has less amount of ash, obviously the refuse coal or reject coal will have a higher amount of ash, and we can also get that yield. So here, the entire material balance and species balance will be followed. And in coal cleaning, we have to see the environmental impact and better utilization. Coal washing is preferred just after mining and before utilization. This coal cleaning method is typically characterized or differentiated by three different ways. Like we can clean the coal or we can beneficiate the coal before utilization, just means after mining of coal and before utilizing it in thermal power plants or steel plants, we can clean or we can reduce the mineral matter or sulfur content of that coal. That method is called pre-utilization cleaning or well known as pre-combustion cleaning. That means before combustion, we can reduce the sulfur percentage and we can reduce the ash percentage of that coal. That method is called pre-combustion cleaning or pre-utilization cleaning. In some cases, it is observed that washing of coal is not possible even before the utilization of cleaning. In such cases, we call that after combustion or during combustion or during utilization, we can also clean that coal and we can also reduce its environmental impact. This washing of coal is considered with emphasis on both ash reduction and sulfur reduction. Whenever we wash the coal, we have to see both the reduction of ash as well as the sulfur. We have to keep it in mind. In physical coal washing, typically chemical reagents do not react with coal.

Some parameters are identified which are different for hydrocarbon-rich coal and mineral matter-rich coal. Like density or specific gravity of hydrocarbons. It is observed that the hydrocarbon part of this coal is typically lighter in nature. So, their specific gravity is around 1.2 or 1.3. Like that means their density will be 1200 kg per meter cube to 1300 kg per meter cube. So typically, they are the lighter part of the coal. So, their hydrocarbons are here the density or their specific gravity is less. Whereas the mineral matter part as they are rich in clay and other. In most of the cases their specific gravity is around 2.6 or 2.7. But these two values are only some empirical values.

They exactly vary from source to source, coal mine to coal mines. So, they have a wide difference in their density. So actual density or actual specific gravity depends on the coal composition whether it will be 1.3 or 1.4 maybe 1.5 or maybe 1.1, that actually depends on the coal composition or amount of hydrocarbons present types of hydrocarbons present their compaction everything. Decides their exact specific gravity. So, they are in general their specific gravity is 1.2 to 1.3, but it varies from source to source. So, in case of physical coal cleaning, mostly we use this specific gravity or density of this mineral matter and density of this hydrocarbon to segregate the coal that means if we can segregate. Coal based on their density or specific gravity like if we can separate coal particles of 1.4. Obviously in such coal their specific gravity is 1.4 that will be rich in hydrocarbon and mineral matter percentage will be less and in case of other process we use or in some cases we use modify the structure of the hydrocarbon. To make it hydrophilic or hydrophobic, because in some of the cases some of the hydrocarbons are naturally hydrophilic or hydrophobic. Sometimes we add externally chemicals or reagent, which will increase its hydrophobicity or hydrophilicity so that we can separate even based on their surface tension on surface properties. So here mineral matter is typically hydrophilic. And we use suitable acids, chemicals, or oils. Whereas, in the differences in surface tension and contact angle, we use those parameters. Such a process is known as the froth flotation process. So, in the case of the froth flotation process, we use their surface properties like surface tension and contact angle to separate or segregate the coal. Based on their surface properties, whereas in some cases, we can modify the agglomeration properties of hydrocarbon-rich coal through surface charge modification. So, by adding some suitable oils or chemicals, we can modify the surface charge. So that the hydrocarbon-rich coal particles agglomerate in one location, and the mineral matter-rich coal particles do not agglomerate; they remain in another size.

So, by such a process, we can increase the size of coal particles through agglomeration with the help of different types of oil. Such a process is known as oil agglomeration. And in such a process, the separation of coal with hydrocarbon and mineral matter occurs. In all such cases, coal needs to be crushed or ground to a smaller size so that we can separate their properties. Separate to such an extent that their mineral matter-rich coal particles entirely show some properties, surface properties, whether it is hydrophilic, hydrophobic, or has some surface charges. So, coal must be crushed or ground to a suitable size. This is most important and is mostly the costliest method in any coal beneficiation process. To expose the coal surface to a smaller size, we have to crush it or grind it. In most cases, like froth flotation and oil agglomeration, they are very useful if we can grind them to their finest size, like 75 microns, 40 microns, 30 microns, or similar sizes. But at this size, although the process is feasible, it is sometimes economically very difficult to go for such a process because, even after cleaning, the final coal may have the price of exactly the nearby ROM coal. So, the size where we can expose or segregate the coal particles based on their surface properties or surface charge is called their liberation size. So, that means if there is a big coal particle, there may be some small particles which are mineral matter-rich particles, so we have to Grind them or crush them to this level. That means the initial coal particle can have a 50 mm size. But after that, we may have to grind it to 2 microns or maybe 100 microns. So, this micron level is called the liberation size. That means if we crush it or grind this coal to this 2 mm size or 100 mm size or 100-micron size, whatever that size, we can separate the coal particles which will be rich in hydrocarbon and another part will be rich in mineral matter.

So, that size is called the liberation size. This liberation size estimation is very important, and deciding this liberation size is most important in coal beneficiation. Like to what extent this coal needs to be crushed or needs to be ground, so that we can separate the mineral matter part or mineral matter-rich coal and we can separate the hydrocarbon-rich coal. So, getting this liberation size is sometimes very difficult. And this process may be wet, meaning in most cases, water is used as a medium. To separate this or to conduct this oil agglomeration, froth flotation process, mostly all this beneficiation process is done in the presence of water. But in some cases, some dry methods are also possible. Now, the difference is that if we use the dry method, water will not be exposed to any type of water or liquid water. As during this beneficiation process, coal particles will get in contact with water, so they will become heavier, and their gross calorific value and other properties may decrease. So, as a result, coal may lose its actual value, and there will be some additional cost for drying the coal or there will be some higher cost for transporting the coal.

So, it is preferred that the coal beneficiation process be dry, but dry beneficiation processes are not so popular or useful. In the present industrial stage. So, at the present stage, mostly water is used as the liquid medium or medium to conduct all these froth flotation or oil agglomeration processes as well as the normal coal cleaning process. So, using this water and particularly this specific gravity in the coal beneficiation process, typically water is added and it acts as a medium. And in the presence of this medium, coal particles are separated based on their density and specific gravity. So that these coal particles can be separated in this way. Like if this coal has a specific gravity of 1.5. So, what we can get is that some of the coal can have a specific gravity of 1.3 in this part and the remaining part maybe a specific gravity of 1.7 will come to this part. So, this is actually done in the coal cleaning process. So, in the case of physical coal cleaning, there will be no chemical reaction or only a minor chemical reaction.

But mostly there will be no chemical reaction, only some change in surface properties, some surface charge, or maybe differences in specific gravity we will explore. In the case of chemical coal cleaning, we use some chemicals which will react with either the mineral matter or the hydrocarbon part of the coal. And in this coal cleaning, it is only the segregation of coal particles into different phases. Like if there is some part of coal, we have to crush it, like if we have 100 kg of coal which is mixed. So, we have to separate some of the coal particles which have less specific gravity or differences in surface properties. So that we can get coal with some less quantity of ash because their specific gravity is less. So the clean coal will have a lower amount of specific gravity and reject coal or residue coal, we can have a higher amount of specific gravity and this process we can repeat and continue in different ways like from one process we can make these two circuits and further this coal can make another circuit and this coal can make another one so in this way we can get different Types of coal have different types of mineral matter or different types of hydrocarbons and different GCB to meet industrial requirements. For example, if it is a very low ash coal for cooking, this coal will have very good cooking properties. However, this coal may not have very good cooking properties, so it may need to be further separated to get another set of products. This product may have high market value, while this product may have a lower market value. Accordingly, these products or the separations are done in multiple pieces of equipment, as there is not only a single piece of equipment. There will be series or parallel types of equipment by which we can get the desired quality of coal. For example, if we have 40% ash coal, we can get 10% ash coal.

Maybe only the mass percentage will be less. But that coal may have a higher market value. And another coal may have a higher ash content. That may have a lower market value. But it is suitable for domestic applications. There can be another coal which may be suitable for thermal power applications. So, from one type of coal, we can get some clean coal having coking properties which will be used in steel plants. If we further wash this coal, we can get another coal that will be used for domestic applications. This coal can be sent to cement plants or thermal power plants. So, in coal cleaning plants or during coal cleaning, we can get multiple products to meet the industrial requirements of different industries based on their calorific value, carbon content, caking index, etc. We can get different types of coal from one coal field. So that individual coal can be marketed with its higher market value, and the cost of this beneficiation can be Somehow absorbed by this process because the cost of this coal is very low, and it is almost a cheaper fuel. So even somewhere if we get ROM of less percentage. This clean coal should match with the price of that coal. So even the ROM coal may have a low price, but after beneficiation, its market price will improve as its gradation is improving. They are now graded with a lower ash percentage, with higher grade, washery grade, or higher grade. Plant grade or washery grade or grade 1, grade 2, grade 3 for the non-coking coal.

So, based on this concept, the entire coal washing or coal cleaning is done. Even during this coal cleaning, whether we are doing the physical process or the chemical process, we also have to keep an eye on the sulfur content present in coal. Like that, we are only removing or reducing the ash percentage of coal, but there can be some organic sulfur. So maybe after coal cleaning, Ash content is reduced, but organic sulfur content is improved, so that process will not be viable. That typically happens with the northeast coal. So, in the northeast coal, if you see that their ash content is less, even if we beneficiate it, their ash content can be further reduced, but we cannot reduce the organic sulfur present in such coal. So as a result, in the beneficiated coal, there can be a higher amount of sulfur content. In such a case, the purpose of the entire coal cleaning doesn't serve, and this process is not technically or economically feasible.

Thank you.