Introduction to Mineral Processing
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Lecture – 42
Hydrocyclone (Contd.)

Hello welcome back. So, we are discussing about the cyclone, hydrocyclone, we have already discussed in the last class about its performance evaluation, about the corrected efficiency curve all this. So, the interested people they may have a look at the literature a detail if you are interested in modeling related literature.

Now, we are talking about the design and operating variables. Now, let us start with the what are the different design variables with this apparently simple equipment and how do they affect by performance.

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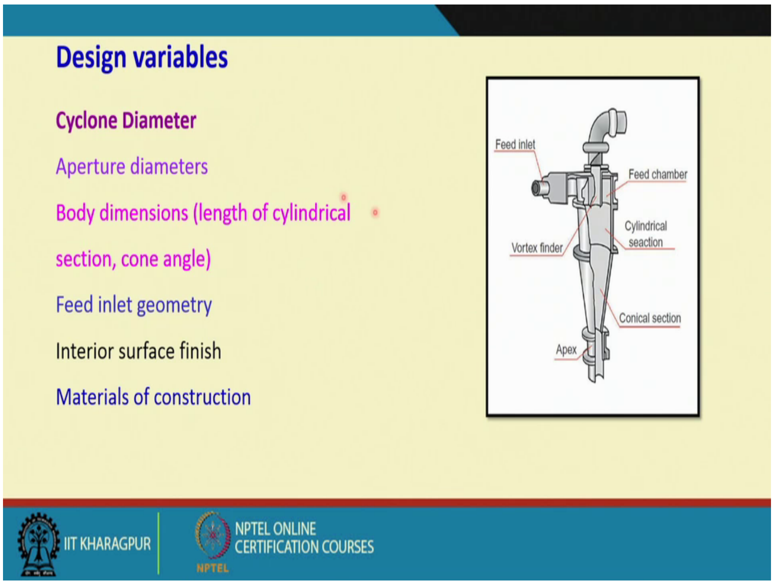

So, the design variables are like cyclone diameter what should be the diameter of my cyclone aperture diameters like your vortex finder diameter and spigot diameter. Body dimensions length of cylindrical section cone angle, feed inlet geometry what should be the geometry of my feed inlet; what should be my interior surface finish even that is also design variable and materials of construction what could be the material of construction.

I will try to discuss the importance of all these design variables one by one in simple terms.

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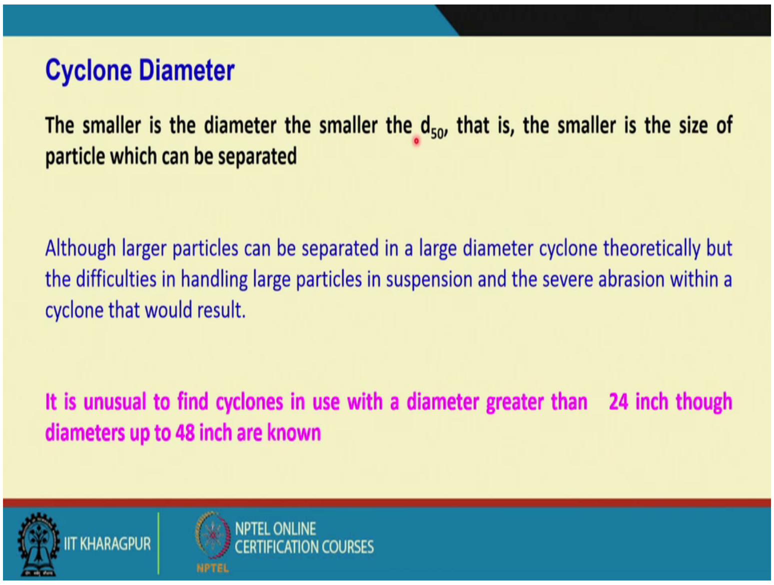

Cyclone diameter. So, smaller is the diameter the smaller the d 50 because we try to explain most of the things about the cyclone in terms of d 50 that is the cut size we call it cut size. The flat people they can relate it then if you say the d 50 is 40 micron another case if you say d 50 is 10 micron. So, you know that this is your the cyclone of smaller diameter for the d 50 of 10 micrometer whereas, the d 50 of 40 micrometer is relatively bigger diameter.

So, the diameter is bigger your capacity is more, but you need your of the cyclone and when that diameter is less, your per unit capacity is less. So, the smaller is the size of particle which can be separated that is smaller. The particle the smaller the cyclone diameter you should have because as I said that your all other your design parameters they are linked with this cyclone diameter mostly. So, why you need smaller diameter for smaller particles? Again I am coming back to that mv square by r.

So, when your m is less that is your smaller diameter. So, you can only play with the r to have a more increased centrifugal force, otherwise they will not be pushed towards the wall. Although larger particles can be separated in a large diameter cyclone theoretically, but the difficulties in handling large particles in suspension and the severe abrasion within a cyclone that would result. So, we have discussed about that that is normally coarser than 200 micrometer particles we try to separate them based on screening using industrial screens or sometimes we may use the your hydraulic classifiers like that.

Theoretically we can also use a cyclone for that, but what will happen the essential criteria for this separation in a centrifugal force field is that particle has to be in suspension. So, when the particles are very big and very difficult to keep them in suspension then your body force becomes more dominant that is a gravitational your component start playing a dominant role than your centrifugal force. So, it will also interfere into that and then the bigger the particle you will have severe abrasion that is your it will become abrasive because you are feeding it at a very high pressure tangentially. So, because of that abrasion there would be weir in the cyclone surfaces.

It is unusual to find cyclone in use with a diameter greater than 24 inch though diameters up to 48 inch are known. So, normally in mineral processing for size separation we do not use cyclones bigger than 24 inch; however, these days even up to 48 cyclones are known, for some typical purposes.

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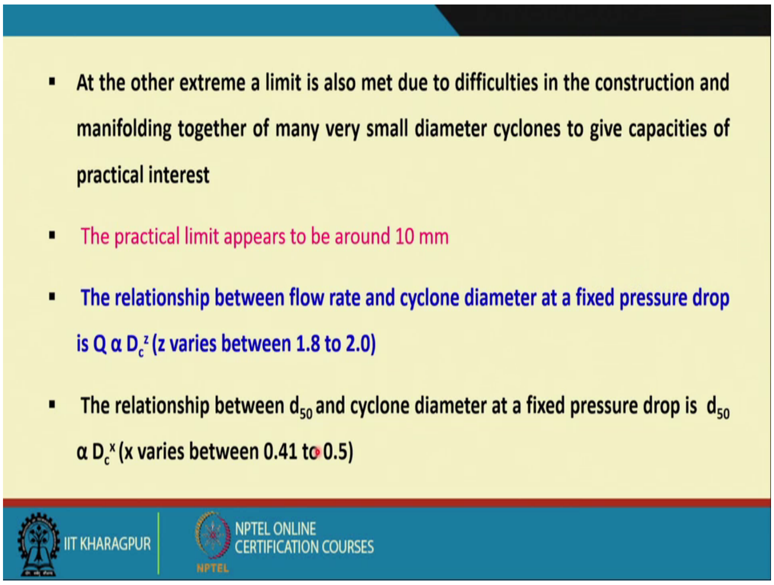

At the other extreme a limit is also made due to difficulties in the construction and many folding together of many very small diameter cyclone to give capacities of practical interest the very important thing. That is I can use a smaller diameter cyclone, but as I said that a unit capacity will be very less what I need to process say suppose 100 tons per hour then I need many numbers of this cyclone and now, how do I configure them and how do I feed them though these become a basically to match the capacity that becomes a typical or severe engineering problem.

The practical limit appears to be around 10 millimeter, that is we can have your 10 millimeter diameter cyclone 10 millimeter is cyclone is a very small diameter very small cyclone just like your out of this size, a very small cyclone for very fine particle processing like one example is clay processing industries. But to match the capacity you need number of that cyclones I will show you at later stages how do configure them how do match the capacity with while using smaller diameter cyclones.

The relationship between flow rate and cyclone diameter because your feed inlet you have and cyclone diameter if it is smaller. So, naturally your flow rate and your cyclone diameter they has to be matched and then the relationship these are all empirical relationship at a fixed pressure drop is Q is proportional to D c to the power of z, D c is the cyclone diameter Q is the volumetric flow rate and z it varies between 1.8 to 2.

So, these are all typical empirical parameters and I caution you that or any cyclone you are using you should try to have this type of relationship developed based on your laboratory scale operations because you should not use all these models all these equations blindly because these as I said keep repeating it that they are all empirical parameters. So, in your case it may not vary from 1.8 to 2 it may be some other number. So, we must do that if it is important to know.

The relationship between d 50 that is the cart size and cyclone diameter at a fixed pressure drop is d 50 is proportional to D c to the power x and x varies between 0.41 to 0.5. So, these are some of the relationships between your cut size and cyclone diameter. So, what it is saying that if I want your cut size to be finer your D c has to be your cyclone diameter has to be reduced because this is 0.41 or 2.5. So, it has to be reduced.

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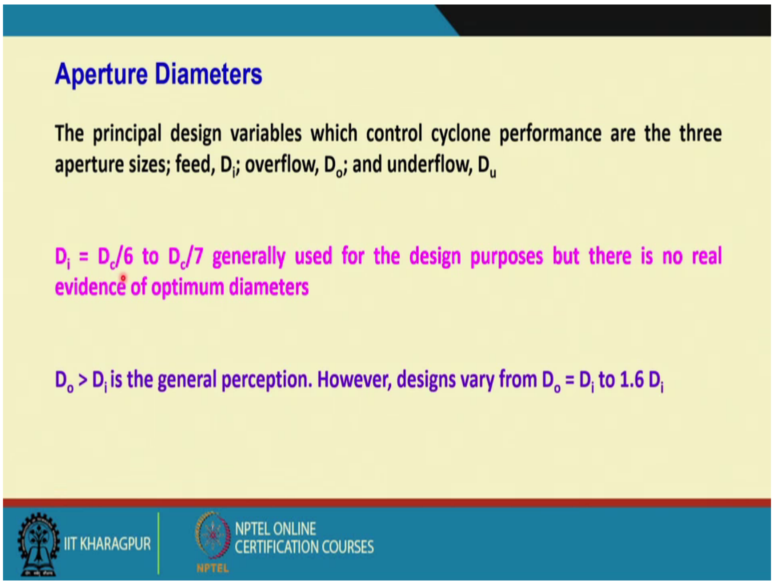

Now, aperture diameters that is the principle design variables which control cyclone performers are the 3 aperture sizes. What are those? That is your feed inlet diameter. What is the inlet diameter? What is the overflow diameter? That is your vortex finder diameter and what is the underflow diameter D u?

Now, why they are important? Now, when cyclone is in a dynamic state or when it is in operation the major part of your two outlet us that is your under flow and overflow that is a vortex finder and your spigot they are filled up with air. So, the available cross sectional area all together if you add them up that is your vortex finder and your spigot the available cross sectional area for your slurry to pass through because whether it is coarse particle or whether it is your fine particle they are being carried through these two orifices they are in the slurry form.

So, how much is the available cross sectional area left because these are mostly filled by air. So, that will determine that what how much is the back pressure at your feed inlet. So, what is the inlet diameter? So, diameter that inlet diameter will dictate that at what velocity you are sending your slurry, that is at what velocity your slurry is being feed to the cyclone because your velocity is again a function of your cross sectional area that is what is the flow rate and what is the available cross sectional area at the point of injection at this at the cylindrical your portion of the cyclone.

So, that is why this your these are the three principal design variables which control cyclone performance because if you are the; if your inlet slutty velocity is less. So, your that term b is less. So, when the b is less your intensity of centrifugal force becomes less. So, it will have a different your performance your of the cyclone then if you have much more increased your velocity of the feed flow rate.

Normally now, you see that they are all in terms of cyclone diameter D i is equal to D c by 6 that is your cyclone diameter that is one-sixth of the cyclone diameter or one seventh of the cyclone diameter these are four standard designs generally used for the design purposes, but there is no real evidence of optimum diameters that is why these are all basically the exclusive your design parameters for different cyclone manufacturers. They spend a lot of money for say fine tuning their design variables even they go for patenting that is we will use this type of your inlet dimension and your inlet design even.

So, D o that is your overflowed diameter that is a vortex finder diameter is generally greater than your D i that is the general perception that it is it is normally great bigger than your inlet diameter that is the general perception. However, designs vary from D o that is your overflow diameter is equal to D i it could be in terms of your inlet diameter to 1.6 times the d i. So, again D i is a function of your cylindrical diameter and then that you can put it here. So, once I have fixed the cyclone diameter I can fix to start with that is to start with a basic design of my cyclone I can have a D i I can fix the do similarly I can fix the your say spigot also.

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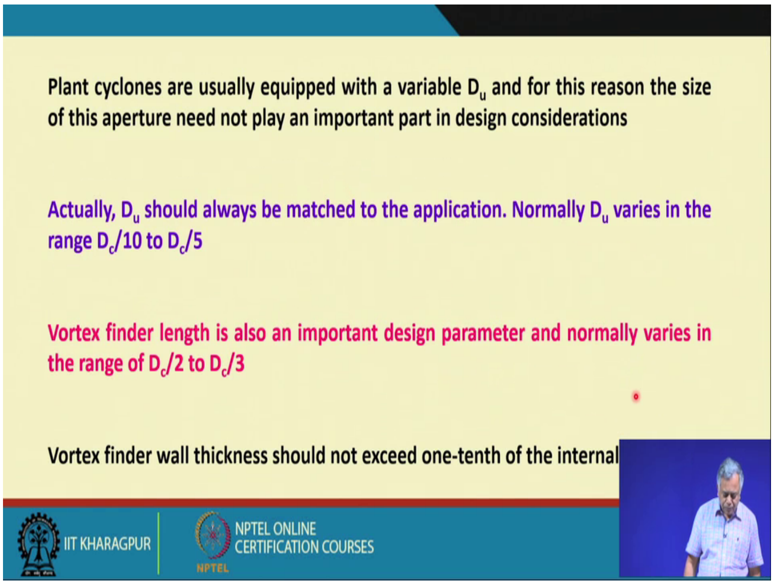

Now, planned cyclones are usually equipped with a variable D u that is normally that d u that is your spigot portion normally you leave it as your process variable which as a design variable. But which you can play with depending upon the your the performance of your cyclone like it is because of the logistics that is you can have some kind of your threading mechanism for the your with the entire cyclone body that is with the cortical part I can have your spigot a you are fixed into a trade or maybe in a clamp with the using a clamp. And then when it gets thrown out because that is the most we are prone part of a cyclone because you have got much relatively much coarser solids passing out through that and you have got less quantity of water.

So, that part is basically prone to here and because of that we have that flexibility in the design normally for plant scale hydrocyclone and even when you have that flexibility why do not you think of changing the dimension of that with a little bit of your range. So, that I can manipulate the my quality of my product. And this is why the size of this aperture need not play an important part in design considerations although it is mentioned, but then also you should know that in my inventory from what range to what range I should have this D u.

So, normally this D u varies in the range of D c that is a cyclone diameter that is one-tenth of cyclone diameter to one-fifth of cyclone diameter. So, you see that, now you can play with this that is you can have a basic cyclone fabricated and now, you have got a material you know the objective of separation. Now, depending on the responses, now you can play around with your vortex finder diameter with your inlet diameter and with your spigot diameter and you may quickly arrive at a situation where you can reach the optimum condition for that this is normally the standard practice in any plant scale your cyclone optimization.

Vortex finder length, that is also an important variable that is what should be the length of this vortex finder. And normally it varies in the range of D c by 2 that is half of the cyclone diameter to one-third of cyclone diameter. Vortex finder wall thickness that is how thick should be the vortex finder wall, that should not exceed one tenth of the internal diameter, because otherwise what will happen you will have lesser volume available for your slurry at the entry zone. So, but this vortex finder is also prone to your weir. So, if it is very thin it may not last long. So, you may have to replace the entire cycle. So, you see that what are the finer details you have to monitor for this apparently simple equipment.

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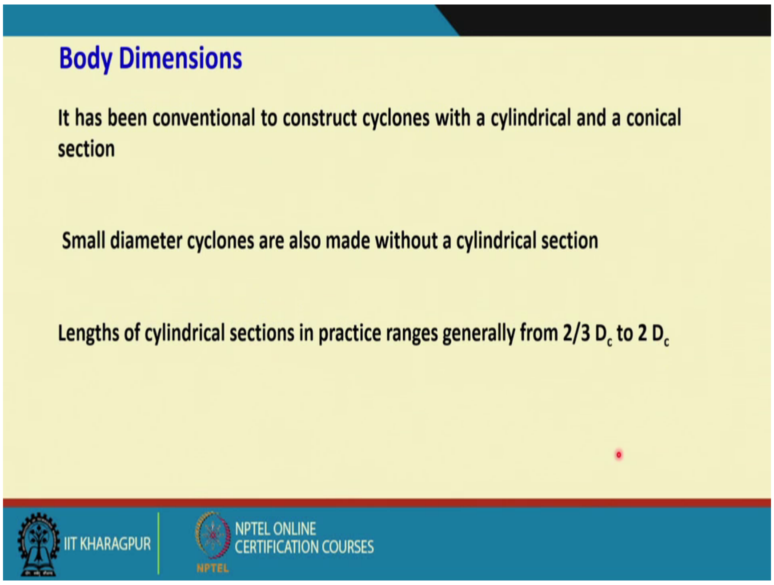

Then the body dimensions, what are the body dimensions? Now, it has been conventional to construct cyclones with cylindrical and a conical section that is the cylinder conical section.

Small diameter cyclones are also made without a cylindrical section. So, many times that is the standard design that you have a cylinder conical design, many times we have seen that your many manufactures they come up with this idea the small diameter cyclones are made without a cylindrical section. Length of cylindrical sections in practice ranges generally from two-third of cyclone diameter to two times of the cyclone diameter and also you can you can represent it in terms of included angle.

Normally for various purposes the cyclone that angle varies from 5 degrees to up to 20 degrees and that is for different purposes what we have discussed that is from solid liquid separation to solid solid separation he used different angles because lesser the angle longer the your conical part and the finer the particle you need that conical part extended. So, he can have a separation at the finest sizes.

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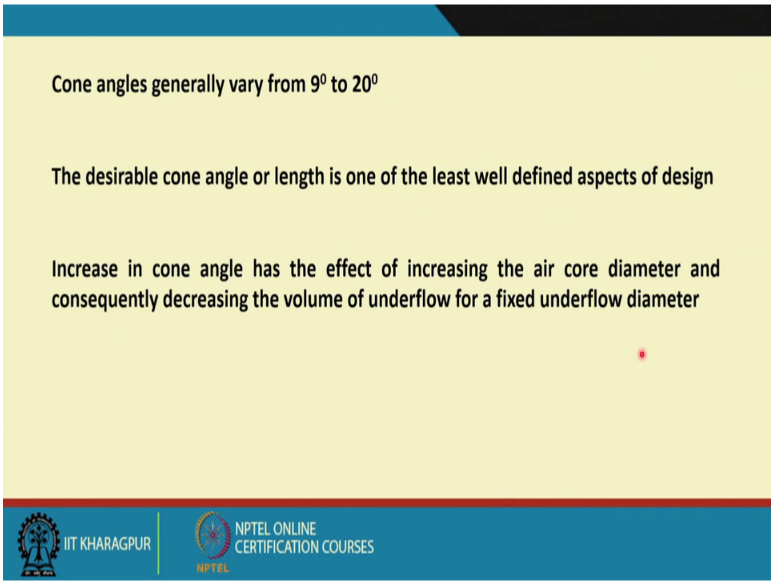

Cone angles generally vary from although it is written from 9 degree to 20 degree that is for classification, that is for size separation, but for other purposes like your dewatering purposes it may range from 5 degree to 20 degree.

The desirable cone angle or length is one of the least well defined aspects of design. That what should be the desirable cone angle there is not been researched at length. Increase in cone angle has the effect of increasing the air core diameter and consequence in the volume of underflow for a fixed under flow diameter.

These are all general observations. Now, these days the there are many research groups across the globe they are working on your fine tuning the hydrocyclone design based on different end uses and they are approaches are through fluid mechanical approaches which is the probably the right approach because it is essentially a fluid mechanical device. So, these days with up your computational power has gone up like anything. So, we are using a computational fluid dynamics based approach and then in a CDF platform they are trying to fine tune these design parameters for various applications.

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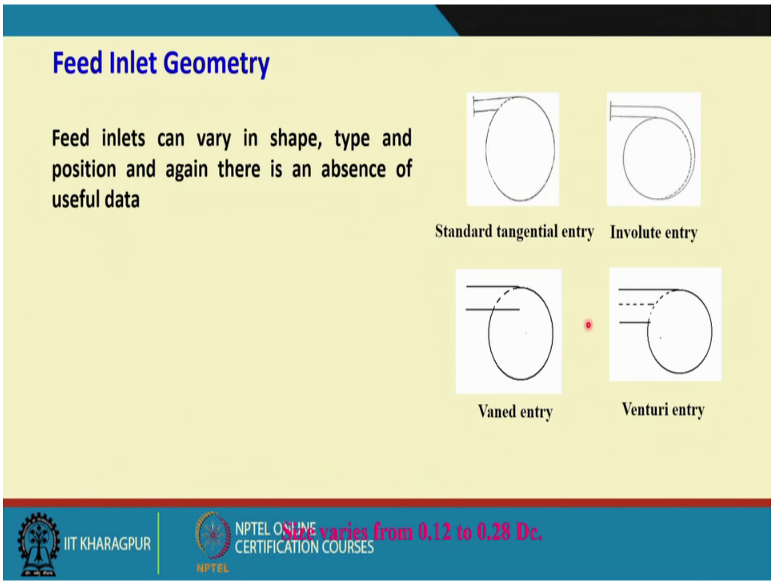

Now, feed inlet geometry. There could be many varieties of feed inlet geometry again these are again the say patented your say design features of many cyclone manufacturers. Feed inlet us can vary in shape type and position and again there is an absence of useful data not much research has been done in the which is in public domain, most of this research was done by the equivalent manufacturers and they want to protect their your intellectual say findings you know the intellectual resources they do not want to disclose it in the public domain.

But look at it could be a standard tangential entry that is the most of the cyclones they use this type of entry that is your entry could be tangential. Now, there could be involute entry. Now, some of the well known manufacture they are using this that is your involute entry. So, that is your spiraling action. So, what is happening? In this case of standard the tangential entry the fluid and the slurry is directly hitting the opposite wall and this wall is prone to much more weir.

So, even the kinetic energy of these is being dampened because it is directly hitting the wall. Now, here if I have a spiraling action the weir is less and there is you are you have reduced the dampening effect because of the spiraling motion of that. So, with the same flow rate you can have generation of more in situ of centrifugal force because of this involute entry and that is what is being claimed by different manufacturer. There are also other types like vaned entry and venturi entry they are not that preferred design because of many say manufacturing related issues. So, they are not that popular. So, these two are very popular that is your tangential and involute entry for cyclone manufacturers.

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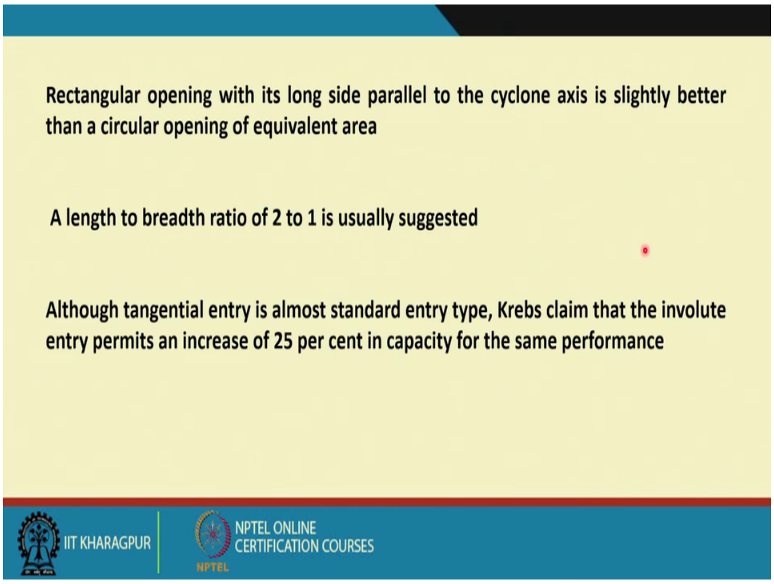

Rectangular opening with his long side parallel to cyclone axis is slightly better than a circular opening of equivalent area that is when it is inlet. Now, whether you have got a circular opening at the point of discharge into the cyclone or you should have a rectangular opening that is also another your design variable. But it has been observed that your rectangular opening with is long side parallel to the cyclone axis that is here it is like this rectangular opening and it is parallel to the cyclone axis is slightly better than a circular opening that has been claimed by many equipment manufactures.

A length to breadth ratio of 2 to 1 is usually suggested that what should be the length of the entire cyclone that is your 2 to 1 is usually suggested. Although tangential entry that is your for your rectangular opening that length to breadth ratios could be 2 to 1 that I can have your say square opening or rectangular opening. Although tangential entry is almost standard entry type Krebs claim that that is one of the your largest manufacturers of this cyclone and. Now, they have been taken away by another company. So, the Krebs claim that the involute entry permits an increase of 25 percent in capacity for the same performance; But you have to check it that for your application which one is better.

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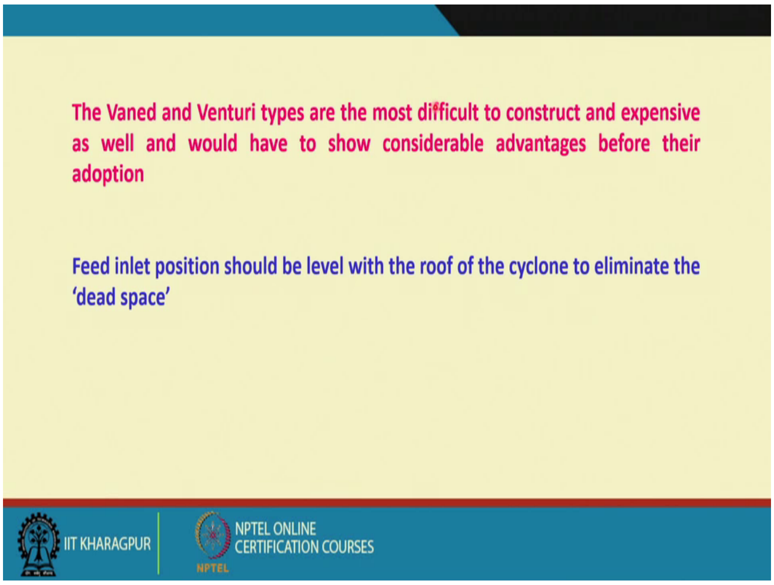

So, the Vaned and Venturi types are the most difficult type to construct and expensive as well and would have to so, considerable advantages before their adoption. So, they are not that popular yet, but people have tried.

Feed inlet positions would be level with the roof of the cyclone to eliminate the date space; that means, these are all very technical details you do not have to worry much about this.

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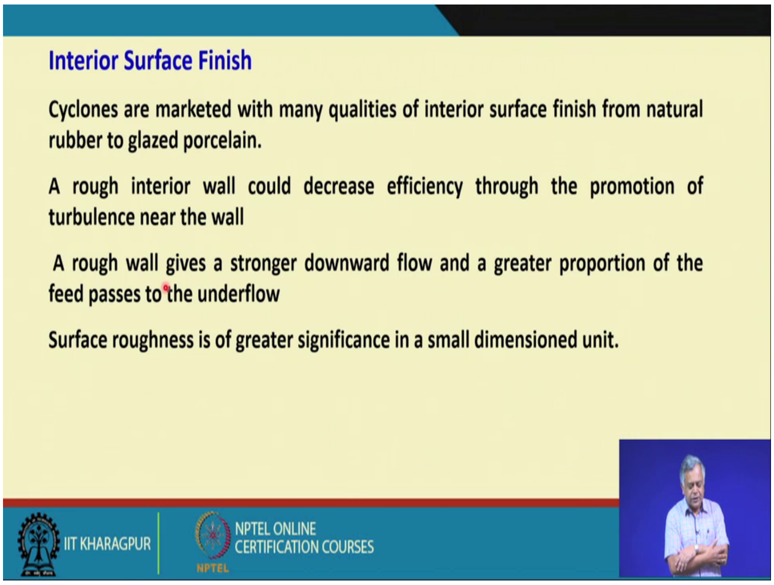

Now, interior surface finish. Why it is important? Now, cyclones are marketed with many qualities of interior surface finish from natural rubber to glazed porcelain. Well you see that, if I know my material is abrasive. So, your cyclone life will be very less. So, it is not the not only the replacement cost of cyclone, cyclone does not cost you much, but if you remember that it is used that it is basically a linkage between your combination and your processing circuit, so is the downtime cost. So, the cyclone manufacturer the plant people they want more life of their cyclone because the downtime cost is much higher that is the replacement cost not only the material cost equipment cost is the downtime cost.

So, for that when you are using normally the mine oats they are abrasive in nature. So, many times the natural rubber or glazed porcelains are being used as an internal surface finish and also a rougher interior wall could decrease efficiency through the promotion of turbulence near the wall because if I have rough surfaces, because of surface roughness I will have much more turbulence inside by cyclone and this turbulence will interfere with the proper separation of my particles based on their relative settling velocity differences.

A rough wall gives a stronger downward flow and a greater proportion of the feed passes to the underflow and also what is not mentioned a rougher wall will dampen much of my your kinetic energy. So, it will have a reduced centrifugal force and much of my feed material will pass through the underflow. Surface roughness is of greater significance in a small dimension unit when you have a small dimension unit you are trying to generate much more centrifugal force if you have a rougher surface you are dampening this your say centrifugal force parameter, but you need to generate that. So, it will have adverse effect on your separation performance.

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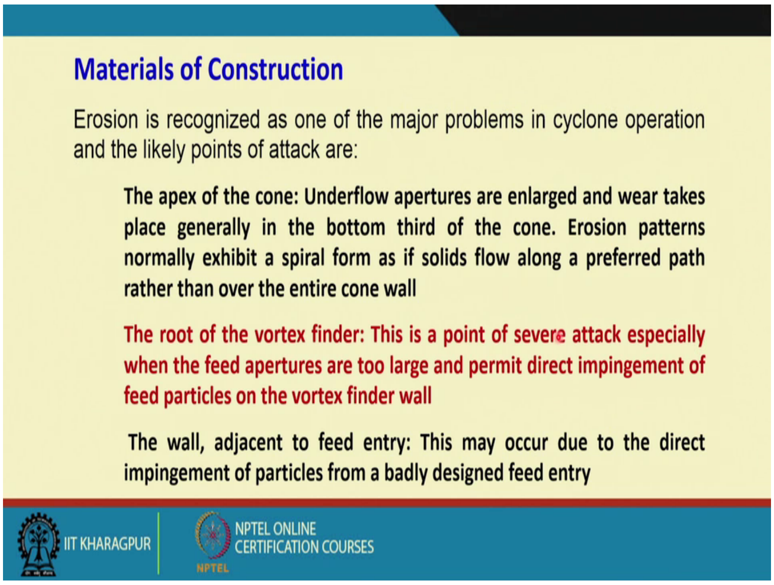

Similarly materials construction, materials of construction that is erosion as I said that the apex of the cone is the more we are prone zone, so that is your spigots. Now, many manufacturers they are coming with this idea that we will have a different material for my epics than the cyclone the remaining portion of the cyclone.

So, this will have enhanced life of the epics. So, I can have your lesser maintenance related issues and my downtime cost also will be less significant. The vortex finder a route that is when it is inside even that is also more where prone zone. So, there is a point of severe attack especially when the feed apertures are too large and permit direct impingement of heat particles on the vortex finder wall; that means, when you are dealing with relatively coarser particles this particle will heat that your tip of that vortex finder and then it may result in to erosion of that.

The wall adjacent to feed entry I have already discussed it and this may occur due to the direct impingement of the particles. So, for a badly designed feed entry if your feed entry is not properly designed. So, they will directly hit the opposite wall and that will create problem. So, if you have that type of design maybe you have to have a better material for the entire cyclone body.

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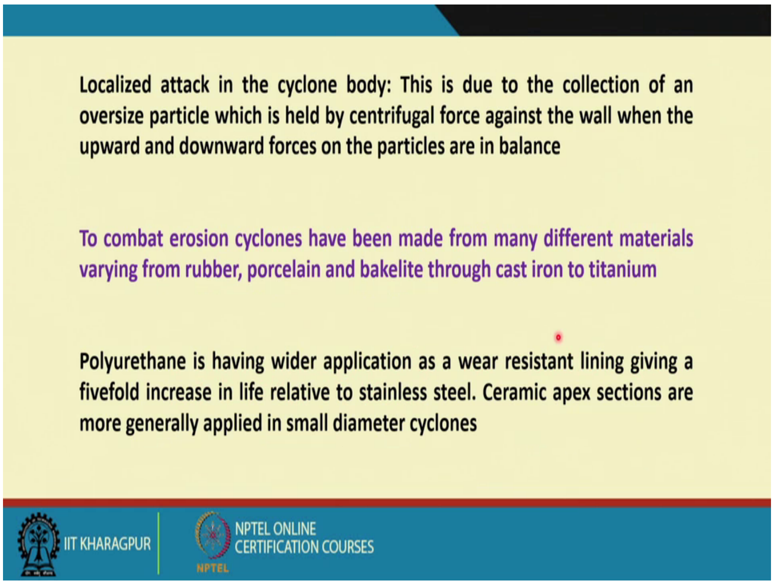

Localized attack in the cyclone body that is this is due to the collection of an oversize particle which is held by centrifugal force against the wall when the upward and downward forces on the particles are in balance. So, there could be localized attack in many places and main problem is the erosion. So, you have to select your materials. So, these days the many manufacturers almost all the manufacturers they are coming up with this your cyclones made of rubber, may be porcelain, may be bakelite or maybe through cast iron to titanium. So, that is you have your structure is with the cast iron or maybe with the titanium and inside you have got a rubber or porcelain or bakelite depending on your relative abrasivity of your material which you try to process.

Polyurethane is also having wider application as a weir resisted lining giving a pipe old increase in life relative to stainless steel. So, these days the modern cyclone manufacture the modern cyclones they are made of mostly poly urethanes because they give more life to your cyclone in relation to even stainless steel.

Ceramic epic sections are more generally applied in small diameter cyclones see that ceramic is basically abrasion resistance material and that is you are using it for small diameter cyclone you are using a ceramic material only for the epics because it will cost you much because the machining and your giving that shape is will cost you much.

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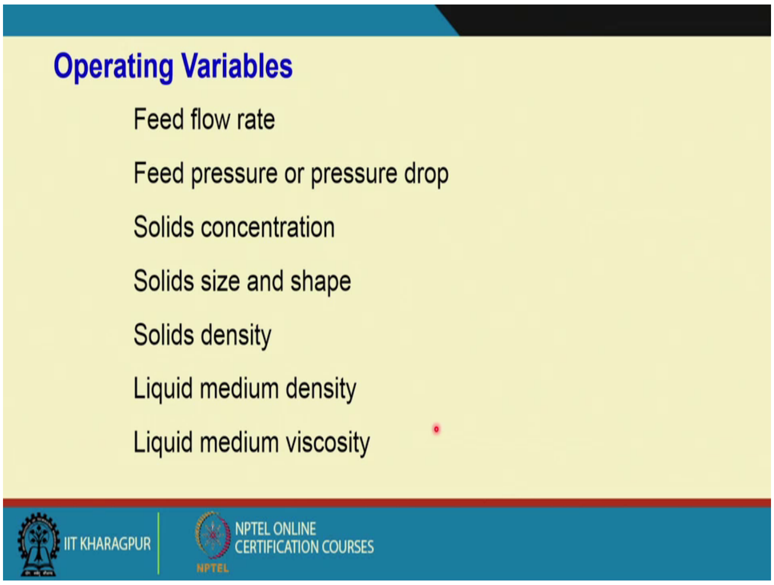

Now, you have got operating variables as well. So, we have discussed about the design variables we have got operating variables like your feed flow rate feed pressure or maybe the pressure drop then solids concentration, how much is the feed solid concentration, solid size and say what is the whether your particles are all flaky in nature or whether they are spherical in nature or they are angular in nature. So, solid size and shape they what is their size distribution, what sizes, then solids density, what is that density of your solid particles then liquid medium density that is even the water when you use many times we use the recycled water.

So, recycled water may have some suspended solids. So, that liquid medium density also may be different than your density of your water then naturally when you have a liquid medium density more than your water density; that means, you have got some suspended fine particles and naturally your liquid medium viscosity will also start playing a role and even your liquid medium density and viscosity depends on the temperature.

So, the same separation if you have done it in extreme cold weather and in the extreme summer condition you may have different your say result or the different performance of the same cyclone and the same identical operating conditions because the temperature has changed the density and viscosity of your water. So, please do remember that you should monitor all this, and I will try to explain in the next lecture that how these variables operating variables affect your performance. And then when we summarize I will try to come back to this your design variables again. I will try to explain that what will happen if I my vortex finder is bigger than what is required if my apex is more than what is required and I will try to think of that that is on your own based on the explanation I have given and that how a cyclone works.

So, till the next class I would request you to think of that how this operating variables and design variables you think that will affect the performance based on the your conceptual explanation I have given on the separation mechanism or particles inside a hydro cyclone.

Till then, thank you very much.