Introduction to Mineral Processing
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Lecture – 43
Hydrocyclone (Contd.)

Hello welcome. So, last week, so last lecture we were discussing about the effects of design variables on the hydro cyclone performance. So, this lecture I would like to talk about that, what are the operating variables which are very significant with respect to your performance of a hydro cyclone?

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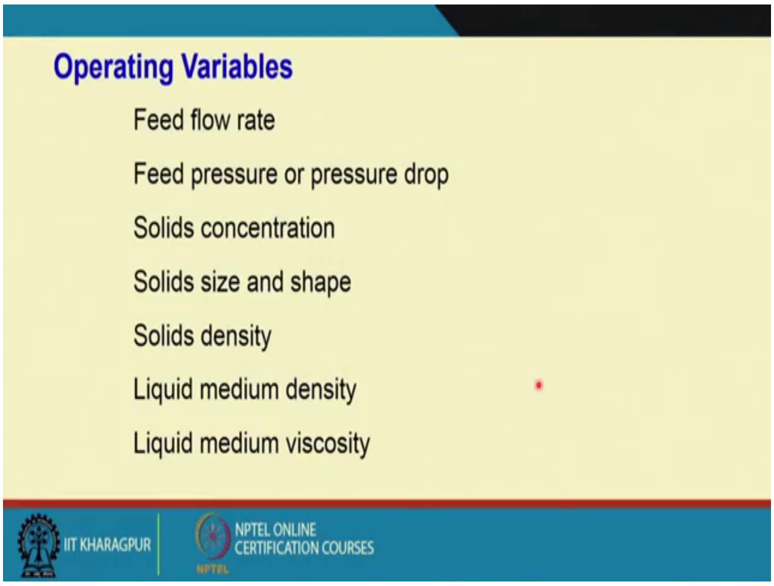

So, the operating variables are feed flow rate, feed pressure or pressure drop solids concentration, solid size and shape, that is the particle size and shape solids density, that is the particle density, liquid medium density and liquid medium viscosity.

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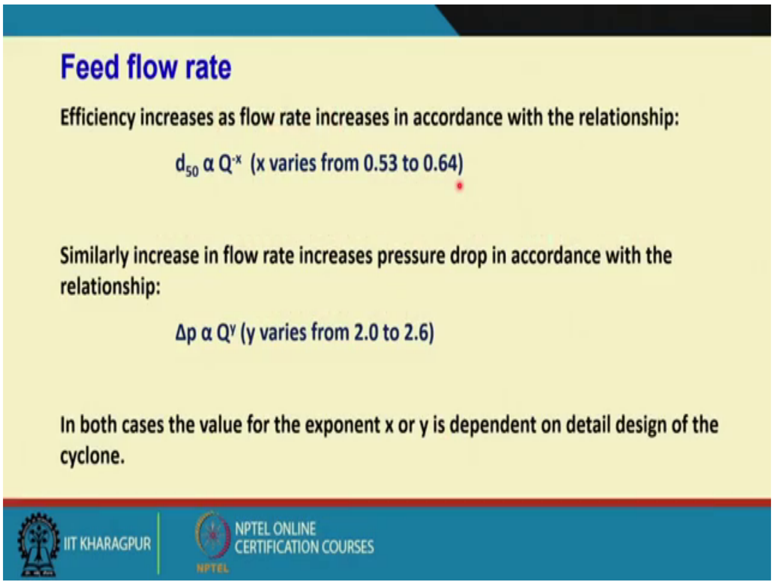

We discuss them one by one briefly. Feed flow rate, that is efficiency increases as flow rate increases, in accordance to the relationship because, we always designate our efficiency of a sized separator like hydro cyclone, in terms of cut size that is the d 50 size. So, what happens when the flow rate increases? So, your velocity of the fluid inside that increases. So, if you remember the concept of m v square by r that is for the centrifugal force. So, when the velocity is more; that means, the particles will experience more of centrifugal force.

So; that means, more particle will be discharged through the under flow. So, naturally whatever we get through the over flow, there will be much more finer. So, that is why it is said that, that is your d 50 is proportional to Q to the power minus x and x varies from 0.53 to 0.64, again I am cautioning you that, these are just a empirical relationship. If you want to develop a model or you want to use a model I would strongly recommend that, for your design or your material you develop your you generate your experimental database and then you develop your own model, but these are the guiding tools.

Similarly, increase in flow rate also increases pressure drop, pressure drop means that is in case of hydro cyclone, the pressure drop is defined as the pressure at the inlet and pressure at the tip of the vortex finder. So, that is the pressure drop. So, in accordance with the relationship del p is proportional to the Q to the power y where y varies from 2 to 2.6; that means, with increase in your feed inlet, flow rate your pressure drop also increases.

In both cases, the value for the exponent x or y is dependent on detailed design of the cyclone, that is why I am again repeating this, that these are only guiding tools. You must develop your own model based, on your own data at your laboratory to verify that, what will be the values of these exponent?

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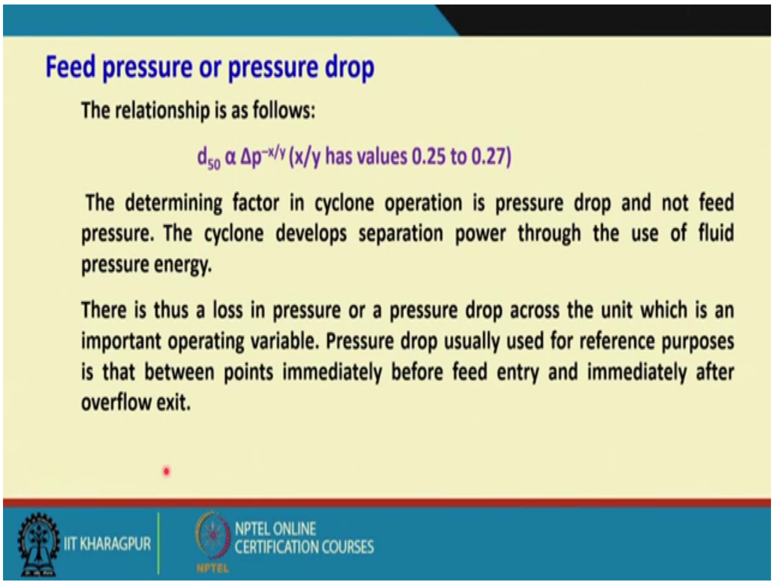

Now, feed pressure or pressure drop normally, we try to have in the inlet flow rate before that, when the slurry is fed through the inlet flow rate, we normally have pressure gage. Why we do not have say flow meters? Because, for the particles as a mass flow meter are very expensive and they are very the maintenance intensive.

So, we try to measure the feet inlet pressure and from that, we try to develop the correlation ship, that is what is the feed inlet flow rate? What is the feed inlet pressure? And then what is the flow rate of your cyclone? So, the relationship is as follows, that is d 50 is proportional to del p to the power minus x by y where x by y has values from 0.25 to 0.27.

The determining factor in cyclone operation is pressure drop and not feed pressure, because that feed pressure, which will help in creating the air core and maintaining the stability of the air core, it will also control the velocity of the air core. So, at what rate your fine particle will be collected through the overflow that, depends on the inlet pressure that is or how much of pressure drop, you have created inside the cyclone.

The cyclone develops separation power through the use of fluid pressure energy, that is what I have explained it. So, the loss in pressure or a pressure drop across the unit, which is an important operating variable, because it dictates, it determines, it helps you to monitor the performances of your cyclone, that is by manipulating the pressure drop values you can control that, how much of what particle can be collected through the overflow.

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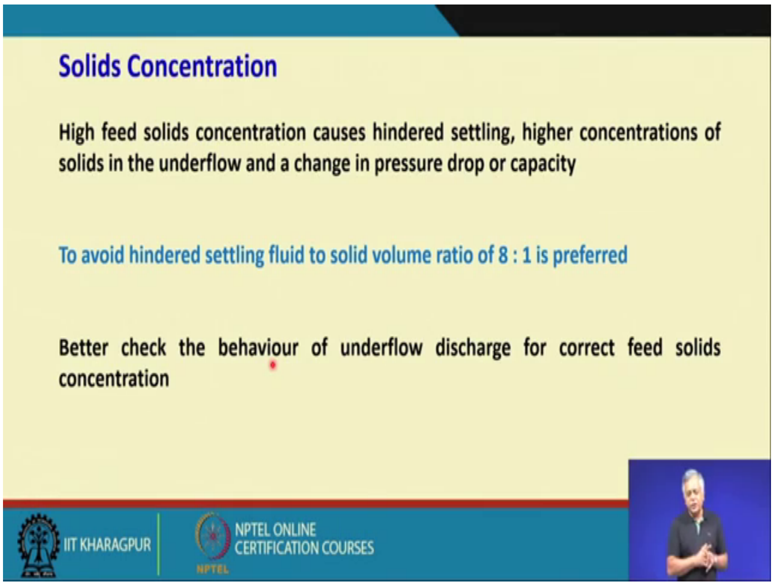

Now, solids concentration, that is the feed solids concentration. Now, what happens? If your feed solid concentration is very high, the one problem is your fluid that the slurry will be viscous. So, you will have problem in the fluid flow inside the fluid flow related problems, inside your cyclone number 2 is that, when your solid concentration increases, the particles will experience the hindered settling mode, that is your although you will be getting more capacity, but the quality control of product will be very difficult, because in that condition that is why I have written that is high feed solid concentration causes hindered settling.

Higher concentrations of solids in the underflow and a change in pressure drop or capacity. So, what will happen when you have a high feed inlet your solid concentration. So, because of the hindered settling condition, the much of your material, that is a load on your under-flow discharge will gradually go up and you have seen that, your apex that is your under-flow discharge diameter, is much less in comparison to the vortex finder diameter.

So, when it is getting crowded, I will show you some images or say sketches that, what happens when you increase the solid concentration. Now, to avoid hinder settling fluid to solid volume ratio of 8 is to 1 is preferred, that is that is the maximum that is the your normally we have found that, if you maintain a fluid to solid volume ratio within 8 is to 1, the cyclone gives the best performance; however, many a times the operators are basically forced to increase the capacity of the cyclone. So, they have to increase the feed solid concentration.

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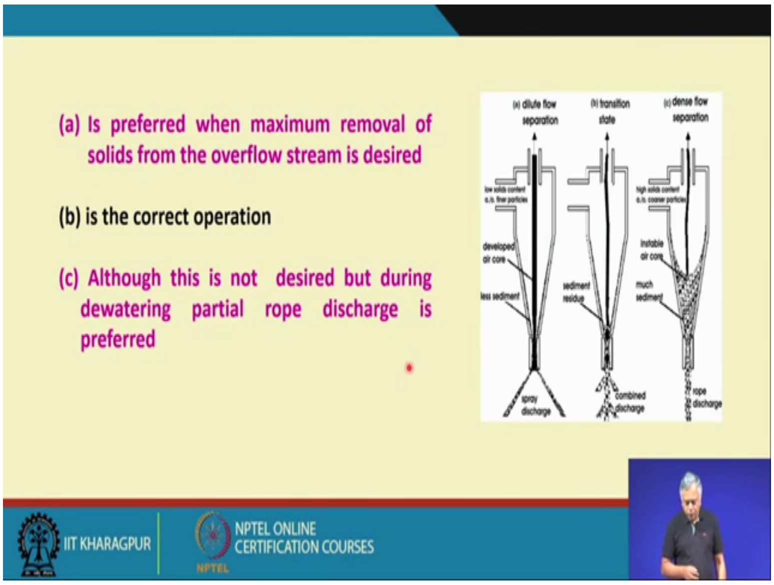

So, in that case how do you know that, how much of feed solid concentration you can give? So, normally the experience operators of hydro cyclone they look at it the underflow discharge. Now, what is the discharge profile? That is, this is what I wanted to show you, that what happens that you will have normally a classifying cyclone, that is a size separating cyclone. If we just open up the bottom, that is fluid what is getting discharged through the spigot, if we look at their profile they have got a spray profile like this, we call it spray profile why we have a spray profile?

Now, because the fluid was having a your swirling mode inside that. So, when it is trying to go out, it will also try to go out in a say spray fashion, if you look at the your if you talk in terms of your say fluid mechanical language. So, that is your tangential velocity that is your exit, your tangential velocity component is much more dominant here and that is why you are getting a umbrella shape, that we call it spray pattern. What should be the ideal spray angle and all this? That is another research topic, but these are only qualitative estimates, that is the spray discharge is preferred when a maximum removal of solids from the overflow stream.

Overflow stream is desired, that is what I want more of the solids of the feed solids, that I want to collect it through the overflow. So, in that case it is the say spray pattern we are basically interested. Now, this one there is called the rope discharge rope, discharge means; that means, you see that here I have shown it that, you are near the conical bottom part of this cyclone that is getting crowded with more solids; that means, there is a solids pile up; that means, the rate of discharge through this spigot opening is less than the rate of accumulation of particles here and the reason is, when the particle is trying to go through this, it will displace the fluid that is the water from that.

So, you will have less much less percentage of your water and you will be having more of these solids. Now because of that so, that is why is the this rope discharge sometimes it is not desired, although it is not desired for classification purposes, but for the purposes when the cyclone is used as a solid liquid separation; that means, dewatering in this case for mineral processing, that is I want to take out my water, through the cycl1 overflow and my solids I want to send it through the under flow.

So, that time this type of rope discharge confirms, that you have much lesser percentage or volume fractions of water, but the risk is your cyclone may get choked anytime. So, that may cause you the maintenance related issues, but normally the ideal condition is, in between condition that is in between spray and rope discharge that is called the combined discharge. Now, there is a research field now that, how do I quantify this profile? How do I separate out this profile and this profile; that means, what should be the ideal spray angle? Is it 10 degree to the vertical or is 20 degree or 40 degree.

So, these are the things which is being researched now. So, this is how an operator can monitor the performances of your cyclone, that is if it is spray that is it is spraying the spray angle is very big, that is it is spraying like this so; that means, you are sending majority of your solids to the top, you are getting less solids to the underflow and then I have to adjust that, no I do not want this.

So, you try to do something that is you try to either reduce the pressure drop or maybe you try to reduce the feed solid concentration and try to bring it to this stage and that, these are the practical measures of bringing back your cyclone at it is optimum operating conditions.

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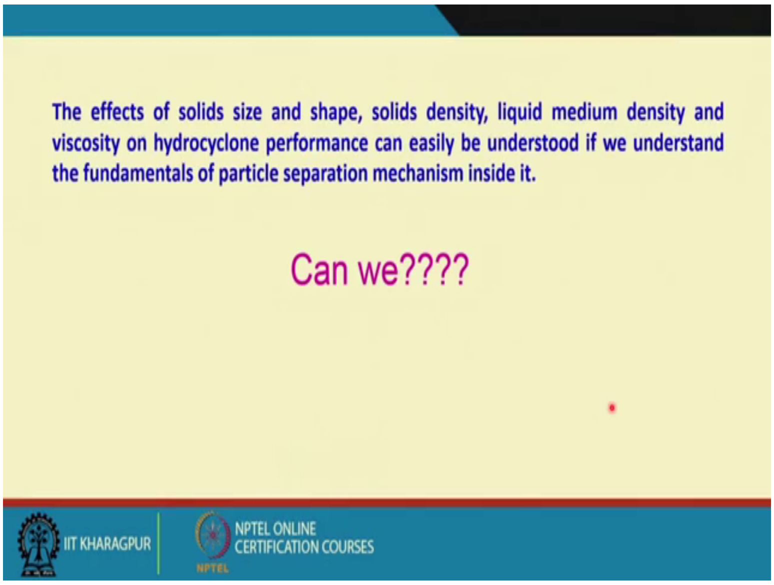

Now, I pose this question to you, that is I leave it to you to discuss amongst you, if you are a student group or individuals also I would like to think, I would like to tell you to think about this that is, when we have discussed so many things, if we understand how a cyclone works can we not predict the effects of solid size and shape that is, what will happen if my particles are flaky nature and if my size is say coarser or finer. What will happen? What is the role of particle density? What is the role of liquid medium density and viscosity on hydro cyclone performance?

So, if we understand the fundamentals, we can definitely predict this. So, I leave it to you to think over it, if you have travel when we have the common forum for discussion we can discuss this issues. Now, if we look at the hydro cycles in operation, in a mineral processing circuit normally, it is used I have told it many times that, it is basically a correcting stage in between combination and separation.

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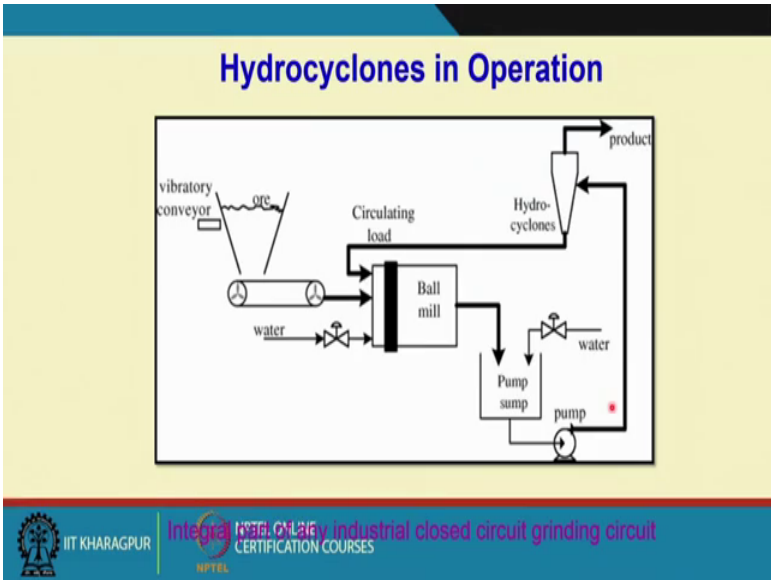

So, in combination, that is a ball mill example I am giving and is normally used in a closed-circuit operation, what is the meaning of closed circuit? Now, you have seen the feed material to the ball mill and the ball mill when it is moving. So, you have set the rpm may be 40 percent of the critical speed and it is a continuous operation. So, material going in, it is supposed to be ground there and then it is being discharged, but how do I know that, whether my material has been ground to that desired size or not, I want all my feed material to be ground below 40 micrometer size.

So, how do I ensure? It is it is almost impossible to ensure, that whether my ball mill has done my job or not, without checking the particle size. So, what do we do? We normally send the ball mill discharge first to a sum, why? Now, we have discussed already, that hydro cyclones best operating condition is, fluid to solid ratio we have to maintain 8 is to 1, that is your volumetric concentration.

Otherwise my cyclone will not do my job properly. So, here if we know by mass balancing, that is if we know how much of water is coming. And so, what is the solid percentage? And what is the volume percentage of water here? So, normally it is not having that ratio, that is your 8 is to 1 to volume your fluid and your solid concentration is not that ratio, it is little bit your say thicker; that means, the relative percentage of solids is much higher.

So, we have to make it dilute and even the hydro cyclone is sitting somewhere. So, I have to pump this material. So, if my material if my slurry is thick. So, well I have trouble in pumping that. So, it is a requirement for both, that is for my optimum cyclone operation and it is for optimum pubs performance. So, we add water how much that we calculate, based on how much of water and solid is coming here and then we try to mix it here, properly then we pump it and then we send it to the cyclone, that is a hydro cyclone and there the hydro cyclone is basically shed, at a with adjusting the operating and design variables. Whatever we have already discussed, to separate it separate my particles at a size of 40 micrometer.

So, ideally the overflow whatever is going out that we are assuring, that they are below 40 micrometer size. The giving this assurance is a little bit problematic, but that is why you need expertise you need to do your you need to understand how hydro cyclone works and this is the reason, why I have given so much of emphasis on hydro cyclone. So, the particles which are coming to the underflow; that means, they are coarser than 40 micrometer.

So, these particles we send it back to the ball mill for further grinding, because I want the entire feed to be ground below 40 micrometer. So, whatever has been the finer than 40 micrometer we are taking it out, and the particles which are still coarser than 40 micrometer, we are sending back to the mill for further grinding. So, this is called the circulating load and or we may say that that is the recycled material. So, how much of the fresh feed and how much of the circulating load, you have a you will add here that is dependent on again the ball mill operating conditions that, is at what solid concentration and at how much of the mill charge that you can have.

So, if I know the ball mill operating conditions, suppose my ball mill can accept your 100 tons per hour of solids feed solids. So, your recycled solids say suppose this is 50 tons per hour so; that means, I can only add at a rate of 50 tons per hour of fresh solid. We will do some calculations on this and the next week lecture. So, till then this much is enough.

So, it is one of the very important application of hydro cyclone in mineral processing plant. Now, if the cyclone is not doing his job that is, suppose if it is separating the particle at a much coarser size than 40 micrometer says suppose that 60 micrometer. So, we are thinking, that my product that is overflow product, they are below 40 micron a 40 micrometer, but they are actually 60 micrometer.

So, what will happen now this product is being sent normally to a process called floatation or may be it may be other processes, like magnetic separation or maybe some electrical separation or maybe some gravity concentration. So, those unit operation those equipment are also set or selected, keeping this in mind that those, equipment will process particles below 40 micrometer.

But because of the abnormal performance of hydro cyclone, they are getting particle sizes coarser than 40 micrometer. So, what will happen they are performance also will be detoriated and how you have selected 40 micrometer? Now that is based on your liberation analysis. So, if hydro cycl1 overflow is 60 micrometer; that means, the particles are not properly liberated so; that means, the separation again will not be that optimum or at the best possible manner.

So, you are ultimately your product quality, will get hampered and your entire process will be termed as inefficient. So, that is why I mention that the hydro cycl1 plays a very, very critical role, in controlling the product quality and in other cases suppose, the hydro cyclone is separating that is the overflow size in place of 40 micrometer it is separating at 30 micrometer.

So, what will happen? So now, in between 30 to 40 micrometer, which are already supposed to be sent back to the downstream processes, they are coming through the underflow and they are coming back to the ball mill and they are getting over ground. So, additional energy is being consumed, which is not required for regrinding the already ground material to my desired sizes. So, that is your additional cost, plus this material may be ground to a much finer sizes like below 20 micrometer, which will again be sent through this and if your downstream processes, are getting much of finer sizes than 40 micrometer, that is you are getting more of alter fine particles, again their performances will be also hampered because they were designed thinking that, by majority of my particle may be within 40 micrometer to 20 micrometer sizes.

So, this is why again and again I am repeating these that hydro cyclone performance plays a very critical role, in the overall performance of a mineral processing plant and that is why it could be called (Refer Slide Time: 24:11) or heart of the mineral processing operation, various sizes, styles and configurations of hydro cyclone available in the industry; that means, we can have various sizes we have already discussed it, different styles I will show you what do I mean and configuration like many a times, your particle properties have forced you to select a smaller size cyclone.

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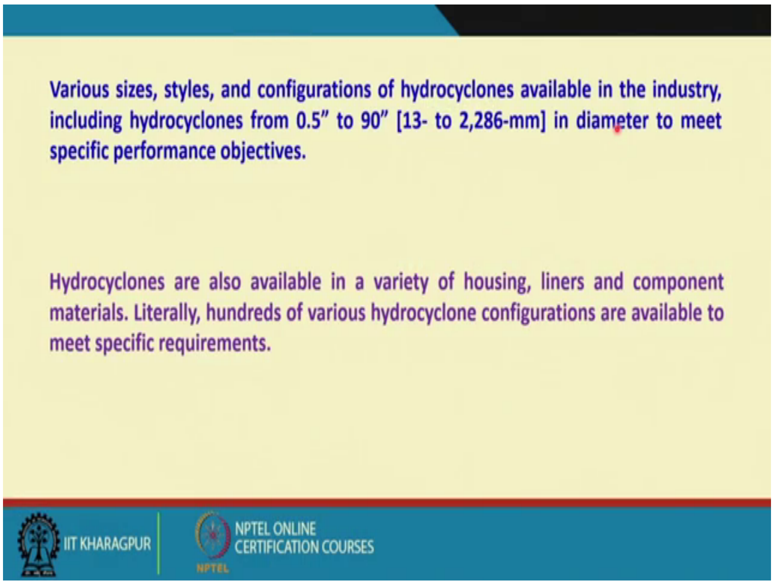

Now, you have to process as suppose 100 tons per hour and your east cyclone can only process 10 tons per hour. So, you will be requiring 10 of these cyclones, to match the capacity of your plant including. So, configure various sizes styles and configurations of hydro cyclone available in the industry, including hydro cyclones from 0.5 inch to 9 ties that is 30 into 2286 millimeter, but normally these sizes we use it for coal, diameter to meet specific performance objectives.

Hydro cyclones are also available, in a variety of housing. I will show you liners, that is you can have a different liners to protect it from the wire and component materials, we have already discussed it that our cyclone materials and your surface finish, literally 100s of various hydro cyclone configurations are available to meet specific requirements.

So, when you are selecting a hydro cyclone for your mineral processing plant, you must be very clear that what are the particle characteristics? What is your desired product you want? And what is the capacity you want? And then you will select your cyclone, based on that and you must take care of the maintenance related issues.

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This is one of the configurations, I have taken it from open sources. So, there are this is called the cluster of cyclones. So, what happens? Here it is they are all relatively smaller dimension the smaller diameter of cyclones. So, what is not feasible, but you have got a your central discharge, that your feed is coming in the form of slurry here, then you have got a distributor.

So, then you are distributing, the feed at equal pressure and with equal solid concentration, volumetric concentration to each of these cyclone and once the product is, that is your hydrocycl al1 overflow they are being collected all this overflows, they are they are collected into one vessel and then, they are sent back to the downstream processes similarly, under flows are also collected and they are sent back to the grinding circuit many times. This is again another configuration and the style, you see the style there is a difference between the style and configuration.

This is the central feeding system and these are the challenges to the mechanical engineers, that is how do I design this, because the requirement is that each cyclone should be having your identical inlet feed pressure and having identical your volumetric concentration of solids.

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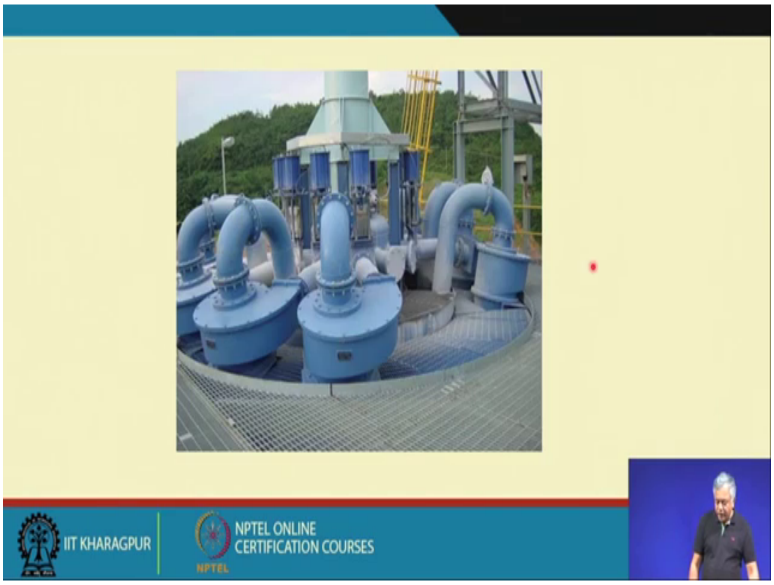

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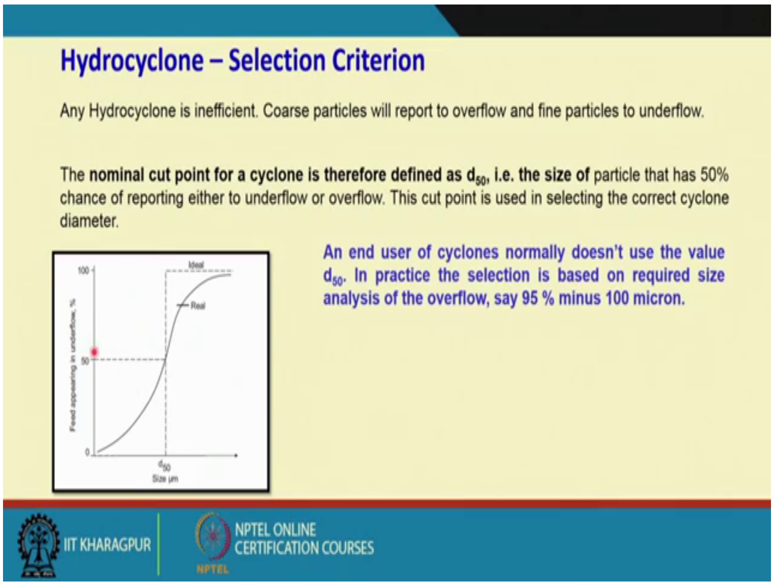

This is also another design and configuration. Now, let me give you some hints that is, in an industry the presenting industries, how they are selecting the cyclone for their permitting their requirements.

So, that is the selection criteria, what do they follow? They do not go by normally with the fluid mechanics-based model or for CFD based models and all this. So, they use the empirical models that is, what one example I have given you illustrated, that is your previous lecture that is the plates model, then there is another model called (Refer Time:

28:43) model as a model called lynch and (Refer Time: 28:46) model like that there are several scheme model. So, there are many models are available and when you have generated your experimental data, you must check that which empirical model gives you the better prediction of your the product quality, you know or maybe the performance of your cyclone.

So, each manufacturer or each you are say plant operator, they have their own selection criteria. So, one general criteria I am giving that is and as a basic understanding, the basic concept is that hydro cyclone is fundamentally operation, is fundamentally inefficient and coarse particles will report to overflow, that is fine particles to underflow, that is some coarse particles will definitely report to overflow and some fine particles will report to underflow, that is called the miss placement that is, you cannot guarantee that my overflow does not contain like, if I want all my particles to be finer than 40 micrometer. So, you cannot guarantee that no particle, coaser than 40 micrometer will be reported through the overflow.

Similarly, it is impossible almost to guarantee, that no particle finer than 40 micrometer will report to underflow. So, that is why the hydro cyclone operation in a plant scale level, is considered to be inefficient. So, we accept that hydro cyclone performance is inefficient. So, based on that, that is we prefer to use the method proposed by trop, that is the your say performance carp-based analysis. So, what they do? The plant people now, they go by the nominal cut point that is the d 50 size. Now, what is the d 50 size; that means, what is that imaginary size? At that size where my 50 percent of the feed material have gone to the overflow and 50 percent of the feed material has gone to the underflow.

So, the nominal cut point for a cyclone is therefore, defined as d 50, that is the size of particle that has 50 percent chance of reporting, either to underflow or overflow, the cut point is used in selecting the correct cyclone diameter. So, once you have selected the correct cyclone diameter, I have already discussed in the previous lectures, that your other design parameter, they are basically linked with the cyclone diameter. But, that is what the equipment manufacturer they tell, that is the d 50 of my cyclone.

But the question is, what about the particle density? Is that d 50 for any particle, that is that d 50 40 micron is relevant to gold, suppose if I have all the gold particles, because it has got a density of 1900 kg per meter cube or is it for coal also, which may have around say 1.4 specific gravity, but normally when you are saying that d 50 cut size is this.

Normally, it is understood that it is for the kwachi density particle; that means, it is for a particle equivalent to a density of 2650 k g per meter cube. So, you have to adjust it based on that, but this is the equipment manufacturers way of giving assurance to the end users. I will stop here and then I will continue this lecture I will tell you, how the end user he selects his hydro cyclone for his operation till then.

Thank you very much.