Introduction to Mineral Processing
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Lecture – 40
Hydrocyclone

Hello, welcome to this 8th week of this lecture series. So, last week we have discussed about movement of solids in fluids as well as the classifiers mostly the gravitational settling classifiers, where you use a gravitational force. This week we will talk about hydro cyclone which is nothing, but a centrifugal classifier; that means, where we use a centrifugal force to have a size separation.

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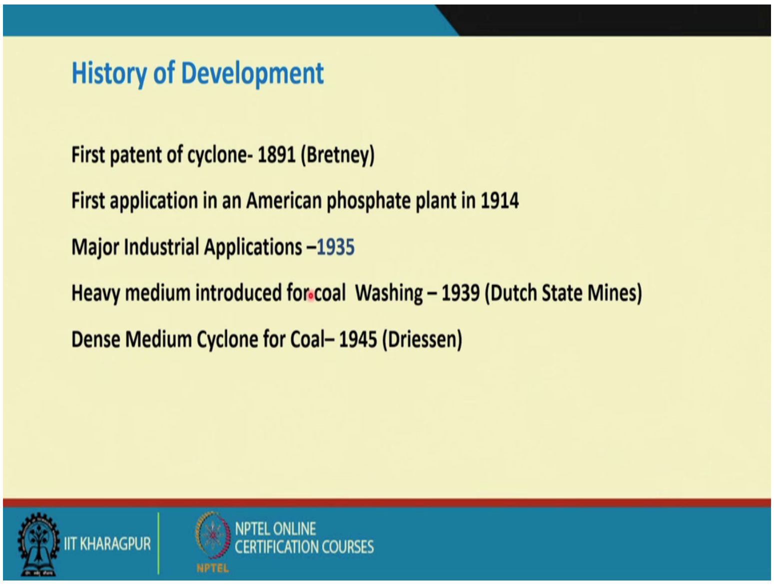

Why a hydro cyclone and what is the history first let me discuss that. If we look at the history of the development the first patent of cyclone was taken in 1891 by Bretney. However the first application was in American phosphate plant in 1914 look at the time difference and major industrial applications started from 1935 onwards.

So, it is the old equipment and even in this hydro cyclone some heavy medium that is in place of your water we have introduced some kind of a suspended medium and that we started using for coal washing that has started in the Dutch state of mines in 1939 and they are known as dense medium cyclone for coal of course, we are not going to discuss this two.

So, we will focus more on this hydro cyclone because this is mostly important in mineral processing operations.

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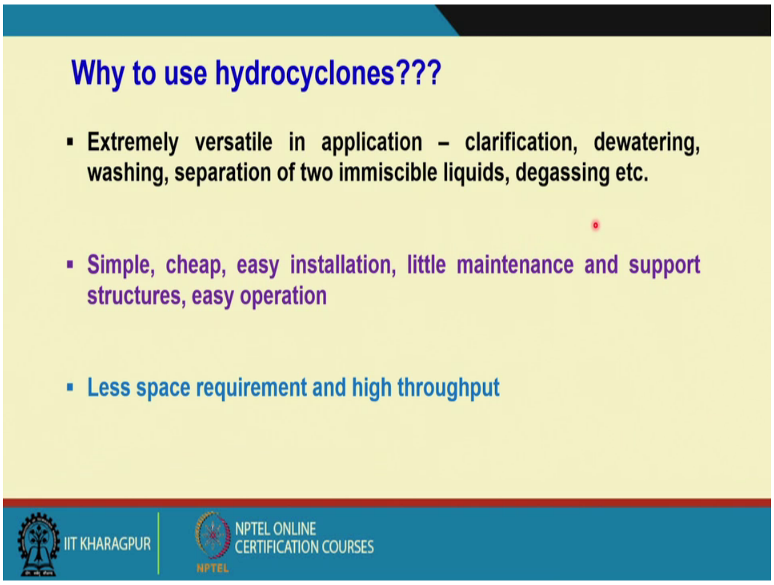

Why to use hydro cyclone? Now, it is extremely versatile in application in the previous lecture the last week lecture, I have given you some kind of your comparison between your gravitational classifiers and centrifugal classifiers and we mentioned that because of many advantages associated with the centrifugal classifiers they are much more popular than the gravitational classifier as a size separation device.

However, it is not only used for size separation it has got a versatile application like we call it clarification we will explain it what is that dewatering, washing, separation of two immiscible liquids degassing etcetera. A very simple relatively, very simple in design, cheap, installation is very easy it has got very little maintenance and support structure requirement is minimal and aberrantly easy operation. And it has got less space requirement that is they do not need much space it is not a huge your equipment, but your per unit volume it has got very high throughput. So, because of all these they are very popular in mineral processing field for various applications.

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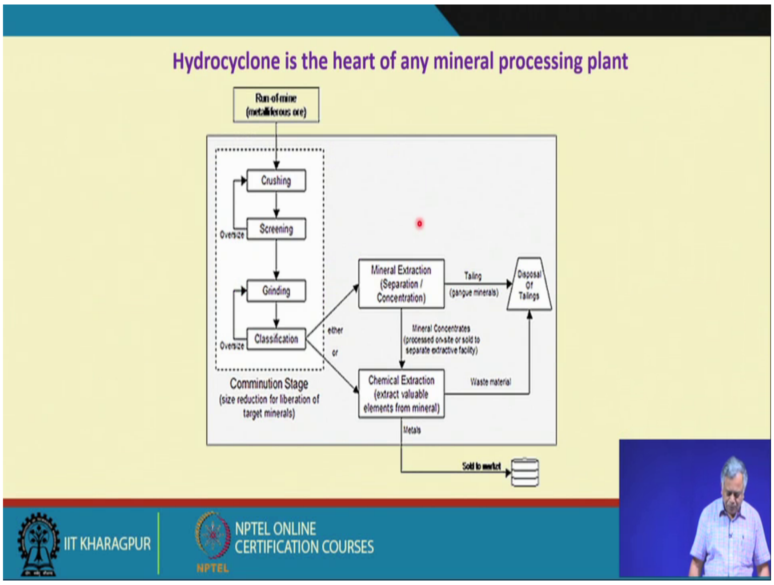

Now, if you look at a mineral processing plant I would say that hydrocyclone is the heart of any mineral processing plant. Why I am saying that? Now, let me remind you that a general your stapes in their mineral pulsing plant. What do you normally do? That is we have got enough mine or that is what your colleagues from mining engineering they are sending you to process. First you cross and screen and then you grind them that is only for liberation purposes. So, that is the combination stage, that is for liberation.

Now, liberation size you have seen that under microscope that is when you are doing the liberation analysis they have seen that the ore has to be ground below just say suppose 50 micrometer. So, how do I ensure that this combination circuit followed by crossing screening and grinding they are sending only the particles below 50 micrometer for downstream processes? So, it is there that is where you use the classifiers and they are mostly the hydro cyclones are used.

So, if the classification if the hydro cyclone performance is not at it is best what will happen. Now, it will start sending more of this material into the as a recycled material to my grinding system and grinding we have already discussed that it is a very energy intensive process and it will consume lot of energy. So, your cost of your combinational circuit will go up and if because of this over grinding you may be generating a higher percentage of ultrafine particles that is I wanted to have below 50 micrometer particle, but I end up generating more of below 20 micrometer particles.

Look at the downstream processes. So, once they are ground either they are saying for chemical extraction that is for hydrometallurgy and all this. Of course, this is not the part of this course, but then you have prepared your material for separation now you are sending it for mineral extraction that is for separation or concentration. So, it is the hydro cyclone that is your classification is being done by a hydro cyclone. So, it is the linkage between your combination circuit and your processing circuit that is why I am saying that this is the heart of any mineral processing plant.

So, this is the reason why I have decided that I would try to devote this entire week discussing on various aspects of hydrocyclone, although I will not be able to cover all the aspects of hydrocyclone even in a complete week of lecture. But I will try to show you that is where and how we can your use the cyclones and what are the different operating and design variables you should be aware of because how do I operate my cyclone at its best operating condition and that is what my aim of this week's lecture.

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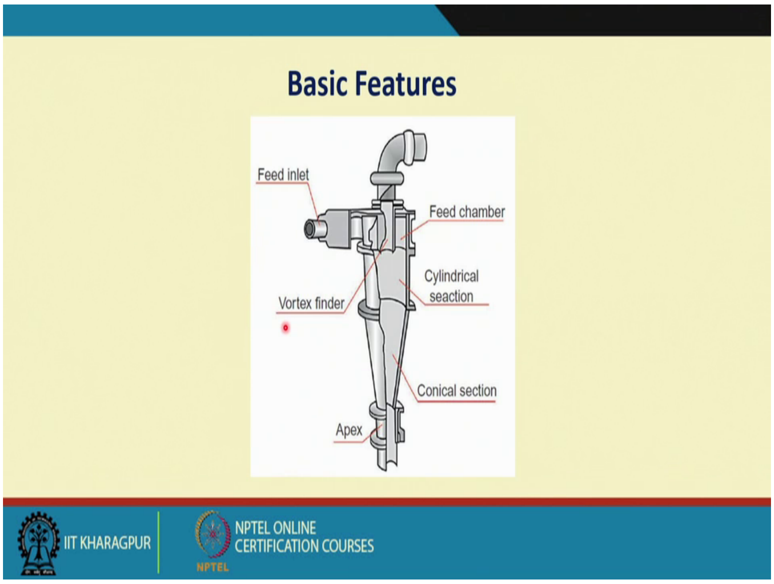

If you look at a hydro cyclone what are the basic features that is what are the different terms we use for a cyclone. Now, it is a cylinder conical vessel it is apparently very simple I said that it is a cylinder conical vessel and you feed in the form of your slurry that is consisting of a mixture of different sized particles with water they are fed at some pressure here mostly tangentially here in this, because of the tangential entry and at a high pressure. So, what is happening? So, there will be a spiraling action because of that.

So, anyway we will come back to this how it works later on. So, where it gets entered that is what we call it feed chamber, this is the feed inlet and you have got two exits, one we call it blow or we call it vertex finder that is through which it goes out and you have got you call it under flow or the epics. So, this is known as vortex finder through which you have got some overflow and here it is the under flow discharge and we call it epics and this is the cylindrical section and this is the conical section.

Normally in mineral processing field the cyclones are designated based on their cylindrical diameter that is when we say that this is a 75 millimeter or 76 millimeter diameter cyclone; that means, the cylindrical part that is the cylindrical portion they are diameter internal diameter is 76 millimeter while doing like this.

Now, because the other ports is that what should be the your say your the length of this conical part or what should be the apex diameter, what should be the diameter of the vortex finder, what should be the diameter of the feed inlet they are all in terms of the cylindrical diameter we write. Only exception is that is your conical section we try to put it as an angle that is what is that your included angle here. So, that differs from manufacturers to manufacturers it also differs from your where we are using the hydro cyclone for what purposes.

So, apparently it is a very simple geometry as has got a cylinder conical geometry feed enters your at a tangential at a high pressure you have got two orifices it is called vortex finder and the bottom one is called a your epics.

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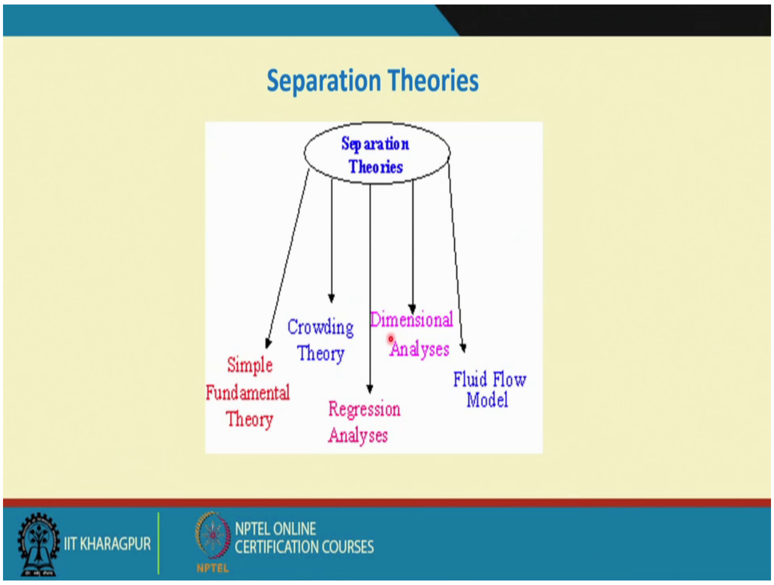

If I look at the separation theories that is how the particles are getting separated inside a hydro cyclone this has been the very active research topic for more than maybe last 50 years and because of that there are many theories have come up. And if we just summarize all this separation theories we can group them into 5 different categories.

And the one is simple fundamental theory that is based on your analytical approaches, another one is called crowding theory, another one is based on dimensional analysis this is more recent that is your fluid mechanics based approach that is fluid flow model based on your CDF approaches it may be based on your analytical based on your solving the your equation of motions like you are in a fluid medium and the regression analysis that is your input output correlation based on your observed pattern of your data.

I cannot deal with the details of all these theories and all this because probably you need a separate course even on hydrocyclone to do that. You will be surprised to know that even till today that although we have got so many theories, but still our plant operators they still rely on the models developed based on the regression analysis. They are based on your input output correlations. One of the very popular models among this is called the blitz model based on which actually you try to select your cyclone or you try to adjust your variable parameters, but it will give you some kind of your inaccuracy in your predicted values. Anyway I will try to gradually show you that this apparent is simple looking equipment what are the difficulties associated with it to understand properly that how the particles are getting separated.

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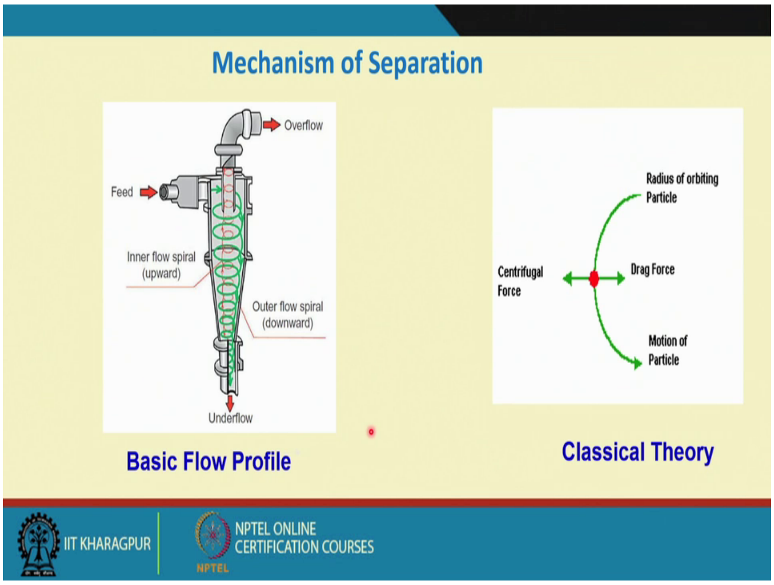

Even look at the classical approach that is for varies your simpler way of explaining that is how a cyclone works. I would have to explain you like that. So, what happens this is your feed it is getting entered at an angle at tangentially, these days maybe many manufactures they are having spiraling action also anyway that is not a very different thing. So, you are sending your feed that is your pulp that is your the different size materials and your water at a high flow rate that is your at a high velocity inside this chamber. So, what will happen? Because of that the fluid along with your solid particles they will try to have a spiraling motion downwards like this. Now, in that case what will happen suppose it should have been the other way down, but if I say that now there is a particle here which is experiencing a spiraling action like this.

So, if I do a simple force balance on that what will happen no one force will be acting downwards because of this mass that is the mg, but that mg we can ignore because the intensity of your centrifugal force what is this centrifugal force in Laymen's your explanation that is your mv square by r. What is that m? m stands for the mass of the particle, v is the what is the velocity of that that at what velocity they are moving and r is the radius orbit of radius that is at what radius they are moving.

So, that centrifugal force we try to bring the particle towards the radial direction that is it will try to bring it bring the particle towards the wall whereas, you have a fluid medium that is your water. So, when you have a fluid medium you will have the drag force why you are ignoring the buoyancy force because the particle sizes we are treating it is very small. So, you are buoyancy also you can neglect, but you cannot neglect the drag force.

So, what will happen? This drag force we try to resist that. So, it will try to pull it towards the center of this. So, the particle is trying to move like this, while having this movement if I have a particle the centrifugal force we try to send it towards the wall and the drag will try to bring it towards the center. So, there is a pull of the two opposite forces now the particles whose mass is more. Now what is this mass? Mass is again a function of volume and density because m is equal to mass is equal to volume into density.

Now, the volume is again a function of your size. So, basically mass is a function of your particle size and density. Now, let us assume that the density of the particles what you are sending here there of there of equal density. Now what will happen? A bigger particle therefore, will have higher mass than the smaller particle. So, that m in that case for a relatively coarser particle would be much higher than the relatively finer particle. So, the intensity of the centrifugal force will be more pronounced on the particle which is coarser. So, these relatively coarse our particle will hit the wall very fast because it is the nothing, but your sending velocity concept into the radial direction we have discussed so far sending velocity into the vertical direction, but as because of this geometry and how you are feeding it we are trying to have a radial your settling velocity in the radial direction.

So, the faster settling particle into a centrifugal force field we will try to heat the wall very sooner than the relatively finer particles. Now, once it hits the wall it loses its radial momentum now because of gravity now this particle will slide through and then this will report through the underflow. Now, what will happen to the relatively finer particles? These relatively finer particles will be moving somewhere in this zone.

Now, you see that there is another inner spiral marked with the rate where from the inner spiral has come. There are many explanations to that very simple explanation for this many people may have objections to this explanation, but for the beginners I try to explain it like this, that is both the openings that is your overflow and underflow they are open to the atmosphere. Now, what will happen? Because of the conical part and you have a cylindrical part here. So, there is a change in the mv square by r. So, that r is changing you have not changed the particles though the same particle the same fluid now if I say that fluid is also a continuum of discrete droplet us then what will happen this fluid droplet they will also experience this centrifugal force.

Now, when the r is changing so that means, your; what is the pressure? Pressure is pores per unit cross sectional area. So, what will happen? The pressure gradually builds up there is a pressure drop gradually builds up in between this section to this section. So, you have a very high pressure zone here you have got a relatively low pressure zone here. So, when you have a high pressure and low pressure zone.

So, this fluid we try to go up or you want to balance it your system will try to bring the pressure difference into equilibrium; because of that what happens? Now, this part this opening underflow opening is open to the atmosphere. So, automatically atmospheric air gets sucked and that is and then because of your spiraling action of your soil that is we call its soil flow. So, that is your fluid that is your water is moving like this and when the air is sucked it will start rotating in opposite direction and it will try to go out through the overflow.

It is just like your many times you have experienced this that while you are walking you will find that there is localized some kind of your turbulence is created and you will find that there is a spiraling action we call it local cyclone and there you will find that even the leaves and your some small paper and all these they are also being transported along with that your cyclone and they are rotated in along the central axis and they will try to go out like this. It has got a similarity with that, but it is a properly controlled one.

So, let me repeat it. The relatively coarser particles because this radial settling velocity is much higher than the finer particle, it will heat the wall, it loses his radial momentum and they try to they will go out through the underflow discharge. As because underflow is open to the atmosphere and there is a pressure drop created between these zone and this zone, so the air is sucked and these air will have an opposite spiral that is your spiraling into a opposite direction we call it air core. So, that is the inner flow spiral this will try to go out through the overflow.

Now, when the air is going out through this overflow my simpler explanation is like this that is you have got a air column and it is also moving in this direction at a very high speed at a very high velocity it is going out. Now, because of its high velocity of this air core it creates a local drag, now because of that local drag whatever the fluid particle that is your water droplet us or whatever is the water droplet us along with the finer particles whatever are there they will be also dragged with this and they are also being transported through the overflow.

So, what is happening? You have got the relatively coarser particles discharged through the under flow and because your under flow opening is exposed to the atmospheric air. So, the air is sucked because of the in situ pressure drop created or generated and when the air will try to bring the system into equilibrium it will try to pass through that escape through that your overflow and because of its high velocity it will induce local drag and that will drag your relatively finer particles and the your water whatever is available in that periphery and then he will be collected like that and that is how you have a separation.

Now, we try to understand that that I said that it is a simplest of the explanation can give that is why it is being researched for even more than last 50 years that is how a cyclone works. To be frank, till to date there is no well accepted explanation that how exactly it works because if you look at the complexity of the problem it is a fluid mechanical device you have got your water you have got solid particles of different sizes let us assume that density are identical, but you have got different sizes so; that means, particles are having different Reynold's number and in a dynamic condition you have got a third phase which is the air.

So, if you say that air is synonymous to gas so; that means, you have got a solid liquid and gas that multi phase problem and you have got a cylinder conical geometry that makes everything a very complex your system. So, although it is simpler to be operate and all this thing I have mentioned, but what I am trying to say that if I try to predict if I try to explain that how it works it is really very very difficult to explain you properly that how real it works. And this is the reason why the separation and this hydrocyclone is never perfect and that is why still many researchers are working with the hydrocyclone that how to make it perfect, but still why they are being used because of the advantages associated with that which I already explained to you.

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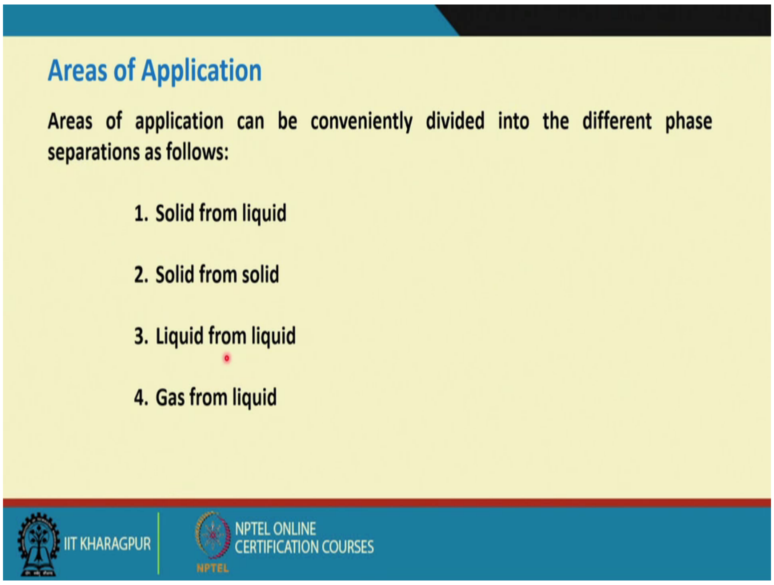

Now, what are the areas of application? The areas of application can be conveniently divided into the different phase separations as follows, like I call it as a phase separation device I do not say that hydrocyclone is only a classifier, it is much more than. That it is it is any phase separation theoretically it is possible to be carried out by this cyclone. So, it can separate solid from liquid that is you can have solid liquid separation, you can have solid solid separation in a fluid medium that is your size based separation or density based separation, but you need a fluid media.

Liquid from liquid that is two immiscible liquid I can have a separation based on this, a good example of that is the application in the petroleum industry where you want to separate your water from your crude petroleum, gas from liquid that is also possible.

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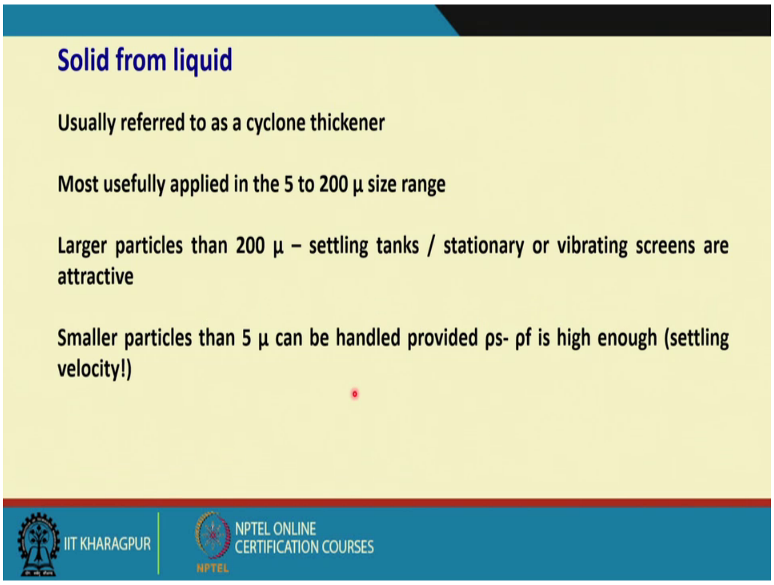

Now, solid from liquid one of the very important application area for mineral processing that is when it is used for solid liquid separation we do not say it is a cyclone as a classifier we say that it is a cyclone thickener, that is a solid liquid separation. Most is fully applied in the pipe to 200 micrometer size range relatively finer sizes. Why? I have explained I have given the explanation.

There is larger particles than 200 micrometer you do not need this your centrifugal force a simple settling tank or maybe a simple hydraulic classifier or maybe a your simple sedimentation basin and you can use it. So, your settling tanks stationary or vibrating screens are attractive that is you can use a screen for separation coarser than 200 micrometer. So, screen will give you much more precise separation than cyclone. So, why do you use cyclone coarser than 200 micrometer.

Smaller particles than 5 micrometer can be handled it is not impossible. Even these days people are even thinking of or say trying a cyclone separator for nano particle size separation even. But the problem is the smaller particles than 5 micrometer can be handled provided rho s minus rho f that is density between your solid density and fluid density is high enough that is the settling velocity difference. As I said theoretically or practically it is possible even below 5 micrometer particles to be separated, but in that case what do you need to know need to have, that we need to have the a much more increase in the intensity of the centrifugal force.

So, the complexity associated with your cyclone design many times inhibit the operation below 5 micrometer in mineral pulsing industry where it is a requirement that we have to process large volume of material per unit time. But in some other application areas where you do not need to process a larger volume like this you can think of using a smaller diameter cyclones. We will continue with this lecture,

Till then, thank you very much.