INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL

NPTEL ONLINE CERTIFICATION COURSE

Unit Operations of Particulate Matter

Lec-02
Sedimentation and Design of Thickener (Part-1)

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Welcome to the second session of week 1, and this session includes sedimentation and design of thickener. Now this particular session considers two lectures, first lecture we will speak about the sedimentation and in design of thickener we will discuss the diameter, how to calculate the diameter of the thickener. In second lecture of this session we will speak about how to calculate height of the thickener, and we will illustrate design of the thickener through few examples. So let us start the first lecture of this session that is lecture 2 of week 1.

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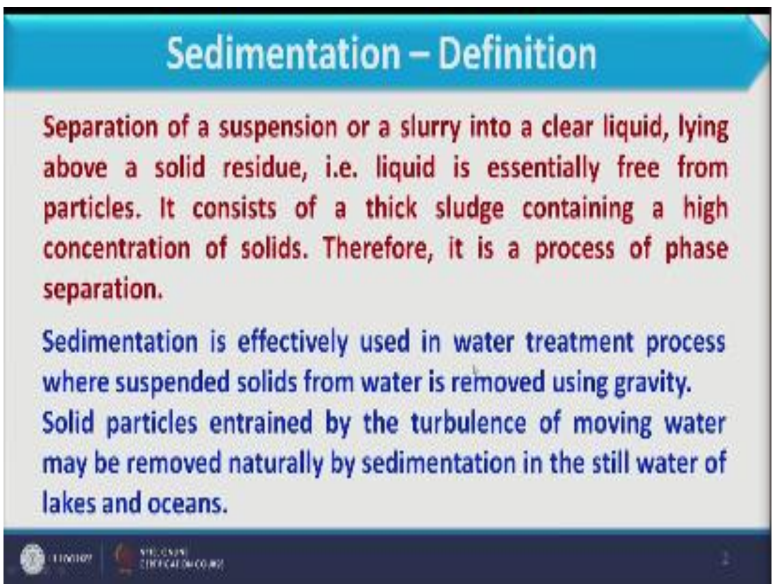

So in this particular lecture we will define the sedimentation and we will see how sedimentation process proceeds. So first of all the definition of sedimentation that is the separation of a suspension or a slurry into a clear liquid, lying above a solid residue, that is liquid is essentially free from particles. It consists of a thick sludge containing a high concentration of solids. Therefore, it is a process of phase separation.

Now as far as sedimentation is concerned this is the definition where we want to have the clarified liquid from the slurry or thick sludge from the slurry. If we want to obtain that we go for the sedimentation process. So as far as sedimentation is concerned that is nothing but the phase separation process where we get the clarified liquid as well as thick sludge and the feed in this case would be the slurry or the solution.

So sedimentation is effectively used in water treatment process where suspended solids from water is removed using gravity. Solid particles entrained by the turbulence of moving water may be removed naturally by sedimentation in the still water of lakes and oceans. Now what is the meaning of this, that when we consider the moving water whatever solids are available in that, that remains at the suspended position.

However, when we consider a still water, when water is not movable, what happens the solid particles which are available in the slurry that starts settling down and we can get the thick sludge as well as the clarified liquid as the product. So that is nothing but the sedimentation, so one thing you have understood over here that sedimentation proceeds when solution is available at quite still position, it should not be movable.

So we have to collect the liquid in some container and then let it settle, let it rest for sometime particle will be settle down and then we can get the thick sludge and clarify it liquid. So here we have to consider the liquid which we are considering the solution which we are considering that should be at quite still position. Why I am using quite because we are using the sedimentation process for continuous operation.

So in continuous operation also we tried to have least turbulence during the operation that is why I have used the word, it should be quite still, not a still.

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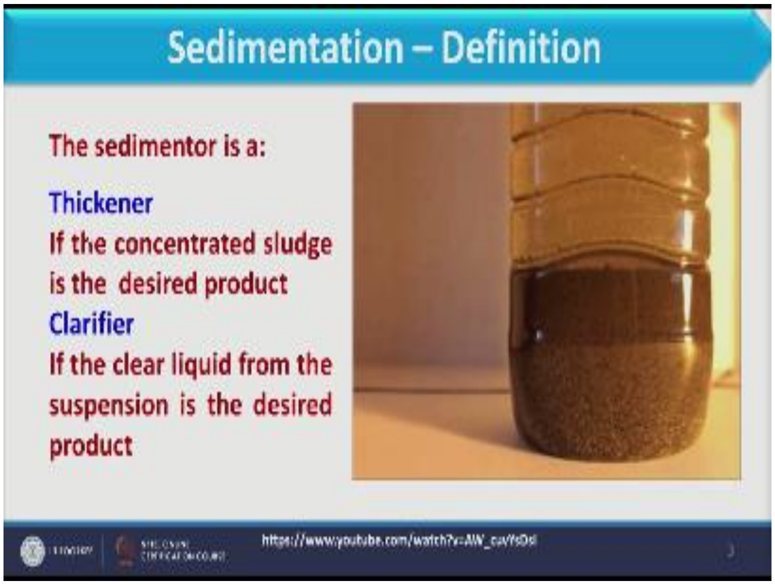

Therefore, if you consider this particular diagram figure here what is appearing is one bottle where we have put the slurry and that slurry is completely mixed with the solid as well as solvent. So this slurry we have put over here and we rest it for some time and then after that we can get the particles at bottom. So if you consider the bottom a most section of the bottle that is we have the solid, we have slightly larger particle in comparison to above layer.

And at the top of this we have the clarified liquid, so that is the sedimentation process where slurry is allowed to remain at a still position for some time and then we have the product of this. So when we consider this particular process here we have two product, first is the thick sludge, and second is the clarified liquid. So a sedimentor is a thickener, if concentrated sludge is the desired product and it is clarifier if clear liquid from the suspension is the desired product.

So here we have two product from the same operation first is the thick sludge and second is the clarified liquid. If you want to see it in detail you can visit this sight. So through this diagram we can have the idea what is the sedimentation. Now we will see its application. The application of sedimentation is again to have clarified liquid and the sludge.

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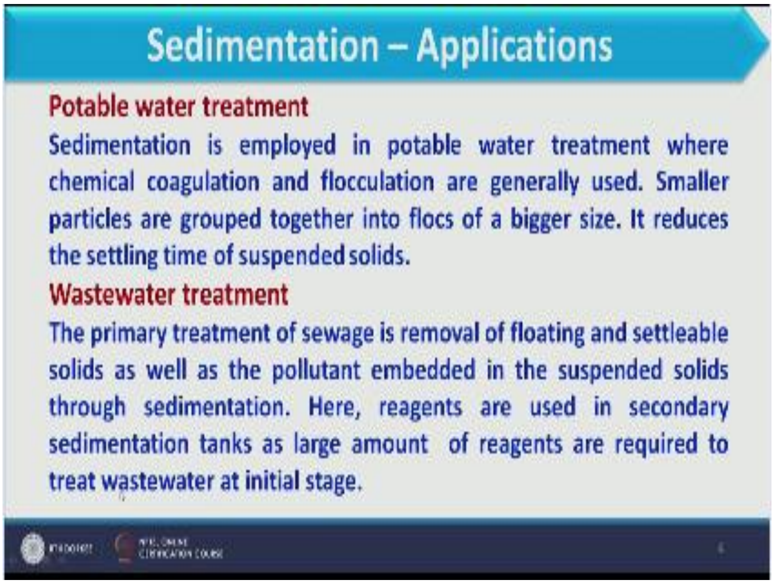

So it will be used in portable water treatment plant where sedimentation is employed in portable water treatment where chemical coagulation and flocculation are generally used. Smaller particles are grouped together into flocs of a bigger size. It reduces the settling time of suspended solids. Now in this statement what we have understood is when we are considering a smaller particle they coagulumerates or they join to each other and make a floc instead of this much particle we can have the particle of bigger size, because many smaller particles are joined to each other.

Now why they join, because we add some of the additives into this for this coagulumeration process and flocculation process, so they prepare the floc and because it becomes of higher size it will have higher mass, so more mg will be applicable over here, so it will be settled faster in comparison to smaller size. So it is used in portable water treatment and it is also used in waste water treatment plant.

The primary treatment of sewage is removal of floating and settleable solid as well as the pollutants embedded in the suspended solids through sedimentation, so the floating and settleable product solids are the pollutant which are available in the solution that are separated thought sedimentation, so here regions are used in secondary sedimentation tank as large amount of reagents are required to treat wastewater at initial stage.

Now hats I the meaning of this at time based stage we use we let the slurry settle itself we do not add additives because waste water treatment plants are huge in size so they will require more amount of regents also. So first it will settle in itself then we go for the secondary sedimentation process where the amount would be silently reduced then the initial stage and then we use the reagents over here for further separation.

So it is used in portable water treatment as well as waste water treatment plant, now as for a sedimentation is concern what is the advantage of this it as excellent reproducibility it means it regenerates clear liquid as well as think slug.

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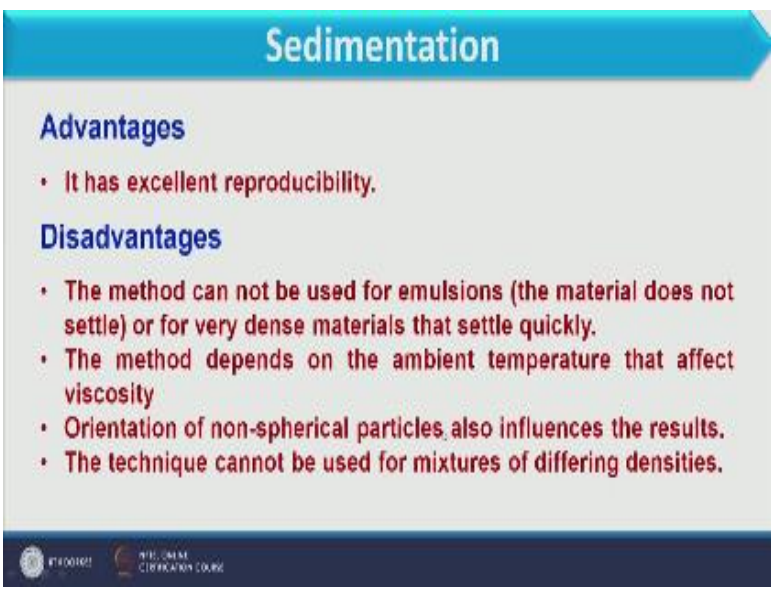

In a proper way disadvantages of sedimentation the first is the method cannot be used for emulsions the material does not settle or for very dense material that settle quickly so here it is also not use for the material would not settle and which are settle very fast they also cannot be separated by this sedimentation so it is not used for emulsion as well as very high density material.

Second disadvantage is the method depends on the ambient temperature that affect viscosity, so that is the disadvantage because usually the sedimentary are open tank equipment they are open to the environment so when the temperature reduces in winters viscosity of the solution will increase and it will not allow the particle to settle faster, so obviously it will be affected by the weather and the temperature outside and therefore that is the disadvantage that if we are considering this for faster in summer we have the sufficient we have satisfactory performance but in winters we do not have.

Orientation of non spherical particles also influences the result yes here we have the orientation of the particle it means when any particle as different shape let us say it is it has the needle kind of so it when it will fall it will lie in the at water surface it will be at floating condition but when it will fall in this condition it will settle down so orientation will definitely affect the settling of the particle and thus the sedimentation.

Another disadvantage is the technique cannot be used for mixtures of different densities so this technique will be used for homogenous material if we want to separate for different densities then they can also be they cannot settle layer by layer, so that is when we considering the mixture it will be in slug in we have the picture not layer by layer separation of different density material so it cannot be used for that purpose because it will settle together.

So you can understand why it is so because when we are considering densities of different material for example one is having higher density one is having lower density but if the particle which as lower density if it has higher size it will settle faster and if the material is having higher density and the size is very small it will be settle after the large particle of a smaller density, so that the slug we whatever slug we obtain that would be the mixture of different material not layer by layer material we can obtain through this sedimentation process. So that is the disadvantage of this now factors which influence the sedimentation process.

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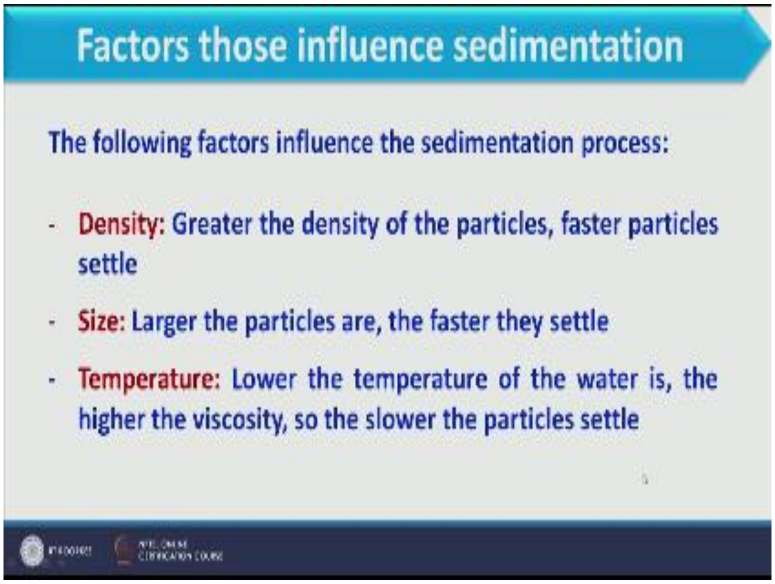

The first one is the density greater the density of the particle faster particles settle so obviously the density will be a factor along with the size so when density of the material will be high it will settle faster but if it has the size different sizes so that will can obtain as a mixture but obviously we can have the idea like if it as the higher density and two particle is having same size one is having higher density one is having lower densities so obviously higher density particle will settle faster.

Size larger the particle faster they settle that we have already discuss that if practice size is higher we can have more mass in that MG will be applicable more in that so it will be settle faster. Temperature lower the temperature of the water higher the viscosity so lower the particles settled, so here we have in the previous slide we have discussed the effect of weather on the sedimentation in winter it is settle slowly in comparison to summer now why it is so because that is it as the effect of the temperature when win summer we have higher temperature viscosity will be less particle will settle faster however when temperature is low in winter viscosity would be higher and the settling will be slower.

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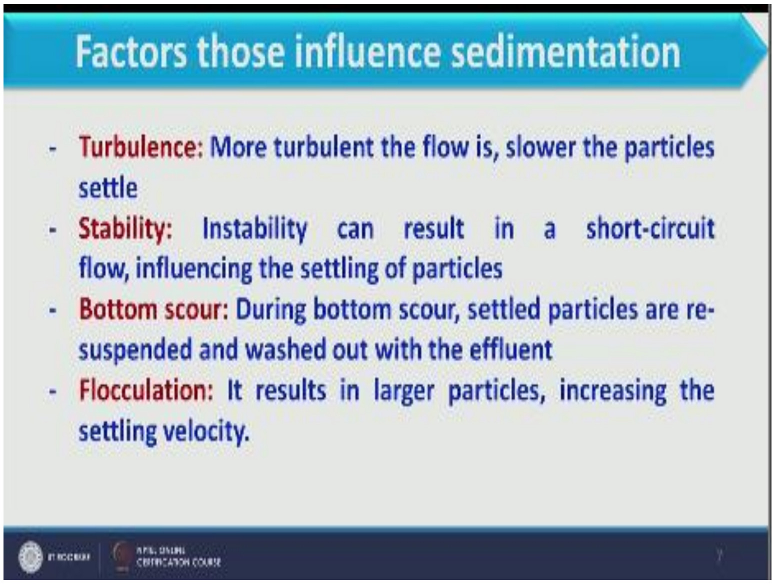

Now another factor is the turbulence more turbulent the flow is slower the particles settle turbulence affect the settlement of the particles greatly because when stream will be moveable the particle which are available in that it will move with this it will not have sufficient time to settle it will move the particle if it will move with fluid so turbulence is not required turbulence is not desirable as far as sedimentation is concerned stability.

In stability can result in short circuit flow influencing the settling of particle so here we made the stability in settlement of the particle next factor is bottom scour during bottom scour settle particle are re-suspended and washed out with the influent now what is bottom source is scour is basically the sludge is sludge available and the bottom of the tank so when we clean this it will be taken out it will be suspended and washed out with the influent flocculation it results in larger particles and thus it is increasing.

The settling velocity so flocculation will increase the size of the particle and this the settlement of the particle will be faster as we have discussed in portable water treatment system so these are the few factor which affect the sedimentation process.

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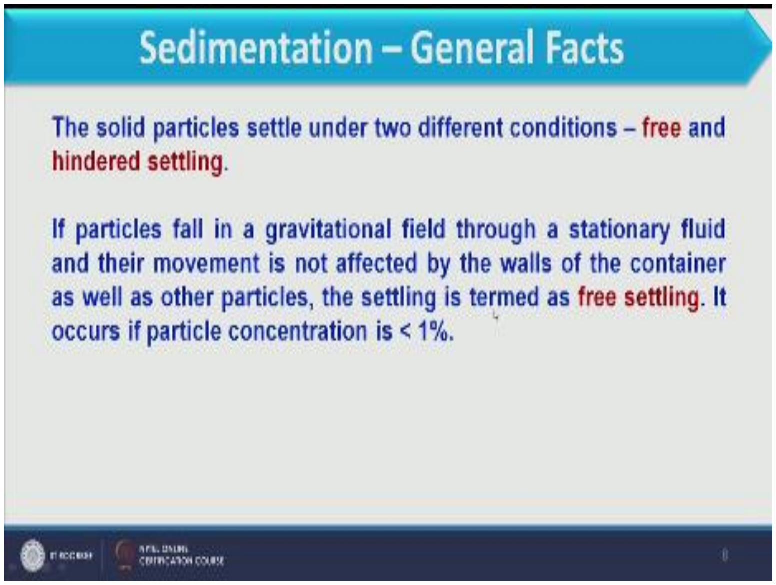

Now here we have the sedimentation general facts the solid particles settle under two different condition the free as well as in their settling so when the particle will be settle in the sedimentation here we have two condition first is free settling and second is hinder settling free settling is basically if a particle falls particle is available in the solution and it will settle it will not affected by the movement of other particle or by the availability of the wall of the tank so it will not affected by other circumstances it settle on it is own flow.

On it is own velocity therefore if the particle falls in a gravitational field through a stationary fluid and their movement is not affected by the walls of the container as well as other particle the settling is termed as free settling so when it settled with it is own velocity without affecting b other factor we can call this as the free settling. Now free settling occurs when the concentration of the solution is less than 1% so when the concentration is increased it means more particle is available in the solution.

So it will be definitely affected by the movement or of other particle as well as the wall so there we called as the hinder settling because the movement of particle is affected by the movement of other particles so free settling as well as settling hinder settling both will occur in sedimentation.

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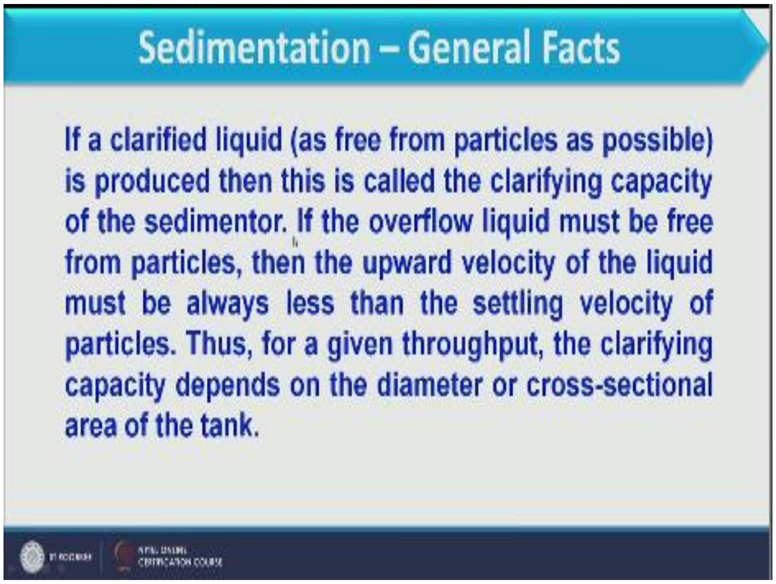

So here we have another fact that if a clarify liquid that is the liquid as free from the particles as possible is produced then this is called the clarifying capacity of the sedimentar it means when we have clear liquid which is free from the solid as much as possible we can call it the clarifying capacity of the sedimentar if over flow liquid must be free from the particles then the upward velocity of the liquid must be always less than the settling velocity of the particles and thus for a given through put the clarifying.

Capacity depends on the diameter or cross section area of the tank now what is the meaning of this particular statement that when we need the clarified liquid it capacity will depend on the diameter of the tank no why it is so because when we have the solution in the big in the sufficient diameter or sufficient cross sectional area tank what it will happen the particle will start settling down and what particle will start settling down with more velocity and liquid which is coming up is with is having them.

Is having lesser velocity then the particle otherwise what will happen particle will take the liquid will take particle with itself and it will remain suspended so when we provide larger cross sectional area the fluid which is entering into this it is a velocity will reduces then the velocity by which it is entering so when it comes to the sufficient cross sectional area it the velocity of particle which is moving in this direction that will be slower down.

So it will start settling down with faster rate and liquid which is penetrate through these particle it will have lesser velocity so what will happen the particle will settle in a lesser time and we have clarified liquid so it all depends on the diameter a cross sectional area of the tank. So if you want to get the clarified liquid diameter is the main concern that is the conclusion of the statement.

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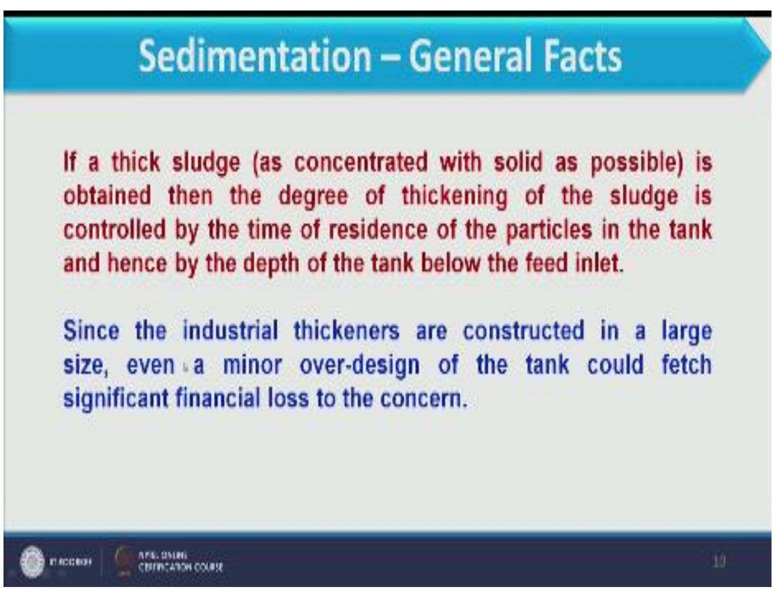

Secondly if a thick sludge as concentrated with solid as possible is obtained then the degree of thickening of the sludge is controlled by the time of residence of the particles in the tank and hence by the depth of the tank below the feed inlet now when we obtained the thick sludge what will happen and the particle will have to stay in the tank for sufficient time it means when we consider when we start collecting the sludge it should not be a very initiate then the feed is entering some time is required.

So when we need thick sludge height is the main concern of the thick of the thickener so as for as sedimentation is concerned there are two design factor first is it is diameter on which clarified liquid capacity depends and the thick sludge capacity the thick sludge production capacity will depend upon the height of the tank so since the industrial thickness are constructed in large size even a minor over design of the tank could fetch significant financial losses to the concerned so in subsequence slide you will see the diameter of the tank is very high sometimes it is 150m also so if we are provide the such high diameter tank height should also be a factor in this.

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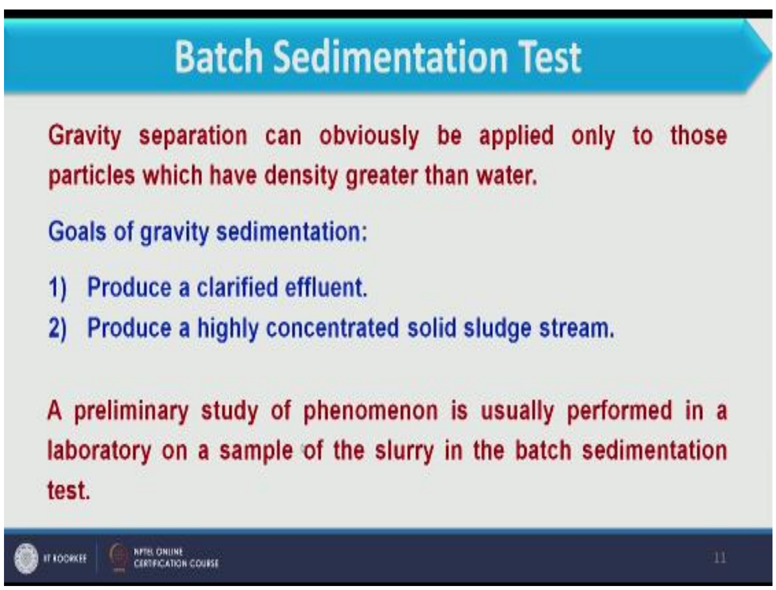

So in subsequent slide you will see the diameter of the tank is very high some time it is 150 m also so if we are providing such high diameter height should also be a factor in this so what will happen, though it has high as it size is too large even if we little bit over design the tank the financial loss will be significant, so we have to design the sedimental very carefully. Now here we have the bad sedimentation test.

Gravity separation can obviously be applied to those particles which have density greater than the water so that is the primary requirement that we can have the settlement of the solid when it has density more than the water otherwise it will remain suspended, so gaol of the gravity sedimentation is, first is to produce the clarified effluent and second is produce a highly concentrated solid sludge stream.

A preliminary study of phenomena is usually performed in laboratory on a sample of slurry in the batch sedimentation test, so here we are going to discuss what is batch sedimentation test, now before this we should understand why we need this batch sedimentation test as I have already told you this is the continuous process so we are not going to design directly the continuous system.

First we will speak about first we will consider the batch sedimentation test we will carry out batch sedimentation that test and we will transpose this data to design the continues system, now why it is so, because when we consider the sedimentation process what is the whole process is, when we consider one the tank and from where from one side feed is entering and particle is start settling down.

Now at initial stage what will happen as the particle is as spread continuously throughout the surface it has they are quite apart from each other, so they will start settle faster but as far as they move down they can be affected by the flow of other particle velocity of other particle or presence of other particle and they will acquire and they will face more and more inherence, so one we carry a out the sedimentation process.

Initially it is faster and after that it slows down so that we can understand that it is nothing but the time dependent process and many other thing happens like if larger particles come over their smaller particles it takes their smaller particle by its velocity not the velocity of their smaller particle, so there are many complications which appears during the operation of the sedimentation.

Therefore initially we will do the sedimentation process at batch level where we consider the same slurry which we for which we have to design the continuous system so to design the continuous system for the slurry first we have to carry out batch sedimentation test using that slurry.

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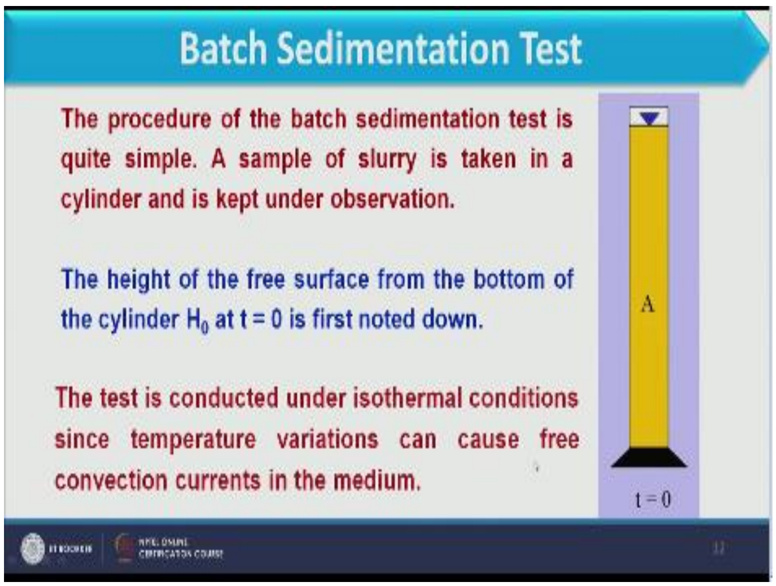

Now the procedure of batch sedimentation test is, it is quite simple a sample of slurry is taken in a cylinder and is kept under observation that all that's all we have to do like we have to take the transparent glass in which we have to fill the slurry which is completely mixed in itself so what will happen, the we have observe the behavior which is carrying out in the glass cylinder. So if you see this figure.

And here we have the glass cylinder where we have put the sample of the slurry for which we have to design the continuous system and this slurry is completely mixed in it, it means there will not be settlement the settlement of the particle is not started at time t = 0 the complete concentration of this solution is homogenous. So the height of the free surface from the bottom or the cylinder H0 at time t = 0 is first noted down now.

What is $H_{0,}$ H_0 is the total height of the solution which is available in the glass cylinder so that should be H_0 at time t = 0. The test is conducted under isothermal condition since temperature variation can cause free convection current in the medium so here we have to carry out the whole process in isothermal condition now what is the process, the process is very simple.

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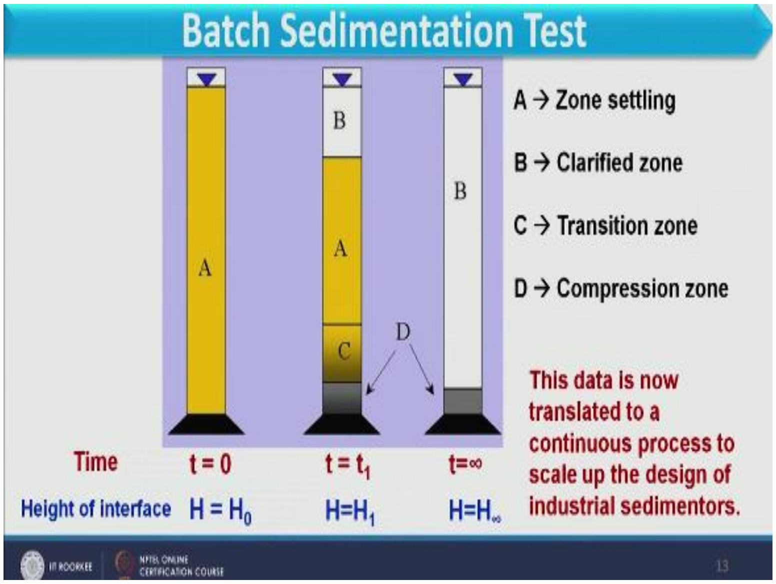

You consider this figure, in first figure we have this glass cylinder where homogenous solution is available upto height H = H_0 that we have already discussed now what we have to observe we have to observe the height of the clarified section, now what is clarified section? Once we have the homogenous mixture which is completely mixed in a glass cylinder when we keep it for sometime what will happen.

The solid which is available in this solid particle they start settling so total volume of the solution will remain same however the from the top we will see some clear water zone to be appear for and it will keep on it will be keep on moving the solid will keep on moving and we have more and more clear water zone, so after sometime we have few zone in the glass cylinder to observe that we have to take the glass cylinder.

Not cylinder which is not through which we cannot see so we have to take the glass cylinder always for this test. Now what happen after sometime we have four regions into this cylinder at the top we have the clarified zone that is clear liquid will appearing in this and below this we have the zone settling or we also called as thickening zone here in thickening zone the solution the concentration of the solution will be almost uniform.

Particle will settle but in this particular zone the concentration will be always will be almost uniform now below this we have a section we have section which we call as transition zone where the concentration varies significantly and at the bottom of the tank here we have the compression zone where the sludge is starts accumulating so here we have four zones among which the transition zone appears disappear quickly and after sometime we have only three zone that is the clarified zone, zone settling that is thickening zone and compression zone only three zone will be available.

And after sometime what will happen when we observe this three zone the height of the clarified zone will be increased and height of the clarified zone will be increased and similarly height of compression zone will be increased because more and more sludge will start accumulating in this section so this height compression zone height as well as clarified zone height it will increase however height of this thickening zone or zone settling will keep on decreasing.

So once it will this section the height of thickening zone will keep on decreasing after sometime one position, one situation appears where we have only two zone that is clarified zone as well as compression zone. Now the time at which this appear this two zone will appear or I say the time at which the thickening zone disappear that time we call as the critical sedimentation time, so at critical sedimentation time we have only two zones first is the clarified liquid zone and second we have the compression zone.

So after that what will happen the height of compression zone will further keep on decreasing because particle which are al particle which are available in the solution they have entered into the compression zone and they further start settling through Hindered, so that process is very slow but that height of compression zone will keep on decreasing. And similarly height of clarified zone will keep on increasing so that is nothing but the bad sedimentation test.

Now what we have to observe over here is time as well as height of interface which interface. The interface of thickening zone as well as clarified liquid zone that height we have to observe from the bottom after certain time, so at time t=0 though that interface will not available we will, we have to consider total height of the solution available in the cylinder so that e have denoted as H_0 at time proceed t_1 the height should be H_1 so that height is basically the height of this interface so at $t=t_1$ this is H_1 and similarly at $t=\infty$ we have $H=H_\infty$ which is nothing but the total height of the compression zone and it takes too much time to achieve this compression zone in height H_∞.

Now this data is translated into the continuous process to scale up the design of industrial sedimentor, so you can understand that this experiment we have performed with the given slurry and this data is now transpose into the continuous system where that slurry will be use for continuous sedimentation process.

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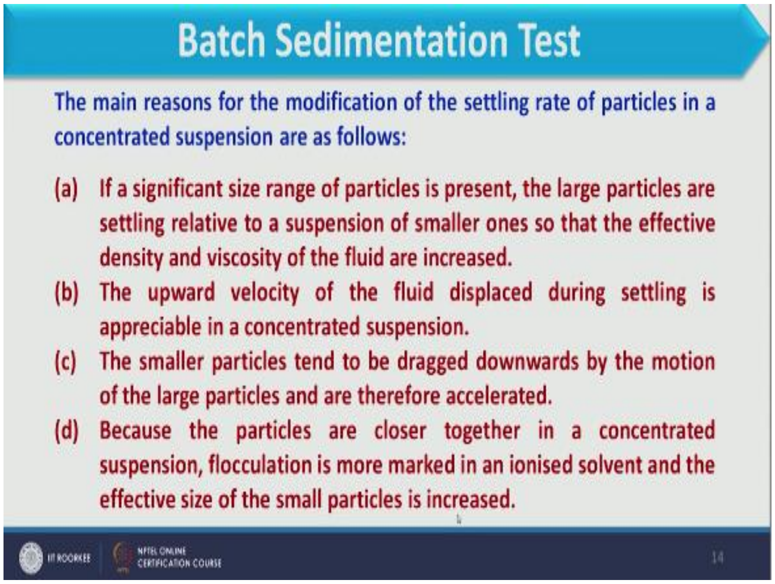

So the main reasons for the modification of settling rate of particle is, so the main reason for modification of settling rate of the particles in concentrated suspension are, the first reason is if a significant size range of the particles is present the large particles are settling relative to a suspension of a smaller once so that the effective density and viscosity of the fluids are increased. So here we have one reason for this settlement that larger particle will settle faster in comparison to smaller one and that is quite obvious also.

So once it will be carried out the density and viscosity of the fluid increased which fluid which is settling not the clarified zone, so upper velocity of the fluid displaces during settling is appreciable in the concentrated sludge, a concentrated suspension. The smaller particles tend to be dragged down by motion of the larger particles and are therefore accelerated this we have already discussed and finally the reason is for the settlement is because of particles are closer together in a concentrated suspension, flocculation is more marked in an ionized solvent and the effective size of the smaller particle is increased.

And therefore the settlement will be faster so these are few reasons why which are mainly affected for the settlement mainly affected by the particle and which are responsible also for the settlement of the particle.

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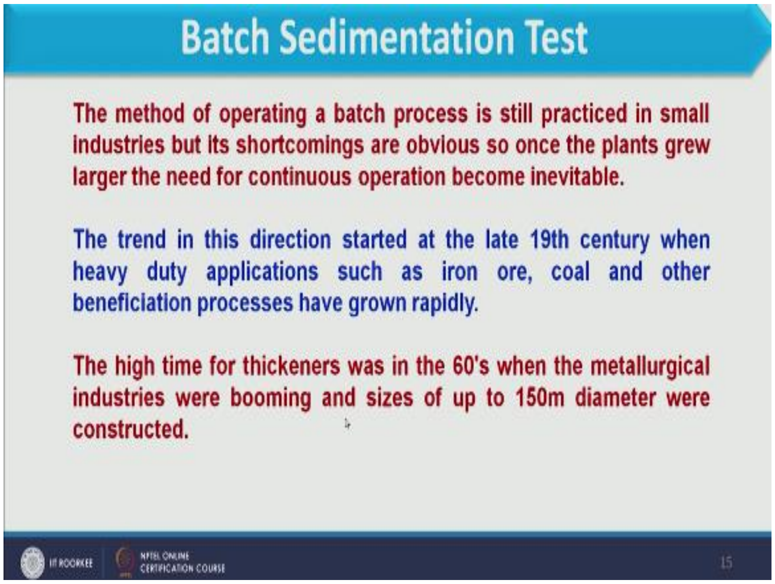

Now the method of operating a batch process is still practiced in small industry but it shortcomings are obvious so once the plants grew larger the need for continuous operation becomes inevitable, so here we have already carried out the test at batch condition in some small industries batch process, batch sedimentation is used but for larger plant the continuous operation is required so we need the design, we have to design the thickener for continuous operation.

So the trend in this direction is started in the late 19^{th} century when heavy duty applications such as iron, ore, coal and other beneficiation processes have grown rapidly so here the design of continuous system is already started in 19^{th} century for beneficiation of coal and other minerals. The high time for thickeners was in the 60s when the metallurgical industries were booming and sizes of up to 150m diameter were constructed.

So here you can observe that we have the diameter of tank is 150 so such huge diameter of tank this one example only we have lesser size also but you can imagine the size larger of this so that therefore we have to design the thickener very carefully because slightly over designing of this will affect the will give the financial loses to the industry person. So if you see this particular figure.

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So if you see this particular figure here we have the in the study mentor which is huge in size so you can imagine the we have to design this very carefully.

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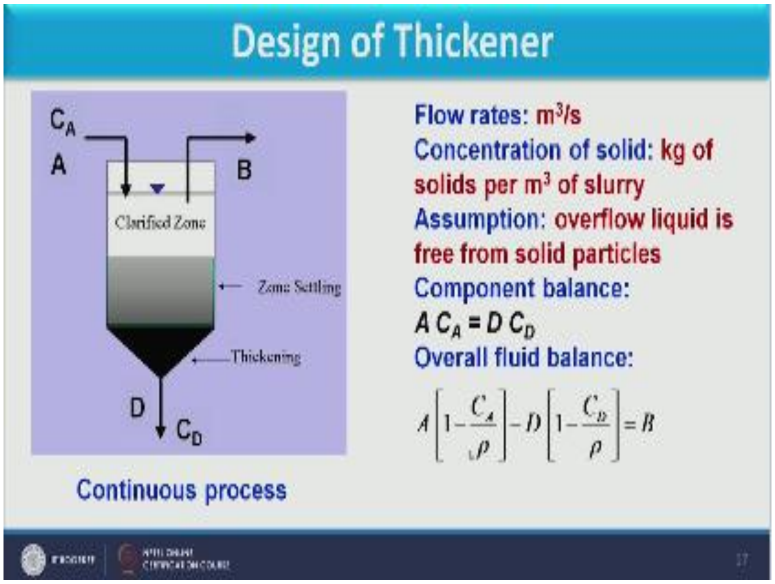

We cannot expect slightly over design thickener. Now as for a design of thickener is concerned we will go for the continuous operation so here we have the continuous process where here we have thickener where feed enter continuously and zones will be formed in between inside the tank and at the bottom we have thick sludge so that is taken out continuously. So here we have the inlet as florid volumetric florid A I will be concentration CA and sludge is taking out with the volumetric flow D with the contraction CD and we have the formation of clear liquid as B stream.

So B is almost free from the particles, so that is the continuous system where the bottom is slightly conical and that conical we have kept for a purpose of easy removal of easy collection of the sludge which is accumulated at the bottom. So here we have the parameters which will use for the governing equation for this design of the thickener and this parameter first is we have defined the flow rate in m3/s so that is all flow rates are volumetric flow rates.

A concentration of solid we have design as kg of solid per meter cube of slurry that is the unit of density also but that is kg solid per m3 of slurry. Assumption what assumption we have taken is the over flow liquid is free from the solid, so B does not contain any solid that we have assumed that is the clear liquid. Now make the balance over here first of all we go for the component balance in component balance what will happen if you see ACA = DCD it means volumetric flow of A x concentration of A that is CA = volumetric flow of under flow or we can called it outlet stream also.

And its concentrates CD because B is free from the solid it so B will not be consider in component balance. Further overall fluid balance we have taken as A1- CA/ ρ – D 1 – CD / ρ = B, now as for as fluid is concerned B is completely free from the solid so that we have consider completely now what is A, A we have taken as 1 – CA/ ρ now what is this 1 – C now what is this CA / ρ, CA is the concentration of inlet feed and ρ is the density of solid.

So when we consider this two that would nothing but the fraction of solid so 1 – fraction of solid when we are considering that should be the fraction of liquid so therefore that fraction of liquid is multiplied with A. and similarly D is multiplied with 1 – CD / ρ, so that is the fluid balance where ρ is the density of the solid. Now from above equation that is from component balance.

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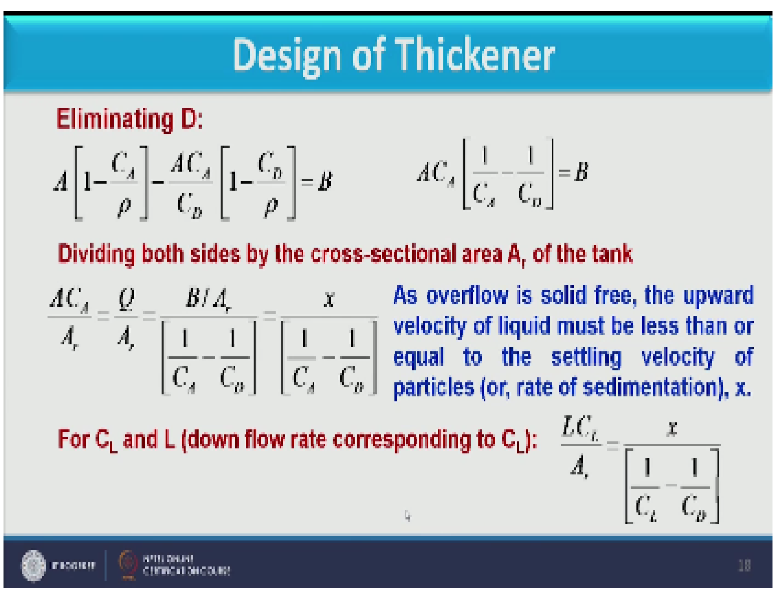

And in overall balance in overall balance we will remove we will eliminate D from the component balance and after rearranging this we have this equation ACA 1/ CA – 1 / CD = B, now dividing both side of this equation by cross sectional area that is AR of the tank so ACA / AR, ACA is basically the mass flow rate of the feet that is Q. Now it is Q because if you consider this A its unit is it is volumetric flow meter cube per second and CA is basically the kg of solid per m3 of slurry.

So that should be the multiplication of this should be kg per seconds, so this Q is the mass flow rate of the feed divided by AR = B, B is available over here that is divided by AR and that whole is divided by 1/ CA – 1/ CD. Now this B/ AR B is what B is the clarified zone and B is the volumetric flow divided by cross sectional area of this so once we consider B/A that will be nothing but the velocity of the liquid clarified liquid which is moving upward.

So that we have denoted as X and that is nothing but the sedimentation velocity or settling velocity of the particle or rate of sedimentation. So here we have consider ACA/ AR = X / 1 / CA -1/ CD, now this equation is applicable when we have assume that the concentration inside the sedimentary and that is of outlet stream or underflow stream though concentration of these two should be equal.

However in sedimentor what happen the concentration inside the tank will continuously change therefore instead of considering the feed inlet feed and underflow we have to consider one layer where the concentration will almost be uniform so that we called as the capacity limiting layer. So ion that lay4er the flow is we have noted with capital L and the concentration of that layer is CL which is moving downward, so we can replace ACA/ AR with LCL / AR and that is X/ 1/ CL – 1/ CD. So this is the final equation for design of thickener, so this is the equation.

Where values of LCL/ A_r should be determined at different values of x CL and the minimum value LCL A_r will find maximum value of A_r which should be the thickener cross sectional area. Now what is the meaning of this that once we have to what we have to calculate from here is the cross sectional area and then only we will be able to calculate the diameter, so to calculate this we need we have two variations.

First is the variation of x and second is variation of CL because concentration the layer will be moving from upper to bottom so concentration of layer CL we keep on moving however the concentration of underflow will be constant so 2 variable x as well as CL. Now how I will find the value of x that is nothing but the sedimentation velocity. To calculate this x value we have to use the batch sedimentation test data.

So you can see this figure here we have batch sedimentation data which contains time as well as height that we have plot over here. Height of the interface and this section we have to we will consider that time all that we have to plot in this, so particular time at particular point we have to draw that engine and we have to see the velocity of that point and how I can calculate the velocity that is dh/dt.

So the slope of the tangent to the curve at any point are which is correspondent to t x tl gives the instant state of sedimentation and similarly we can calculate the velocity at different points while drawing the tangent over here and calculate dh/ dt value. So different velocity at time we can find from this.So x we have already find CL how I can determine

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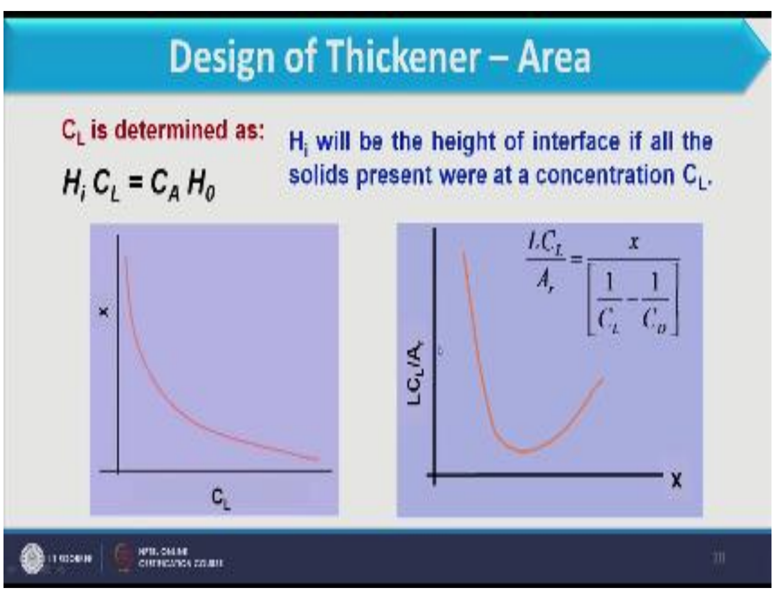

The relation is hi CL =ca h0. Where hi is the height of the interface if all the solids present were at a concentration CL. So how I can hi is hi we can find at any point if you see this figure we can hi at any point where I have drawn the tangent the where it will cut y axis that point we call as hi. So here we have drawn different value of x as well as CL. CL i can find by different hi value now once we draw this we can calculate Lc/ca.

Now lc/ca if you observe it has these covertures which are parabolic nature now how it will be affected. It has only 2 variables first variables is x and second variables is CL and we can understand once CL will be increased. What is CL is the concentration in that layer, so when this CL will increase the liquid which is moving through this it is velocity will be it is the rate of sedimentation keep on decreasing.

The velocity of CL near velocity will be keep on decreasing because presence of other particles. So what will happen at some point initial point x will dominate and if you see this CL that will come at the numerator also after here we can observe and consider as the multiplication of x as well as CL. So in some part x will dominate and in some part CL will dominate.

Therefore this parabolic kind of curve, so once we have drawn this curve the bottom most line in bottom most point will give the minimum value of Lc/ A_r. Now once I have the minimum value of LC_L / A_r from this we can find the maximum value of A_r that is the cross sectional area.

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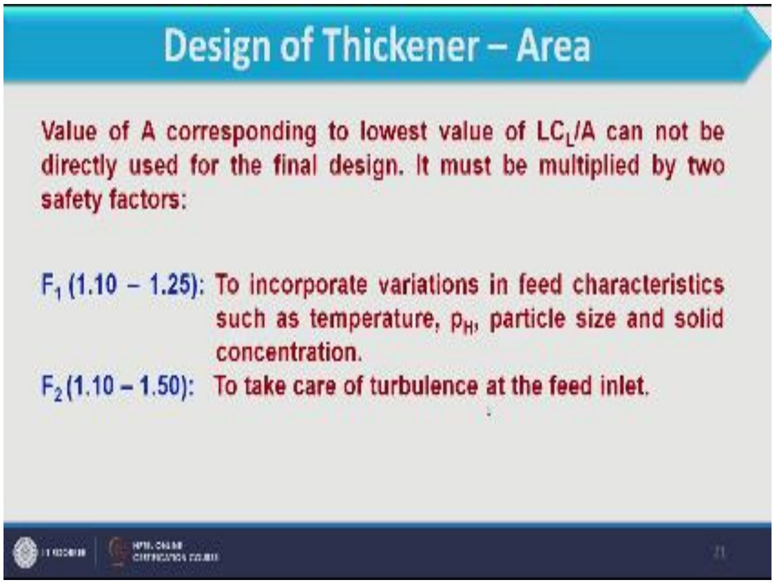

So value a corresponding to lowers value of LC_L / A_r cannot be directly used for the final design. It must be multiplied by two safety factors. So A we have already calculated that is nothing but A_r I should write over here A_r so A_r we can calculate by LC_L / A_r graph and it will be multiplied by two factors.

1st is F1 which varies from 1.1 to 1.25. It is used to incorporate various in feed characteristics such as temperature ph particles size and solid concentration and similarly the 2nd factor we have is F2 which moves from 1.1 to 1.5 and it takes care of the turbulence at the feed inlet. So here you see we have calculated we have derived a expression for cross sectional area and through which we can directly calculate the diameter of tank. So this section I have to stop over here we will consider the height of centimeter in next section. So that is all for now. Thank you.

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