Clean Coal Technology

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Week-03

Lecture-15

Hi, I am Professor Barun Kumar Nandi. Welcome you to the NPTEL online certification course on clean coal technology. In module 3, we are discussing various aspects of coal cleaning methods and various industrial methods which are used in coal washing. Today, I will be discussing the final part, lecture 5, on coal cleaning methods. Biochemical coal cleaning is also another method sometimes used for cleaning sulfur or removal of sulfur, particularly organic sulfur and pyritic sulfur from high-sulfur coal. As we all know, microbes are well known for the degradation of various chemicals and materials. So, in coal cleaning, microbes readily react with the pyritic sulfur, whereas other parts of coal typically remain unreacted. Thus, pyritic sulfur can be removed by microbial activities. Now, if we discuss these microbes, these are various smaller types of microbes which use different types of hydrocarbons for their day-to-day living. For microbes, different types of hydrocarbons, including carbon and hydrogen, are their readily available food. Whenever they work on these carbon-hydrogen atoms or molecules having carbon and hydrogen, they decompose these materials and utilize the energy available from these molecules for their growth. As a result, any hydrocarbon having carbon, hydrogen, even oxygen, and others can be decomposed by microorganisms.

Apart from carbon and hydrogen, they also need different elements like sulfur, phosphorus, nitrogen, potassium, calcium, etc., for their growth. They add these nutrients for their growth. Due to such aspects, microorganisms are widely used in the natural decomposition of hydrocarbons like wastewater, waste food, which we see in the case of aerobic digestion as well as anaerobic digestion for different organic compounds. So, in coal cleaning, similar type of microbes are used which naturally acts on the coal surface and they decompose the coal and particularly pyritic sulphur. So, these microbes are sometimes externally added or sometimes naturally grown in the coal mines or nearby locations where we want to treat the coal. So, these techniques, if we see, these techniques gives a significant amount of advantage compared to the both physical as well as chemical treatment of high sulfur coal. As this process is naturally going on and there is no cost involved in this process.

As most of the microorganisms they naturally decompose the high sulfur compounds or coal along with their impurities. There is no major cost involved in this process. So that is the major advantage which is somehow difficult in case of physical and chemical coal cleaning methods. Second advantage for this method is that this method works without any involving any major handling of coal and coal handling equipments. So, as there is no major equipments involved. Coal is stored in a particular reactor or particular storage location. So, there is no other cost involved for this. So, these are also low working expenses method and very low energy are consuming in this process and that diminishes there are low expenses utilizes is this method as there is no other cost involved during cleaning of coal. Typical issues with the microbial decomposition of sulfur is that they takes longer time like their decomposition time or treatment time is much more. It may take from fewer days to even up to 3-4 months. So, this is the major drawbacks and creation of sometimes an acidic or destructive environment is also there because due to decomposition of pyritic sulfur and organic sulfur sometimes environment become acidic in nature and acid mine drainage and similar issues are also there. So overall this process has only one negative point: it can take a long, long time. For example, the reduction of sulfur for particular content may take 30 days, sometimes 40 days, or even beyond those days. So, coal has to be stored in that location for a longer time. As a result, natural decomposition of coal occurs, and weathering of coal takes place. Coal loses its natural calorific value and volatile material during storage.

So, if we see, the physical coal cleaning method is typically a less expensive method and mostly removes mineral matter from coal. However, this physical coal cleaning only separates mineral matter-rich coal and hydrocarbon-rich coal. So, the distribution of sulfur is also important in clean coal or in the reject coal. Depending on the types of sulfur present, clean coal or reject coal can also have a higher quantity of sulfur, which may exceed the permissible limit of 1%. If we compare the three different types of coal cleaning methods,

we see that there are three different types of coal cleaning methods. In the case of physical coal cleaning, there is some cost. In the case of chemical coal cleaning, the cost is significantly higher. In the case of biochemical coal cleaning, this is a natural process, so the cost is very low, but it is very time-consuming. Therefore, it is not feasible for industrial-scale applications; only some laboratory-scale applications are possible, or where there is no other utilization time period for coal. Only in such cases can biochemically coal cleaning be used. In chemical coal cleaning, the cost is significantly higher, making it applicable only for high-end applications. Physical coal cleaning, however, is somewhat less expensive than the other methods, but it can efficiently remove or reduce mineral matter from coal. Overall, depending on the types of sulfur present in coal, sometimes clean coal and reject coal may have a higher amount of sulfur, which may exceed the permissible limit of 1%. Like if the feed coal is rich in pyritic sulphur or sulphate sulphur. So, if feed coal is rich in pyritic sulphur or sulphate sulphur that means these type of sulphur rich compounds are present as part of mineral matter. So, during washing, all these type of elements containing pyritic sulphur and sulphate sulphur that will go to the reject coal. and so, in such case reject coal will have higher quantity of sulfur present. In the other way if feed coal is rich in organic sulfur, in such case clean coal will have higher amount of sulfur because organic sulfur it is linked with the hydrocarbon and sulphate sulfur plus Pyritic sulfur, they are linked with the mineral matter.

So, in case of physical coal cleaning, if coal has a higher amount of pyritic sulfur or sulphate sulfur, they will have higher particle density. So, they will always go to the mineral matter. And in such case, hydrocarbons will have lower quantity of sulfur. So, in this case, if coal has higher quantity of sulphate sulfur and pyritic sulfur, Clean coal will have less quantity of sulphur whereas the reject coal or refuse coal that will have higher quantity of sulphur. So sulphur percentage in such case will be increased in the reject coal or the refused coal. Whereas if the coal is rich in organic sulphur that means this sulphur is attached to the hydrocarbon structure of this coal. So, in such case all the sulphur rich compounds will be part of clean coal. So, this infers is that so if organic sulfur rich coal cannot be cleaned by any of the physical coal cleaning method. Because in physical coal cleaning method we concentrate the hydrocarbon rich coal and if sulfur concentration in hydrocarbon rich coal is on higher side so in the clean coal sulfur percentage will get increased. Whereas the reject coal sulfur percentage will get decreased. So, as clean coal will have sulfur percentage beyond the permissible limit. So typically, this physical coal cleaning is not possible for the coal which has higher quantity of organic sulfur. So, in such case only chemical coal cleaning is the possible to reduce the organic sulfur present in coal. Overall summary is that if coal has higher amount of organic sulfur, we cannot clean the coal in common industrial practice.

Only using some strong acids, base or solvent we can use to reduce the different bonds present in the organic sulfur. We can use them make it suitable only for utilization. So as the cost of this chemical coal cleaning is significantly higher. So effectively if coal has higher amount of organic sulfur that high sulfur coal cannot be cleaned by any of this method like whatever is industrially feasible. So, if coal has higher amount of organic sulfur there is no such methods which is techno economically feasible for utilizing such coal. Only some chemical coal cleaning is possible which is extremely costlier. As chemical coal cleaning is costly. So organic sulfur cannot be washed. So, they cannot be used for thermal power plants as well as the metallurgical coal, also known as the Met coal. Like if we see some example, like if the feed coal have all this type of sulphur, organic sulphur, sulphate sulphur and pyritic sulphur.

If we use physical coal cleaning method like jigs, Dense media cyclone or others, in such case what will happen? This organic sulphur will get increased in this clean coal whereas sulphate sulphur and pyritic sulphur, it will decrease. So, if coal is rich in organic sulphur. As organic sulphur is increased in this clean coal, if coal is rich in organic sulphur in such case organic sulphur will decrease and pyritic sulphur and sulphate sulphur will decrease typically in most of the coals in India Here, pyritic sulphur and sulphate sulphurs are present. So, in such case, conventional coal washing does not increase the sulphate sulphur or pyritic sulphur in the clean coal. That's why they are accepted. However, coal available in our northeast region, like coal from different mines in Assam, Manipur, Meghalaya, Arunachal Pradesh, etc. So, they are rich in organic sulphur. So, they cannot be washed by these jigs and dense media cyclones, etc.

Whereas, if you consider the sulphur percentage in the reject coal, the organic sulphur quantity will decrease. Whereas the sulphate sulphur and pyritic sulphur will increase. So, if coal is rich in sulphate sulphur and pyritic sulphur, the reject coal's overall sulphur percentage can be increased. So, most of the coal, whatever is washed in India, if we see their reject coal, their sulphur percentage may be on the higher side. That's why whenever we market or sell reject coal, even for domestic purposes or other small-scale purposes where lower GCV coal can be used, we have to be very careful and concerned about the presence of sulphate sulphur and pyritic sulphur because those sulphur can increase or they can exceed their permissible limit of 1% in the reject coal. Now, if we see the Indian scenario on coal cleaning, typically, India's coking coal reserve is very less—around 12 percent of the total reserve is available. However, there is some semi-coking coal also available, so this semi-coking coal or medium coking coal they are those types of coal, like their ash percentage is at present on the higher side, maybe 25% to 30% or 35% of coal. However, if this ash percentage is reduced to 16% to 18%, that means if this coal is washed at 16% to 18% ash, using different physical coal cleaning methods, sometimes this coal shows some good coking properties. That's why this coal is washed at 16 to 18 percent ash, and the other product, which is known as the middling or can be known as the reject, is used in those application. So, in most cases, they are washed at 16 to 18% ash. Now, whether it will be 16% ash, 13% ash, or 18% ash—in some cases, they are also washed at 21% ash, depending on the coking properties of coal. Whether it is at 21%, the coke quality is satisfactory for use in steel plants, or it has to be reduced to 13% to make good-quality coke. So, it depends on the coal properties as well as the ash characteristics.

So, different types of washeries depend on their end consumers; they wash such coal at 16 to 18 percent ash. After 16 to 18 percent ash, typically there is 30 to 40 percent. Whether that means 30 to 40 percent of this entire coal will report to the clean coal, which will be used in coke-making, and the remaining 60 percent ash—whatever is there now—will be analysed for its ash percentage and gross calorific value. If that ash percentage is suitable for a thermal power plant, then that coal can be used directly in the thermal power plant. If the residue coal has ash around 35 to 40 percent, then that coal—meaning the byproduct of these coal washeries—will be sent directly to the thermal power plant for utilization as coal. Sometimes, if the residue coal has a much higher percentage of ash—like if the ash percentage of this residue coal exceeds 40%, meaning it can have 45% ash— then this residue coal is further washed in secondary coal washery circuits. Here, they are typically washed at 33 percent ash, which is a very good and optimum ash percentage for thermal power plants. As they are washed at 33 percent ash, they are called middling coal, and the further residue coal, which will have 60 percent ash or higher, is called reject coal. They are used for domestic plants. Whereas, for non-coking coal, they are mostly washed at 33%, which is very good-quality coal for good-quality Indian coal used as clean coal, and they are sent to thermal power plants. The remaining coal is known as reject coal. So, there are different types of washeries. If it is a coking coal washery, some washeries have two products, like ROM coal. which is washed as two products: one is clean coal, and one is middling coal, depending on the ash percentage of the coal. So, if it is a two-product washery, that means if ROM coal has low ash, they can be washed at two ash percentages.

Clean coal will have an ash percentage around 16 to 18 percent, which is directly sent for the Coke making, whereas the secondary product or byproduct—or whatever that means—we can say the refuse coal here, that is known as the middling coal, will have an ash percentage above 30%, but nearby 33%, 35%, 37%, or 40%. So that is suitable for direct consumption in the thermal power plant. So, this middling coal is sent to the pulverized combustion units or thermal power plant. They are sold based on their gross calorific value, whereas these coals are sold based on their coking properties as well as their ash percentage.

Also, there are some three-product coking coal washeries where the ash percentage of coal is on the significantly higher side. So, in such cases, the first product is the clean coal, which will have ash around 16 to 18 percent, and that is used in the coke making. Then, after washing, this coal is further washed as middling coal, where ash is typically kept at 33 to 35 percent, which is sent to the pulverized combustion. The further residue of this coal, known as the reject coal, has ash more than 55%, 60%, or 70%, depending on the Material balance of the ROM coal. So, those are sold or sometimes used in the fluidized bed combustion, fluidized bed gasification, or sometimes for domestic consumption, depending on the coal properties. And in some cases, thermal coal is also washed. So, in such cases, their ROM coal is washed at 33% ash, which is directly sent to the pulverized combustion units. And other products, like reject coal for such plants, where ash will be more than 35%, are sold to the fluidized bed combustor or maybe for domestic consumption. So, in the Indian scenario, if we see, there are broadly three types of coal washeries available. Some washeries are two-product washeries, and some are three-product washeries. Two-product washeries wash coal typically for the—and again, these two in the two-product washery can be washeries that wash coal For coking coal or for coke making, whereas some of the washeries can be for non-coking coal or thermal coal.

So, for coking coal washery, they can be two-product washery or three-product washery here. So, in a two-product washery, they wash coal around 16 to 18% ash. This 16 to 18% ash value depends on the particular design of the plant. As well as the requirement of the consumer. Some companies or private companies wash coal even at 30% ash or like 15% ash or 16% ash. Because their plants are sensitive to or designed for 16% ash coal. Whereas some coking coal is also washed at 18% or 21% ash. Because they are designed to allow using coal even up to 21% ash for making coke. And that coke meets the design criteria for that plant. So, in the case of two-product coking coal, clean coal is the main product. And they will get the middling coal as the secondary product, which is sent to pulverized combustion in the thermal power plant. If the ROM coal has a higher amount of ash, like if ROM coal has around 40% ash, they can be washed in this way. Or if they have 30% ash, they can be washed in this circuit. Like 30% ash, if we wash it at 16% ash here, the residue coal will have ash around 35%. If it has 40% ash, if we wash it at 16%, the other product can have 45% ash. That is acceptable in the case of thermal power plants. But if coal has above 45% ash, then in such cases, clean coal will have 16 to 18%, and only a very small quantity of mass will report to the clean coal. So here, the yield of the clean coal will be less, maybe around 15% will report to the clean coal, and more quantity will report to the middling coal. The residue will be in the reject coal. Now, why is this three-product washery here? Because our total coal reserve or coking coal reserve is very low. In the Indian context, only 12 percent of coking coal is available. So, there is a significant scarcity of coking coal, and India imports a large amount of coking coal to meet its steel plant requirements for making coke. So, if we wash some of the non-coking coal or some of the semi-coking coal, from which we can extract at least 10 to 15% mass of coal that can be used in the steel plant, that makes it economically feasible as well as beneficial for the country, as we can obtain coking coal. From our coal available in India. So that is in the national interest, that we wash some of that high-ash coal. If they have these coking characteristics. If coal doesn't have any of the coking characteristics, they cannot be washed like this. So, some of the coal mines It is observed that they can have 10 to 15% coking coal if they are washed at a lower ash percentage. So, the three-product washery washes coal only in that aspect, that even if we get 10% mass of the coking coal, we can extract it from the main coal, as the price of this coking coal is on the higher side, making it economically feasible. Whereas if coal is non-coking coal, They are typically not washed. They are not required to be washed because in thermal power plants, we can consume coal even at higher ash percentages, like 45% ash coal, which can be directly consumed. But if that ash percentage is beyond 45% and it cannot be directly used in thermal power plants, in such cases, washing is necessary to run the combustor or pulverized combustion units efficiently. So, in such cases only, they are used. They are washed in the non-coking coal washers to get clean coal, where the ash percentage may be reduced to 33% to 35% or nearby values, and the remaining coal will be the reject coal. Where it will be used in the fluidized bed combustion units, domestic applications, or others. So, typically in these two-product washeries, mostly dense media cyclones are used because dense media cyclones are very efficient in controlling the particular cut density of ash. So, dense media cyclones as well as jigs are combined in these two-product coking coal washeries, where they are Only jigs are used in the non-coking coal washeries. Typically, dense media cyclones are not used, as the cost of dense media cyclones is on the higher side. So, in most cases for thermal coal washing, dense media cyclones are not used, but they can be used. There can be some plants which use dense media cyclones, but typically they are washed mostly on the Jigging principle, and two-product and three-product coking coal washeries mostly use jigs along with dense media cyclones to accurately separate coal based on their ash percentage as well as to reduce their operating cost. So, if we summarize the entire coal cleaning methods, we can see that physical coal cleaning is typically less expensive and mostly removes mineral matter from coal. Size reduction to the lowest possible or reaching almost nearby to the liberation size is required. So, up to what size we should reduce the coal is entirely a techno-economical decision. Although size reduction improves coal washing, it has Involves some higher amount of cost. So, size reduction to the lowest technically feasible as well as economically profitable size is done. So, it is a techno-economical decision and also depends on the quality or types of coal. Sulphur removal is mostly not possible by the physical coal cleaning method. As by physical coal cleaning, sulphur removal is not achieved, and it can even increase the sulphur percentage in some types of coal, depending on whether the sulphur is organic or inorganic. Thus, physical coal cleaning does not remove any sulphur; rather, the sulphur percentage may increase in the clean coal, middling coal, or reject coal. So, we must always monitor the sulphur percentage in the clean coal, middling coal, or reject coal to ensure that the coal meets the desired ash percentage, though it may not meet the required sulphur percentage. Only froth flotation and oil agglomeration are somewhat effective among physical quality methods for reducing sulphur in coal. The chemical coal cleaning method can reduce both sulphur and mineral matter from the coal. However, it is very expensive. As a result, it is rarely used on a plant scale. In some cases, it is mostly used on a laboratory scale. Or it is used only in high-end coal applications where such chemical cleaning is necessary. In the case of biochemical coal cleaning, it is rarely used and is technically unfeasible to wash coal or reduce sulphur after storing it for more than 3 to 4 months. It is the only naturally available method for coal cleaning. But by then, coal weathering occurs, reducing the gross calorific value, volatile matter, and fixed carbon due to the natural decomposition of hydrocarbons, known as weathering. Thus, biochemical coal cleaning is only a theoretical method in coal cleaning. It is never applied on either a plant or laboratory scale.

Now, using ultrasound is also a new and innovative method presently being used or implemented in many coal washeries, only to improve the yield of the coal, as clean coal properties do not change significantly. But we can only improve the efficiency of froth flotation or oil agglomeration by using ultrasonic-assisted oil agglomeration or ultrasonic-assisted froth flotation methods, particularly in the case of fine coal particle processing. In the case of bigger-sized coal or in the case of physical coal cleaning involving dense media cyclones or others, they are sometimes used wherever some chemicals are used there to only make those chemicals or reagents mix with the coal with much more efficiency. So, ultrasound coal cleaning, along with other physical coal cleaning methods or ultrasound-assisted froth flotation and oil agglomeration, will be the future aspects where coal will be cleaned, or many plants will add these ultrasound-assisted units in different coal washeries and use them during coal washing.

Thank you.