Clean Coal Technology

Prof. Barun Kumar Nandi

Department of Fuel, Minerals and Metallurgical Engineering

IIT ISM Dhanbad

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Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are discussing module 3 with the topic of coal cleaning methods. So, in this lecture 2, we will be discussing the topic of dense media cyclone. Dense media cyclone, as mentioned in its nomenclature, is one type of cyclone separator used in air purification or cleaning of air, but here the media is dense, meaning it has higher density. So, in any cyclone separator like a hydro cyclone, it utilizes centrifugal forces and drag forces to separate materials based on differences in their physical properties such as size, density, and shape. So, in the case of a cyclone separator, as we know, in a cyclone separator, the major driving force for separation is the centrifugal force as well as the drag force. Like in any cyclone separator, any particles entering from this side go through this fluid media, enter, and undergo a cyclic motion. Accordingly, some of the particles, like solid particles here having higher density or heavier particles, come to the bottom, and the lighter material, like in the case of water, only pure fluid, goes to the top of the cyclone separator. So here, the main driving force is the centrifugal force, which is mv^2/r, where m is the mass of the particle, v is the velocity of the particle, and r is the radius of the cyclone. So, if we see in terms of mass, it contains density as well as volume density. And this volume term already contains diameter, like $\pi d^2/4$ or $(4/3)\pi d^3$. So, broadly, what we can say is that in this cyclone separator, particles with larger diameters will get a higher amount of centrifugal force and will be separated at the bottom as the heavier product, whereas the particles with smaller diameters will be obtained as lighter material in the fluid media. Similarly, any particle with a density difference—so any particles having higher density will go to the bottom as the bottom product, and any particle with lower density will go to the top. So, what we can get is that any small d and ρ (smaller) particles, both of these will come to the fluid in the top part, and the ρ (higher) as well as the d (whatever is on the higher side) will come to the bottom part as the solid part. So here, it utilizes the centrifugal force as well as the drag force because the drag force means it's This part will be there as the gravitational force, as well as the same amount of force will be given by the water as the drag force. So, by the action of these two forces, it achieves the separation. So, for the best separation, the main driving force is the centrifugal force. Any particles getting a higher amount of centrifugal force will be collected at the bottom, and any particle having a lower amount of centrifugal force will go to the top. If we change the radius of this cyclone separator, the centrifugal force varies accordingly. So, the smaller size cyclone gives higher efficiency, whereas the bigger diameter cyclones give lower efficiency. This is all about the basic principle of a cyclone separator. So, in the case of hydro cyclones, we use the same equipment or the same methodology. The only difference is that, in the case of mass, we change it—meaning we convert it to the relative mass. Here, it is the relative mass with respect to the fluid medium.

In the case of an air cyclone, we observe that the mass is different from that of the density of air. But in the case of a hydro cyclone, we use water or a dense medium. So, if we change the density of this medium—whether it is water or any other dense media—the effect of mass or the impact of mass can be modified. We can adjust this mass parameter, so the entire operating principle or efficiency can be changed. Thus, we can control which particles we want to get at the top and which particles we want to get at the bottom from this cyclone separator. In this cyclone separator, if we observe the top part, the feed product, we get the light particles, and in the bottom part, we get the heavy particles. This is the basic principle of any cyclone. But in the case of a hydro cyclone, we change the density of the entire medium. In the case of a hydro cyclone, we use water. In the case of dense media, we use any dense medium to change the density of the entire cyclone separator, as well as modify the operating principle or working efficiency by adjusting this. So, a particle system that contains a mixture of two density materials, the separation between two components can be achieved by concentrating the mixture into a dense and lighter fraction. So, in the case of a cyclone separator, we can achieve this separation efficiency by separating these two components—by concentrating one part to get a higher density material and another part to get a lower density material. If we compare it with an air cyclone, which is used in air purification, and a hydro cyclone or dense media cyclone, which is used in coal washing, then in the case of hydro cyclones typically it is as plate and as shown in this picture. So overall working principle is almost similar in nature the same way the air particle goes here and it gets separated. In the same way in case of hydro cyclones, we give the feed from here it will contain water, coal as well as the magnetite. Now what is the role of this magnetite ? Magnetite is used to change the density of the media In case of water density will be like 1000 Kg per meter cube or Hg equals to 1. But if we use very fine particles of magnetite, we can get density of this specific gravity around 1.4 to 1.7 or like this.

So, we can change the density of this media or fluid medium used in this dense media cyclone by using magnetite powders. So, these magnetite powders are very fine magnetite powders with size in the range of 10 to 20 micron like 400 mesh or 500 mesh. So, they are very fine particles of magnetite powders is used. They are mixed in water to create an suspension by changing the dose of magnetite like 1 kg per Liter or 2 kg per liter 5 kg per liter. So, by changing the dose of or concentration of magnetite in the water., we can vary the density of this liquid medium. So, if we change the density of this liquid medium. So, this entire in the entire hydro cyclone which product we should get it as the clean product and which was we should get it at the refuse product or the reject product that we can modify. So, by this equipment, we can easily achieve very good separation or very good cut density difference between the clean coal as well as the refuse coal or reject coal, which is somehow difficult in the conventional other physical separation equipment like the jigging. So, in case of dense media cyclone, dense media separation is most accurate and very much efficient technique. Here we can modify the density of the medium or water. So, we can easily get the desired separation at exact cut density like if you want to vary the cut density from 1.4 to make it 1.43 or 1.43, 1.44, 1.45, that exact accuracy is possible in case of dense media cyclone. So, in this method liquid that is used the suspension of higher density material that is then water used as fluid media to modify the coal particle behaviour in the fluid. So, settling, sink float characteristics, gravity force on coal particles, everything are modified as specific gravity of fluid is different from that of water. So, different heavy organic liquids typically are used in the laboratory scale, but in case of dense media cyclone, typically magnetite particles of suspense are used in this plant. So, these suspensions can be altered by changing the magnetite dose like kg per meter cube, they are easily recovery to the magnetic separation. Now why this magnetite particles are particularly used. If we use any other organic liquids that recovery is very much difficult for those organic liquid even in the zinc chloride as we have seen in the possibility analysis. So those are only used in the laboratory scale analysis. In case of industrial scale, we are we cannot get so much of higher amount of organic liquids. They are so much toxic. They are so much costly Even zinc chloride, it has some negative impact in the environment. Getting so much large quantity of zinc chloride also a challenging part. So, to avoid all of this, typically magnetite particles are used.

Magnetite particles, typically their structure is like Fe_3O_4. These magnetite particles, they have typical properties that they are magnetic in nature. So, although we can mix them in a suspension, But if we want to recover them from the water medium, we can easily recover them through the magnetic separation. Like entire water slurry, if we pass through a magnets or magnetic separator, all the magnetite particle will get separated to the magnets and we can get pure water or water as the other product. So we can easily recover the magnetite particle. That's why magnetite is always used in this process dense media separation. Now how this dense media separation it can impact the separation efficiency ? what we can do is that we can easily change the media specific gravity by adding different concentration of magnetite powder like we can make it specific gravity 1.55. If we add higher quantity of magnetite powder if we want to get lower specific gravity material we can use smaller quantity of magnetite powder. So, we can easily modify the specific gravity of the water medium or density of the water medium by changing the doses of magnetic powder. If we use magnetite powders to make dense media set of 1.55 specific gravity. So, in such a case, any coal particles having a density or specific gravity around 1.5 will be lighter in nature. So, those will float here, and any particle with a specific gravity of 1.6 will sink. As we have seen in the sink-float experiment. Similarly, if we use 1.45 as the density medium. Then particles of 1.4 will float, and particles with a specific gravity of 1.5 will sink.

So, by changing the specific gravity of the medium, we can get 1.5 density coal particles as the float. In this other case, we can get 1.5 specific gravity particles at the sink. So, this is used to modify the settling characteristics as well as the separation characteristics in the cyclone separator. Like, if the media in the case of a cyclone separator or in this dense media cyclone. Like, if we send here the coal particles of any particular density and this media density is 1.45. If the media density is 1.45, then in the clean coal, we can have a specific gravity of 1.5 here. We can get it as the clean coal, whereas the material with a specific gravity of 1.5, we can get it as the reject coal. So, we can separate based on the specific gravity any particles less than 1.45 because the media density is 1.45. The principle of the cyclone separator is that, Compared to the density of this media, any particles having lighter density or specific gravity. They will get it as the top product as the clean product and they are any particle having density higher than 1.5 between 1.45, it will come to as bottom as the reject product or the refuse product. So, if we use a specific gravity of 1.45. So, anything less than 1.45 like 1.4, we can get it as the clean coal. So, we can all the particles less than 1.45, it will come to a top product and any particle heavier than 1.45 this will come in the bottom as the reject product. So, if we want to separate coal at 1.45 cut density, we can easily get it and with much more accuracy because All particles will feel that they are lighter corresponding to the specific gravity of 1.45. Any particle they are less than 1.45, they will always be lighter.

They will always go to this and no particle will not go to the bottom. Similarly, if we change the media density like 1.55, if we want to change that for a different coal sample or coal sample, coming from the other coal mines or other seam, we have to adjust that specific gravity should be changed. Because for the other case, maybe that we are getting the desired coal properties of ash percentage at suitable at maybe 1.55. In such case, we can easily add some more quantity of magnetite powder in this media, in this system. So in such case, we can get 1.5 coal particle as the clean product. So, in the previous case we are getting 1.5 coal particle as the bottom product as the reject but this coal particle may be had higher amount of ash percentage but here if we change the media density to 1.55 we can get any coal particle of 1.5 as the top product or the clean coal and any particle heavier than 1.55 like 1.6 that we can get it as the reject coal or the refuse coal. So, what we can get it that from this dense media is that we can easily modify the separation characteristics or we can easily change the cut density or cut point of this coal beneficiation during this coal beneficiation process depending on the coal characteristics. Typically, in jigging, such freedom was not there. We can separate the coal based on their density.

As they will deposit in a stack-wise manner, but still achieving the desired separation efficiency to get this particular cut is somewhat difficult because there is some probability that during settling, some of the lighter particles may go along with the heavier particles, and some heavier particles may deposit over the in-between layer. So, there is some probability that the separation efficiency may not be as accurate. as we think about. So overall, the jigging method is good, but if we compare it with dense media separation, the accuracy of dense media separation is much higher, and we can easily alter the media density by adding different concentrations of magnetite powder. Magnetite powder can also be recovered very easily. using magnetic separation. Magnetite powders are typically pure minerals or raw materials, clay materials available at different hills or different mines in iron ore mines. So, the availability of magnetite powder in higher quantities is guaranteed. We can obtain higher quantities of magnetite powder easily, and their cost is not as high compared to any organic liquids or zinc chloride. That's why in any industrial application or on any industrial scale, magnetite powder is always used. From the control room of that plant, depending on the feed characteristics of coal—even if we can see the online analysis—what the coal properties are getting from the control room, we can easily modify the dense media by adding more quantity of magnetite powder or extracting some magnetite powder for magnetic separation. So, for this reason, dense media cyclone or dense media separation is widely used, or mostly used in coal washeries where much better control of coal product, clean coal product, clean coal, as well as refuse coal, is required.

So, this is one of the models that we can see in the industrial model of a dense media cyclone. So, dense media cyclones are widely used in coal washing. They provide much more accurate and efficient coal beneficiation. Typically, their cost is higher compared to jigs because they require some construction materials. They need some pumps to create the desired fluid velocity and other requirements. So overall, it is a little bit costly. Compared to jigging, but those costs are compensated by much more accurate and efficient separation of coal. And here we have the cost of media, recovery of media, higher pumping cost, and stability of suspension is also a matter of concern. as magnetite powders are very fine powders. Their density, or specific gravity, is almost similar to that of iron—more than five or more than six, depending on the purity. So, there is always a probability that magnetite suspension may get precipitated and they can easily get separated. So, the stability of suspension and all these are some of the negative aspects of using magnetite powders or dense media cyclones, and it also has some cost associated with the media, which is not there in the case of a jig. So, If we compare the jig and dense media separation, the jig has absolutely no cost or very minimal cost—only some equipment or a machine is required to create a pulsating motion. In the case of magnetic separation or dense media separation, we have to obtain some media, like magnetite powder, which we have to recover so that it doesn't remain with the coal. We will have to bear the cost of the media if we are unable to recover that magnetite powder. So, all these costs are there, and the stability of the suspension also matters. It always has to be monitored whether the suspension remains stable or if the particles are precipitating. Sometimes, the availability of magnetic powders is also a concern. is also a concern because we need very good quality or pure magnetite powder. It may not be available at all locations or at all times at a very low cost or cheap rate. This magnetite powder also needs to be ground to the finest size, maybe in the range of 10 microns, 15 microns, or as low as 2 to 5 microns, to achieve the best or very high-quality suspension. These are the major reasons or difficulties when we use magnetic separation. So, this magnetic dense media cyclone separator is widely used in most coal preparation plants as the primary or main unit for coal washing, particularly for coarser-sized coal particle separation. The Mozley mineral separator, oscillating table, or similar tables are also used for the beneficiation of fine-sized coal particles. So, in this Mozley mineral separator, oscillating tables and similar designs of equipment are available in mineral processing as well as in coal washeries. This table is particularly used for the beneficiation of fine particles, or rather, we can say the recovery of valuables from fine particles or tailings. where, if you find that in the tailings or the fine particles, a good amount of coal is being wasted, we can recover it using this Mozley mineral separator. So, in this method typically, suspended coal fines are spread over the table. So, there is a table. This table will have some amount of inclination. It is not exactly flat. It will have some inclination and a curved shape.

So, this shape is curved and it has some inclination, so it has an angle of inclination theta. So, in this case, what happens is that from the bottom, we use a slurry that contains suspended coal particles, and it is sprayed from the top of this table. So, if they are sprayed at the top of the table, the coal particles will go along with this slurry. There is an inclination, so by the natural flow of gravity, they will move toward the bottom. As a result, coal particles will move, and heavier coal particles will precipitate while lighter coal particles will flow with the water. So, in this Mozley mineral separator, heavier particles, like those with a higher ash percentage or density, will not travel along with the flow because they have higher gravity, whereas the lighter particles will go along with the water flow. And in between, this entire table shakes. They move; they have this oscillating movement. So, due to the presence of this oscillating movement, the heavier coal particles are separated, ensuring no low-density coal particles remain with them. So, to ensure this oscillation occurs, as a result of this movement, a much better separation efficiency is observed. So lighter coal particles will go along with the water, and the heavier coal particles, typically the high-ash coal particles, will remain or stay and will travel a shorter distance. So, on this table, we mostly obtain the high-ash coal particles, and along with the water, we get the low-ash coal particles. So, on this table, particularly from this side, we spray the water, and in the suspension, they will flow. So, from this side, along with the water, we will obtain the clean coal with a lower amount of ash and in this path, we will get that reject coal or refuse coal having higher amount of ash percentage. So, after some time, this high ash coal are collected and entire circuit is again repeated for 2 times, 3 times, 4 times or it can be operated for continuously depending on our requirement. So, this table have this oscillating motion and it has very low inclination. This inclination is very low like only 5 degree, 3 degree, 4 degree, this type of inclination is there. So that water will flow but it will take long time to flow.

So that heavy particles can get adequate time for settling, whereas the lighter coal particles can flow along with this water it is not that it has an inclined at a higher angle. So, in such case all the particles will flow along with the water. So, we will not get desired efficiency. So, in case of equipment this is that angle of inclination also is an operating parameter. By changing this angle of inclination, we can change the yield of this coal as well as the quality of coal or the separation efficiency of this coal of the separator. As suspension move across this table, coal particle will get separate based on their specific gravity. Lighter particles travels a longer distance and flows with water where the heavier particles remain on the tables or smooth smaller distance inclination of table. We can change the water flow rate like if we want to get that separation efficiency is not required too much extent. So, we can modify that separation efficiency by changing the water flow rate. If we use a high water flow rate, even the high density particle will also move by force of this water along with this table. So, we can alter this quality of clean coal as well as the reject coal by changing the flow of water. We can also modify the pulp density that if we use a very dense coal particle slurry. So, in such case separation efficiency will be much less. And if we use very low pulp density, we can get much more accurate efficiency. So, depending on the requirement of how much efficiency or how efficient a separation we want, whether cut density is how much separation we want, we can change the pulp density as well as the shaking or oscillating speed. We can even modify this oscillating speed. And if we change the oscillating speed, the heavier coal particles will get much more time or much less time, depending on the oscillating speed, for settling. So, by changing all these parameters like the inclination of the table, water flow rate, pulp density, speed of oscillation, we can also achieve very good efficiency or very good separation of fine coal particles from high-ash coal particles.

So, overall, these Mozley mineral separators and many other similar-design equipment are available. They primarily work on the oscillating principle. So, there are many, many pieces of equipment available, and many are also being invented on a day-by-day basis using similar working principles like changing inclination. Changing the water flow rate, changing the high density of the liquid used, changing the pulp density, maybe changing the surface chemistry of these coal particles, and others. So, there are many, many more pieces of equipment that can also be invented for achieving very good separation efficiency of this material. Fine particles. So overall, this Mozley mineral separator is used primarily for the recovery of coal fines. If coal particles during crushing are of 0.5 mm size or less than that size, or maybe in the 0.2-micron size, and if we want to separate them, we can use this Mozley mineral separator or oscillating tables. One drawback of this equipment is that we need a higher amount of water to be used during this process. So, water consumption, treatment of water, and other costs are always there. So, this equipment should be used almost in the final stage with a smaller amount of coal available, not as the main primary method for the separation of coal. If there is a very trace or smallest quantity of coal particles available, we can use it. It has so many costs and other parameters associated. Primarily, for fine particles, other methods like froth flotation and oil agglomeration are used. Along with them, this Mozley mineral separator is also used. So, overall, if we summarize this physical separation process, primarily, the dense media cyclone separator is used as the major equipment for bigger coal particles, and it is widely used. Apart from the jigs, the jig and dense media cyclone are the two main pieces of equipment used in the coal washery, along with other equipment like spiral concentrators, Mozley mineral separators, and others.

This jig gives the best efficiency, and we can easily control the cut density and other parameters for coal washing. In jigging, we can achieve very good efficiency at a lower cost, but obtaining exact or accurate separation is very difficult in the case of a jig, whereas in such cases, the dense media cyclone performs much better. Along with the dense media cyclone, other types of cyclones, like water-only cyclones, are also used. These have different geometries, achieved by modifying the dimensions of the cyclone separator, and are also used in some coal washeries.

Thank you.