

**Clean Coal Technology**  
**Prof. Barun Kumar Nandi**  
**Department of Fuel, Minerals and Metallurgical Engineering**  
**IIT ISM Dhanbad**  
**Week-03**  
**Lecture-13**

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. In Module 3, we will discuss different aspects of coal cleaning methods and various types of industrial practices used in coal cleaning. So, we have already covered jigging, dense media cyclone, spiral concentrator, etc. as part of physical coal cleaning. So, in this lecture, we will cover froth flotation and the oil agglomeration process used in coal cleaning. So, let's start with the froth flotation process. Now, what is the froth flotation process? Froth flotation is a process that selectively separates materials based on whether they are hydrophilic or hydrophobic, or if they are water-repelling materials or have an affinity for water.

So, hydrophobicity differentiates between the desirable hydrocarbons and waste minerals, or here, mineral matter that is increased using different surfactants and wetting agents. So, in the case of froth flotation, what happens is that some compounds will have a tendency to attach to the water molecules. So, these are some of the coal particles that may have an affinity for these water molecules, while other coal particles may not have any type of affinity. The water molecules. So, this depends on whether these materials will be hydrophobic or hydrophilic. This depends on the chemical structure and nature of the individual compounds, like whether they have some particular type of ions, positively charged ions, negatively charged ions, and whether those ions have some free electrons and others. So, depending on all these properties, some compounds can be hydrophobic, which will fear or they don't want to come in contact with water. So, they are typically water-repelling compounds, and some compounds will have hydrophilicity, meaning they will easily attach to water and come to the water molecules; they have an affinity for water. So, in the case of coal and many similar minerals, it is observed that some compounds or materials have a hydrophobic tendency, whereas other compounds or materials have a hydrophilic tendency during froth flotation. These differences are taken as the driving force.

As we have discussed in previous lectures, for the separation of hydrocarbon-rich materials and mineral matter-rich materials, there needs to be some differences in their properties. Like in previous cases, we have used their differences in properties. Coal particle density and others, which we utilize to separate or segregate hydrocarbon-rich coal particles having lower mineral matter and lower particle density, and mineral matter-rich material which has higher particle density. So, in the case of froth flotation, we use these properties: some compounds or materials will be hydrophobic, whereas some will be hydrophilic. So, in the case of coal, it is typically observed that this property allows us to easily distinguish that hydrocarbon-rich materials have different properties, whereas mineral matter-rich coal will have different properties. To further magnify, zoom, or improve these differential properties, different types of chemicals like surfactants and wetting agents are added so that we can increase this driving force and achieve very good separation of desirable hydrocarbon-rich coal or low-ash coal as well as the undesirable or high-ash coal. In this case, typically, air is used to create bubbles or froth. So, using all these chemicals like surfactants and others, a froth or bubbles is created, and near these bubbles or froth, either hydrocarbon-rich material or mineral matter-rich material will come. They will attach to this structure. So, this generated froth will separate the hydrocarbon-rich coal as well as the mineral matter-rich coal. Typically, hydrocarbon-rich coal.

They are lighter in nature as their particle density is less, and they attach to these bubbles. So, they will create or attach to the froth as part of clean coal, whereas the mineral matter-rich coal will not attach to these bubbles. They will go to the refuse coal or the bottom part, which is typically called the tailing during this froth flotation experiment. So, In the case of froth flotation, what is typically done externally is that in a container or reactor like this, different types of reagents are added, such as mixer feed, hydrophilic material, hydrophobic material (if present), and other reagents, which are then mixed properly at some particular pH. So, here the parameters will be the reagent condition as well as the pH of the solution. So, at this pH, initially all these chemicals and materials are mixed well. Then, we add air. The purpose of adding air is to create bubbles or froth. So, all the chemicals, such as surfactants and wetting agents, are added to this solution. Solution or suspension. So, if we start from or observe the entire process of froth flotation. Initially, all the chemicals are added to this reactor. They are allowed to mix properly to achieve the suitable, desirable pH. Because pH is one of the most important parameter to create whether it will create a stable froth or stable bubbles or not. If pH is not the desirable one, these bubbles will not be created. ionic interaction where pH makes an important role in this entire process. So, all the materials are initially mixed, allowed for 5

to 7 minutes to that mixer get homogeneous. Then air is added from the top through some pipes. So that this entire surfactants and other chemicals create some froth. Then we add the materials or here mixer feed like here we add the coal. So, this coal typically as it is a surface phenomenon or where we use this particular properties like hydrophilicity and hydrophobicity, coal particle size is an important parameter in this process. Very fine coal particles like 75 micron or less. So, here coal particles should be very fine.

They should not be in the coarser size. As in thermal power plant or in the coal washery, all where we get the coal fines, if they need to be cleaned, so typically coals of less than 0.5 mm, they are cleaned using this method. If their size is above 0.5 mm, they will not be cleaned by these methods because whatever this hydrophobicity, hydrophilicity property difference is there, that will not be able to attach very heavier particle or high density particles. So here particle size should be on the smaller size. Typically, it is less than 0.5 mm size what is used, but they are very good efficiency, we get it if their particle size is on the much smaller size. so, in industrial practice it is 0.5 mm and less but their efficiency is much better much more better efficiency separation we get if their particle size is around 75 micron, 100 micron, 200 micron. so, particle size is also as an operating parameter for this process so first process first parameter is the pH of the medium Second parameter is the particle size is also an important parameter. So, this mixture or fine coal particles, they are feed to this froth flotation tank.

Now, in the froth flotation tank, what happens? Whatever the lighter particles is there and whatever this coal particle, which will attach to these bubbles. So, whatever the froth or bubbles are created, so these froth will attach the particles coal particle which are typically hydrocarbon rich or low ash coal particle. So low ash coal particle will attach to this froth and they will be creating one froth which will be floats at this part whereas the mineral matter rich material they will not take part in such interaction. So typically, they will settle down at the bottom. So, we can collect this hydrophilic material which is will not be attached to the surface so they will be collected as the bottom part whether is the top part or the collected froth they will be collected continuously they will be stored here and we can get the hydrophobic material here so by this way, this froth flotation method works and during this different type of surface modifying agents or chemicals are added. So first one type of chemicals is the modifier. So, these modifier chemicals typically they are added to change the characteristics of mineral and insist it attached to the collector.

For example, lime, soda ash, etc., phosphates, different types of silicates are added to modify the surface properties of the minerals so that they will not interact with the created froth and they will typically remain in the water phase and easily settle down. There are also chemicals in a category called depressants, which are used to depress the flotation of certain minerals other than the desired minerals. These act like inhibitors, such as sodium cyanide. So, these materials are also added to modify the surface structure of this material. Then, kerosene oil or fuel oil is used as a collector to improve the froth collection efficiency. Meanwhile, aliphatic alcohols like MIBC (methyl isobutyl carbonyl) and glycerol are normally used as frothers. These materials improve the froth quality and stability so that a stable froth is created, and all the desirable materials attach to this froth and are easily separated. If froths are not stable—like when some froths are created as coal particles attach to the surface and the froth immediately breaks, the entire hydrocarbon-rich coal particles will return to the original mixture of coal. Thus, kerosene oil or fuel oil is used as a collector to create more stable froths and improve froth flotation efficiency. The typical frother dose varies from 0.2 to 0.5 kg per ton of coal. Only a minor quantity, like a few drops of kerosene oil, is added to 1 liter of the mixture. The industrial dosage is typically 0.5 kg per ton of raw coal. So this cost for 1 ton of coal. Only 0.5 kg to 0.25 kg or 0.2 kg is very minor dose is added. So, it not takes too much cost for this froth production process. So, this minor dose is added. The purpose of this frother is to produce a sizable amount of small air bubbles.

These bubbles should be able to carry the coal to the surface without breaking and once out the frothation machine, it should break down. That is the purpose of these bubbles. Whenever we start this solution, some froths are created. So, purpose of those bubbles or froths is that it will attach to this and once we removed it, once we removed it either continuously or in a batch process. So, once we remove this, so this froth will get breaks down and we will get mineral matter less or hydrocarbon rich coal particles as the clean product. Dose of collector, how much collector we should add, dose of frother and other chemicals, they are the major operating parameters including the temperature. As this pH changes, because this entire process depends on the ionic interaction between the frother hydrocarbon rich coal particle and mineral matter rich coal particle. Liquid pH plays an important role. Typically, pH should be around 7, but its efficiency varies depending on the dose and types of materials. We want to separate during this froth flotation. Like for coal, we want to improve this for separation of coal. Similarly, this method is also used for other minerals like iron ore, copper ore and others so it is that depends on the liquid pH dose of collector how much amount of collector to be used if that coal is not

so much hydrophilic or hydrophobic. We may have to add some higher amount of collector but if we again add some higher amount of collector, other parameters may create some problems here. So, all these dose of collector, frother, inhibitor and other chemicals they has to their dose has to be optimized depending on the type of coal and source of coal. So, they are the major operating parameters for any type of coal or if we change the pole this all these parameters has to be fine-tuned once again there will be some minor changes in this all these operating parameters. Typically, it is very much efficient for the powder coal like 212 micron that is 72 mesh or nearby or at least around 0.5 mm. So, this efficiency this froth flotation are very efficient for the fine coal particles as we increase the coal particle size that gravity force acting on these coal particles it will get changed to reduce the impact of this gravity force typically froth flotation process are done for coal particles or fine coal particles of size less than 0.5 mm but we will get very good separation efficiency if they are grinded to 72 mesh or 200 microns or even less than 200 microns. and major advantage for this froth flotation is that we can get clean coal of very lower quantity of ash that means we can easily get coal of ash 10 percent ash is very easily get and we can get even below that amount of coal so from 50 percent ash coal we can easily get 10 percent ash coal for this froth flotation. So that is the major advantage of using froth flotation and in industrial scale as we are getting ash percentage of below 10 percent from even from coal of 50 percent or 45 percent ash coal. This is a tremendous reduction of mineral matter content from the raw coal. So, this process is used actually as this froth flotation process used in coal washery as a method to fine tune the ash percentage of the final clean coal product how typically if we see the physical separation process like dense media cyclone or jigging whatever they have certain limitation that we cannot reduce ash content to very lower percentage because all those ash content reduction happens in the bigger coal size or coarser coal sizes. So if we see the dense media cyclone suppose ash percentage we are getting like 25% ash we are getting in the clean coal so if we are getting 25% ash in the clean coal and if our desired clean coal percentage is 18% as so by dense media cyclone or by jigging or by other methods we cannot achieve 25% as clean coal so what is done there is that some of the coal which is washed by froth flotation, we can add some of the coal from the froth flotation. So, combining these two, making an average, we can get it nearby 18% or 17% as per our requirement. So, typically this froth flotation process is used to get a very high quality clean coal and to adjust the final ash percentage of the clean coal. And this is very little bit costly process as it involves some chemicals. There is involved some major cost in terms of grinding cost. There is also involved some cost in terms of drying of coal as this entire process is happening in the water phase and coal particles are of very smaller size. So, there is always

some cost involved to the drying of coal. There is some grinding cost is there. if we want to go for this process and particularly this method is very much effective for reduction of both ash as well as sulphur present in coal. As we have seen in the other process particularly the physical separation process involving dense media cyclones and others what we can see is that they are mostly used for the reduction of ash from the coal but as we have known that both mineral matter and sulphur creates problem during coal washing or in the coal utilization. So, by this process we can simultaneously get separation of sulphur rich material as well as the mineral matter rich material now how this sulphur is material Typically, any pyritic sulphur is there. They can be easily separated because they have much more these hydrophobicity and hydrophilicity properties compared to the organic sulphur and sulphate sulphur. So, sulphate sulphur will not interact at all. But pyrite sulphur, if it is present in coal, sometimes it is in very small or fine size particles which is attached to the, almost nearby to the hydrocarbon structure of coal. So, for separation of pyrite sulphur, sometimes it is difficult. So, by this process, we can easily separate pyrite sulphur from this coal. So, if coal has any higher amount of pyrite sulphur, they can easily be benefited from this. Organic sulphur will always report to the clean coal. So we cannot do anything with that. But we can separate pyritic sulphur from coal by this method. So as a result, after froth flotation, there will always be a certain reduction in the sulphur percentage in the coal. That's why froth flotation is often used as an individual method for the reduction of sulphur from coal. And the next similar method is the oil agglomeration process.

So, this is a similar process that uses the surface properties of coal or ionic interaction of coal particles to agglomerate the coal particles and to separate the mineral matter-rich coal as well as the hydrocarbon-rich coal. So, by this oil agglomeration process. The difference from froth flotation is that in the case of coal flotation, oil agglomeration takes advantage of the difference between the surface properties of low-ash coal and high-ash gangue particles, which can cope even with finer coal flotation. In this process, typically, coal particles are agglomerated under conditions of intense agitation. The following separation of agglomerates from suspension from the hydrophilic gangue is carried out by screening. So, in this method, what happens is that suppose these are the coal particles and these are the gangue materials—whatever we consider as gangue materials present in fine coals. So, if we want to separate these gangue minerals or mineral matter-rich coal particles from the hydrocarbon-rich coal particles, typically some oil droplets are added. Some different types of oils are used. So, these oil droplets are added. Now, these oil droplets have some surface properties which are also

modified using other chemicals. These oil droplets typically have some hydrophobicity and hydrophilic properties—that difference is there. So, these oil droplets will try to attach Typically, hydrocarbon-rich coal particles. So, what happens is that if we mix these oil droplets with these coal particles under certain conditions, these oil droplets, if we spin them at very high speed, velocity or high RPM, then the oil droplets will break almost to the individual molecular level and very fine size. So, oil droplets will try to get attached to these coal particles. So as a result, coal particles will attach here, and further agitation will cause these oil droplets to agglomerate into a single bigger-sized particle, whereas the mineral matter-rich particles will not agglomerate at all. So, initially oil droplets are added so they will mix with the coal particles and they will prefer As they have some hydrophobic and hydrophilic properties along with some surface churning, So they typically prefer the pure coal particles or hydrocarbon rich coal particles to attach to those droplets. So, this droplet size will increase and further they will create some agglomerates. So once their agglomerates are created, we can get their particle size is bigger in nature. As a result, although they can have some 75 micrometer, but this after attached to it, they will be more than 75 micrometer or maybe 0.5 millimeter or others.

So as a result, through some sieving, if we do some simply screening, oil droplets will create some bigger size particles, whereas the mineral matter rich will create some smaller size particle. So, we can easily separate them through the screening. So, like if we see in this picture there is a mixture of coal, we add some oil. After a while it is mixed for some times, certain times. What will happen is that this hydrocarbon rich coal particles and others they will agglomerate and they will typically float here in this layer whereas the mineral matter rich coal particles they will be in the bottom of this phase. So, here liquid pH, coal particle size, agglomeration time, pulp density or how much solid particles we can add to this liquid phase. That density like typically 5 to 7, 9 or 10% is used. Beyond 20%, it creates very thick pulp. It is mostly not used. So, in case of all this oil agglomeration as well as the froth flotation, pulp density is kept below 20% or below 15%. And it is also another important parameter which affects the quality of the product. This pulp density, oil dose, they are used as the major operating parameter. Mostly different type of edible and non-edible oils are used like mustard oil, coconut oil and non-edible oils like others are also used. in this method and it is very much effective for reduction of ash as well as sulphur from the coal this oil agglomeration process if we see this is very much effective Because it again separates the coal particle based on their surface charge and others. So, very good amount of separation for pyritic sulphur is observed by this oil agglomeration process. So, this is a very good method for reduction of both sulphur

percentage as well as the enrichment of the hydrocarbon rich or enrichment in the GCV of coal or carbon content of this coal as pyritic rich mineral matter they typically does not agglomerate during this process. So if we see the industrial process, how we have to do is that we have to take an container or reactor where we will agitate this and we will add some air if required in some of the cases so this is the almost similar setup that is with the flotation process they will be mixed and we will add the coal fines after we add the coal fines we will find is that these are the heavier particles which is typically rich in mineral matter whereas the hydrocarbon rich particles will float and if we pass it through some screen As this coal make as an agglomerate, so they will be retaining over this screen and the mineral matter rich coal particle which has not gets agglomerated at all. So, they will be going passing through this screen and they will be collected as a reject coal or refuse coal whatever so we wash the get this coal or coke material here we can add some other chemicals or other material for washing of coal because we have added some chemicals if those chemicals are not if those chemicals are harmful for the environment they may contain some other impurities like chlorine, sulphur and others. So, for that purpose typically this clean coal or this agglomerated coal are washed and they are removed so then we wash this coal and we can get the clean coal so here different parameters is that agglomeration time if we increase the agglomeration time what happens is that some minimum amount of agglomeration time is required like 4 minutes, 5 minutes, or maybe 90 seconds or 120 seconds like this. So, some optimum agglomeration time is there. If we kept it for long, long time, so in such case, even some of the mineral matter rich hydrocarbon get also attached to these coal particles.

So, in such cases, efficiency may decrease. That is why typically, oil agglomeration time is also optimized to determine how much time we should allow so that other undesirable particles do not get attached to these agglomerates and remain separated. Pulp density: if we use a very high amount of pulp density, the desired amount of separation will not occur because, at higher pulp density, it will not be possible to differentiate between hydrocarbon-rich coal and mineral matter-rich coal particles. This is also important regarding oil dosage. If we use a higher amount of oil, in such cases, it may happen that mineral matter and coal particles also get agglomerated on their own, and their efficiency in clean coal properties also becomes important. Coal particle size: typically, we should aim for the finest size possible, as finer sizes result in better liberation, allowing us to differentiate between hydrocarbon-rich coal particles and mineral matter-rich coal particles. Similarly, liquid pH affects the stability of this ionic solution. Mostly, it is observed to be very good near a pH of 7 or around pH 7. If we modify the pH to make it

strongly acidic or strongly basic, the ionic interaction or  $H^+$  ion concentration with  $-$  ion concentration changes, disturbing the stability of this agglomeration. Overall, if we consider both oil agglomeration and froth flotation, these methods are very useful, particularly for cleaning fine coal particles, as industries always generate some coal fines that require separate treatment. Mostly, froth flotation is used in coal preparation plants, while oil agglomeration is a relatively new technology. It is also being implemented in many coal preparation plants. The major advantage of oil agglomeration and froth flotation is that both can separate mineral matter and sulphur. If we only want to separate ash content or ash-rich coal, typically larger coal particles can be processed using jigging, dense media cyclones, and other methods. But if we want simultaneous reduction of ash as well as sulphur from coal, we must use fine particle processing methods, such as froth flotation or oil agglomeration. And for the reduction of the cost of this oil agglomeration, we can use different types of other surface modifying agents so that their separation efficiency improves. Typically, diesel oil and kerosene are mostly used along with some minor surface modifying agents and some pH-correcting agents. Whereas in the case of oil agglomeration, different types of vegetable oils or non-edible oils are used, as vegetable oil has the conflict with the food versus fuel conflict. So typically, non-edible oils are used, but overall, it depends on which oil will give the higher amount of efficiency, as not a significant amount of oil is consumed here. So overall, even we can afford edible oil, but non-edible oils are preferred. And by this oil agglomeration, we can also get a significant amount of pyrite sulphur separation.

So, both these methods are used to fine-tune the quality of the final product of clean coal. As for the coarser-sized coal particles, there are limitations in the ash percentage of the clean coal. We may not get the desirable ash percentage in the clean coal, as they are washed in a bigger size, and this froth flotation and oil agglomeration are washed or cleaned at a much finer size. Easily, we can get very low-ash coal from this. So, by mixing this low-ash fine coal from the froth flotation or oil agglomeration along with, somehow, the higher side of the coarser-sized coal particles from the dense media or jig by blending or mixing them at a suitable ratio, we can easily meet the desirable ash percentage in the clean coal as well as the desirable sulphur percentage in the clean coal. So that's why both these methods are used in coal washeries or coal preparation plants. That's why in coal preparation plants; multiple equipment are used. It is not like only a single equipment will wash the coal. There are two different circuits. One is for the coarser-sized coal particles, which may have two or three consecutive pieces of equipment, whereas there will be another circuit for fine particle processing. Finally, the clean

coal will be obtained by mixing the product from the fine particle processing circuit as well as from the coarser-sized coal particle processing circuits.

Thank you.