Physico-Chemical Processes for Wastewater Treatment

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Lecture 23

Settling and Sedimentation – II

Good day everyone, and welcome to this lecture. We have started the settling section in the previous lecture and we studied that how to find out the terminal velocity in the discrete settling zone. And before that we studied the different types of settling zones which are possible so it may be discrete settling it may be hindered settling it may be other types of settling behaviors which are possible. So, we started with discrete settling and finding out the terminal velocity but because that helps in determining the ultimate velocity with which any particle having some particular density and of some particular size how it will settle down.

So, those things we determined in the previous lecture. So, in the settling that there are two important parameters that we come to know one is the what is the diameter of the particle that we are targeting to settle and separate out. And second thing is that what is the density of that particle that is also very important so some particles may be fluffy in nature some may be more denser in nature. So, more denser particles settle out very easily as compared to fluffy particles which have lesser density or otherwise.

Second thing is that what is the density of the liquid also that is important but most often since we are studying the wastewater treatment. So, the density of liquid will virtually be constant because in wastewater we generally consider only dilute solutions where some pollutants are present up to some dilute concentration so under those concentrations the wastewater may be taken as water and the density of water and viscosity of water is good enough for calculating further.

Now, there is lot of similarities there in settling in wastewater or water treatment with respect to other settling behaviors which are there or verification behavior which are there in particulate technologies. So, in many process and chemical industries these methods are used for separating out different particles having different density or different size. So, there is a lot of similarities there and those concepts are used in wastewater treatment or water treatment also. So, there is a separation of solid particles there are two basic methodologies are there, they may be classified as sizing or sorting.

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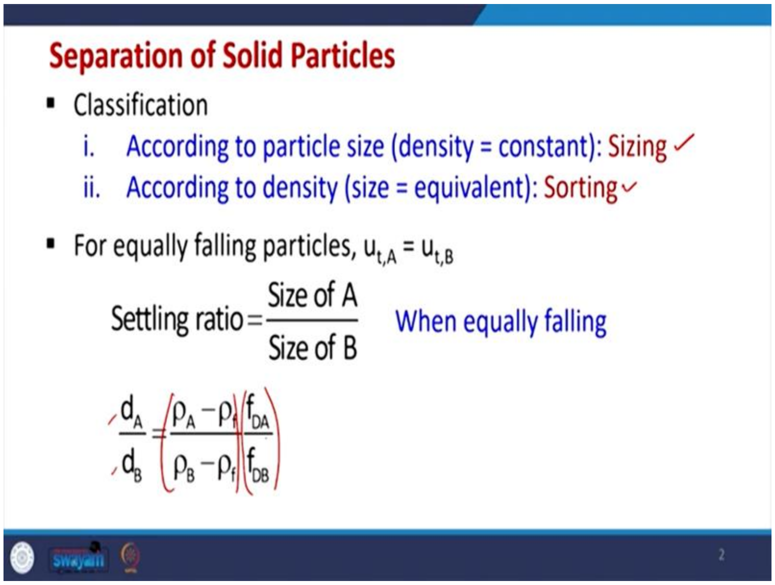
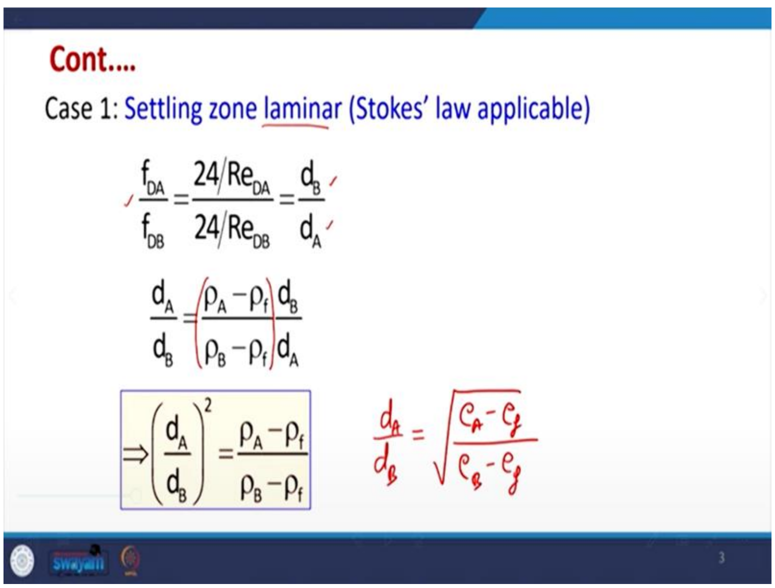


$$\frac{d_A}{d_B} = \frac{\rho_A - \rho_f}{\rho_B - \rho_f}\frac{f_{DA}}{f_{DB}}$$

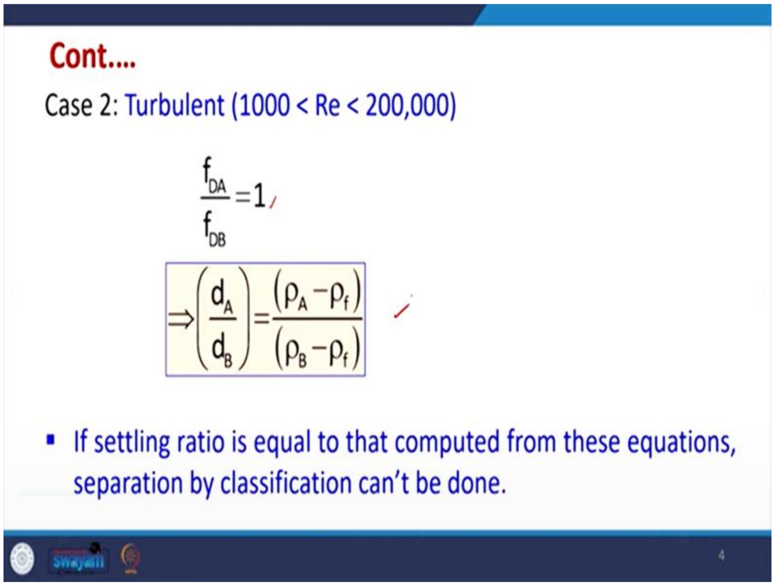


Settling zone laminar (Stokes' law applicable)

$$\frac{f_{DA}}{f_{DB}} = \frac{24/\mathrm{Re}_{DA}}{24/\mathrm{Re}_{DB}} = \frac{d_B}{d_A}$$

$$\frac{d_A}{d_B} = \frac{\rho_A - \rho_f}{\rho_B - \rho_f}\frac{d_B}{d_A}$$

$$\Rightarrow \left(\frac{d_A}{d_B}\right)^2 = \frac{\rho_A - \rho_f}{\rho_B - \rho_f}$$



Turbulent

$$\Rightarrow \left(\frac{d_A}{d_B}\right) = \frac{\left(\rho_A - \rho_f\right)}{\left(\rho_B - \rho_f\right)}$$

So, sizing is like where the density is constant but they have same particle size, so we have like some grains which are there and they have same particle size but they have density difference. So, those we can separate out using the method which is called as sizing. And similarly, it is possible to have a size is same but the density difference is there so under that condition we can still separate them out and they are called as sorting. So, both the methods these two methods are commonly used in the particulate separation methods and these methods can further be extended in the wastewater treatment also.

And how they work out little bit idea we can get from the terminal velocity equation that we calculated in the previous lecture. Now, if suppose we have two particles which are settling down at same terminal velocity somehow there may be a difference in the density or there may be a difference in the diameter but somehow there is they are settling down at the same rate. So, under those conditions if Ut a is equal to Ut b so under that condition settling ratio will be defined by size of a divided by size of b for equal falling.

And actually, if we go further will be finding that da by DB can be given by this particular equation. And where there is a frictional factor also that what is the frictional factor of particle a and what is the frictional factor of particle b. So, both density and frictional factors become very important. Now, under this condition these frictional factors they vary depending upon whether the settling is laminar or turbulent.

So, if we go for laminar suppose the settling zone is laminar so a stokes law region will be applicable and under that condition f DA by f DB can be given by this relationship. So, 24 divided by Reynolds number and that will be true and that can further be written like dB by dA. Now, if we substitute this f DA by f DB in this equation which is here like so we substitute dB by dA here. And so actually if we sort it out this become this particular equation comes out so we can sort it out still as per the diameter of both.

And it will be like rho a minus rho f ever rho is the density of the particle rho b is also density of particle b rho f is the density of the water or the fluid. So, in this wastewater case it will be for the water so this is there so this is one equation where settling zone is laminar. But suppose the settling zone is turbulent so under that condition f DA by f DB is 1. So, under that condition the this is directly proportional now we can see for the previous equation is plus under root in this case it will be not under root it is directly so relationship is little different.

So, if the settling ratio is equal to that compound from this equation separation by classification cannot be done. So, if somehow, we are finding that the settling ratio is equal to that compound for these equations if we find that ok these are exactly same so it may not be possible we will understand it little later more in detail.

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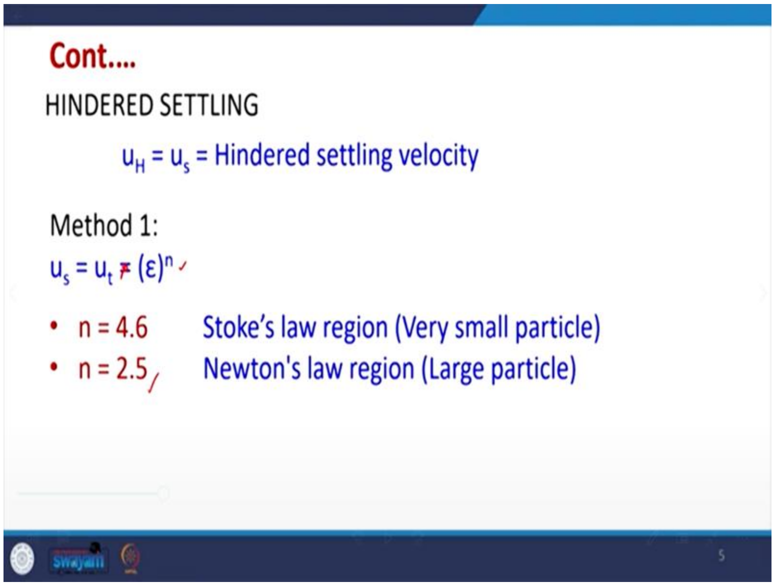

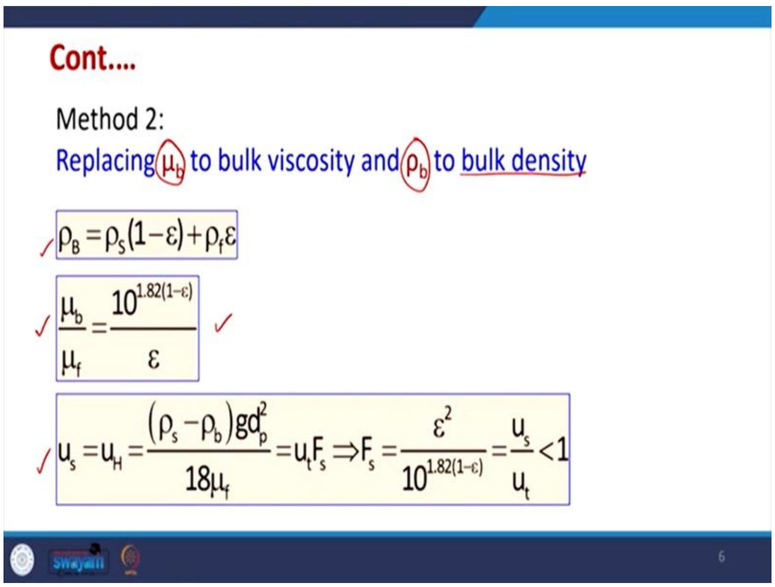

Then there is a possibility of hindered settling also, hindered settling that where the settling of one particle is hindered by another particle so we have group of particle. We will study that more in detail little later in the next lecture maybe but little bit idea only has been given. So, under that condition the terminal velocity can be given by this this is multiplied together and then n the coefficients can be for Newton's law reason they will be different and for Stokes law reason they will be different so this is there for hindered settling.

Now, going further replacing there is this is the one method through which we can find out the settling velocity is another method through which we can find out the settling velocity for hinder settling is that we replace the bulk density by nu B where nu b is found out using this equation.

And within this we have to use the sorry nu B is replaced by bulk viscosity to bulk whatever is the viscosity we replace by term nu b. And similarly, bulk density is replaced by rho B and this rho B can be found out using this equation where e is the wide edge which is there so that we have to find out.

And similarly, bulk viscosity can be found out using this particular equation and if we both are known we can put in this equation and find out the actual settling velocity in the hindered settling zone. So, through these also we can find out but the questions are the related to this hinder settling will be doing little later. And now we will start thinking that how the sedimentation basin how any sedimentation basin is designed. So, there are certain assumptions in designing the ideal sedimentation basin. So, generally, it will be based on the terminal velocity certainly and there are many assumptions that are taken.

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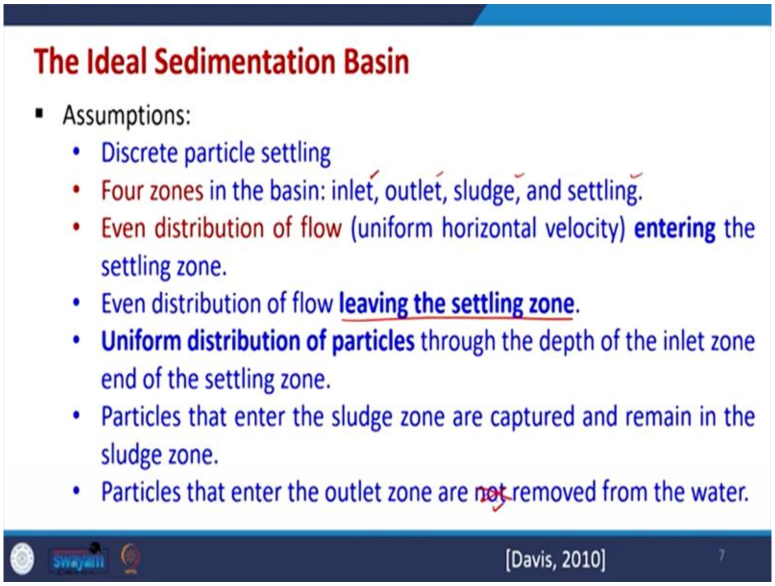

And these assumptions are like we have discrete particle settling which is there we will assume discrete particle settling. Then we have four zones in the basin inlet outlet sludge and settling that will discuss it now. After that there is we also assume that at the inlet in the settling zone there is a uniform horizontal velocity that is the distribution of the flow is even at the inlet and that is very this is the assumption that we consider in designing the ideal sedimentation basin. Now, along with the inlet we also assume that there is a even distribution of flow leaving the settling zone.

So, there is at inlet also at exit also both are we have uniform distribution of flow. Then uniform distribution of particles throughout the depth of the inlet zone up to the end of settling zone. So, that this is uniform distribution of particles is another assumption that we take. Then particles that enter the slug zone are assumed to be captured and they remain in the slug zone that means whichever particles that enter the slug zone we assume that they will be remaining there they are not coming out and re-entering the settling zone so this is there.

Particles that enter the outlet zone are not removed from the water so from are sorry are removed from the water this is assumes so particles that enter the outlet zone are removed from the water this is being assumed. So, the this is coming out and they are going into the water so they are not getting removed and they are going they are not removed from the water but they are going into the exit so that means they are not settling down anyway they are not removed is correct. But they are going along with the exit of the water so that is there.

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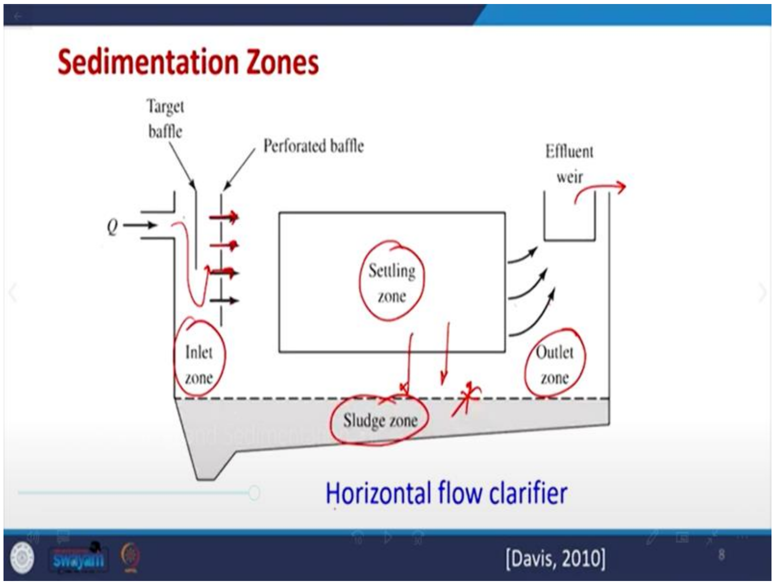

Now, let us discuss the sedimentation zone. So, this is the sedimentation zone so water is entering from here we have it baffle which is actually causing the water to get distributed and we are assuming that there is a uniform flow in this. So, this is the inlet zone we have a settling zone here after that the particles which settle down they go into the sludge zone and then we have outlet zone. So, the particles which are not going into the sludge zone they are going in the outlet zone and these outlet zone particles are not further removed they will be going out along with the effluent so that we so this is the influent and whatever will be coming out that will be going effluent.

So, this is these are the zones and there are certain assumptions which already we have discussed uniform flow here uniform flow out the from the sludge zone nothing comes out so this is not assumed no of none of the particles are coming out so this is the sedimentation zones which are there. Now, similarly for a flow clarifier so this is like horizontal flow clarifier we have these zones.

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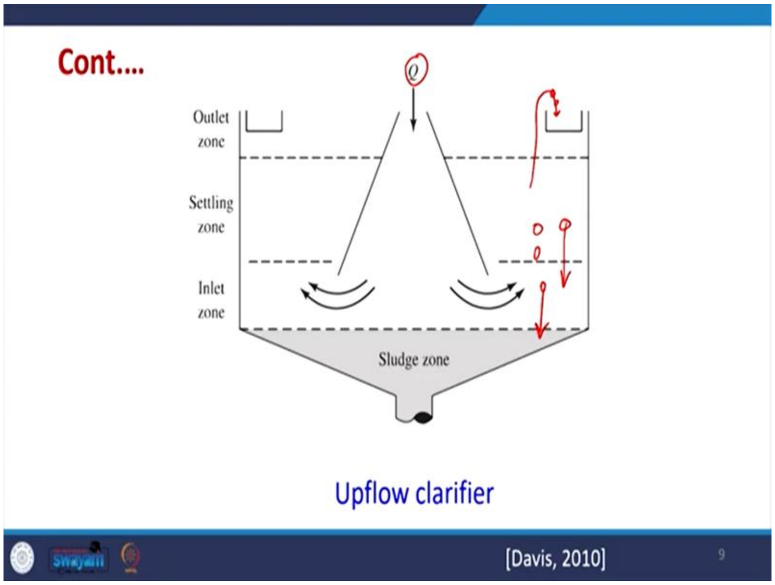

Similarly, for Upflow clarifier also the inlet is from the top and then it is getting distributed from here. And the particles get settled down particles those particles which will be there actually they will be settling down and reaching the sludge zone. And ultimately the treated water containing smaller amount of particles will be going into the outlet zone and going out so this is there. So, we have horizontal flow clarifier we have up flow clarifier so we will go further and discuss this.

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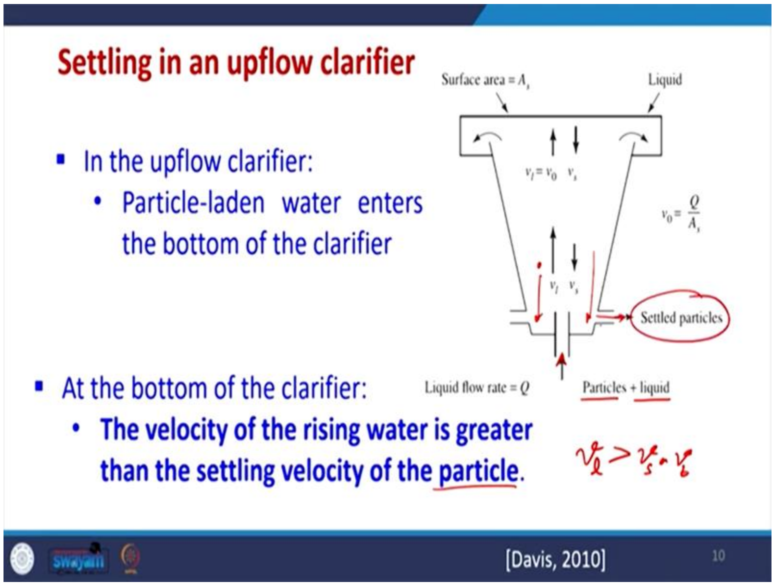
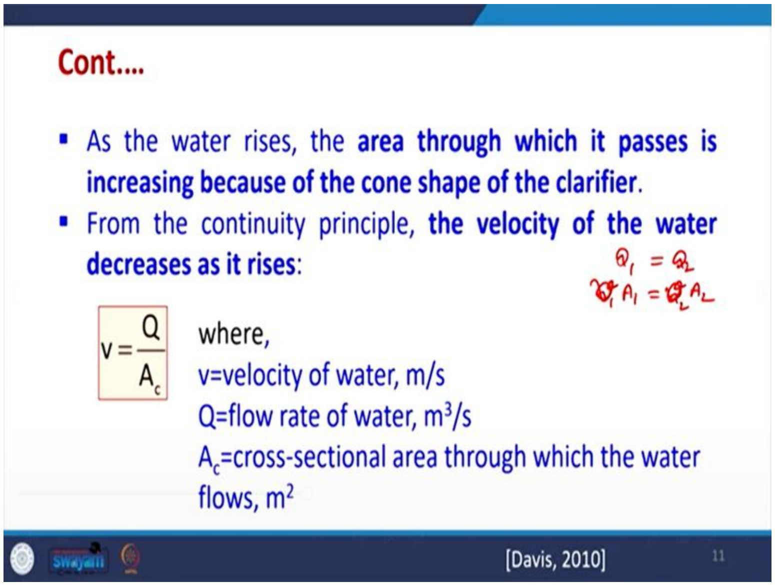




From the continuity principle, the velocity of the water decreases as it rises:

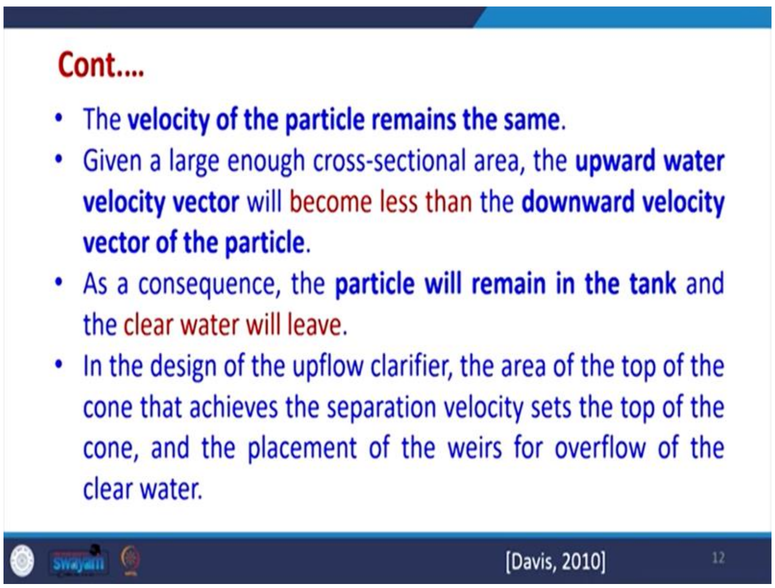
$$v = \frac{Q}{A_c}$$

where,

v=velocity of water, m/s

Q=flow rate of water, m^3/s

A_c=cross-sectional area through which the water flows, m^2



Now, settling in a flow clarifier occurs like this. So, in the Upflow clarifier the particles laden with water enter the this is like up flow from here there can be other designs also which is like here. Here the particles are entering at the bottom and they are containing both particles and liquid. Now, they are entering at the bottom now what will happen as the liquid at the bottom of the clarifier the velocity of the rising water is greater than the settling velocity of the particle.

So, that means the velocity of the velocity of liquid is greater than the settling velocity of the settling velocity or terminal velocity of the particle so this is there under this condition. Now, what will happen that with time the liquid will move very quickly up and settling will because of the settling velocity and because the area is increasing this is in conical shape so with time the liquid velocity will decrease.

And it will reach to the condition where it matches with the settling velocity and in fact after sometime it will become opposite. So, under those conditions the as the water rises the area through which it passes is in increasing because of the cone shape of the clarifier. So, because of the cone shape the area is going to increase.

And as per the continuity principle we know very well the continuity principle so like Q1 A1 is equal to Q2 A2. So, under that condition the flow rate because the A2 is much greater than the A1 so under that condition the flow rate or the velocity the particle decreases I sorry this is V1 A1 so this is their V2 A2. So, Q1 is equal to Q2 flow rate is same but velocity into area is multiplied so because of that the velocity of water decreases at is rises. So, under that condition the velocity can be given by this because area variation is there.

Now, when the velocity of the particle remains as such but the velocity of the liquid is getting decreased and as soon as the area further increases the upward velocity of the particle liquid becomes less than that of the downward velocity of the particle. And because of the that the particle will remain in the tank and the clear water will leave and with time actually the particles settle down to these zones which is ultimately the particle will settle down.

And these settle particles are removed from this size, so the with area actually because of change in area and because of which the liquid velocity decreases as compared to the settling velocity of the solid and as a consequence of that the separation happens. So, in the design of a flow clarifier the area at the top of the cone that achieves the separation velocity says the top of the cone. So, this is very important we keep the area the top of the cone area is very important. And above that there are weirs and from which the water overflows as a clear water into other zones from which it goes out.

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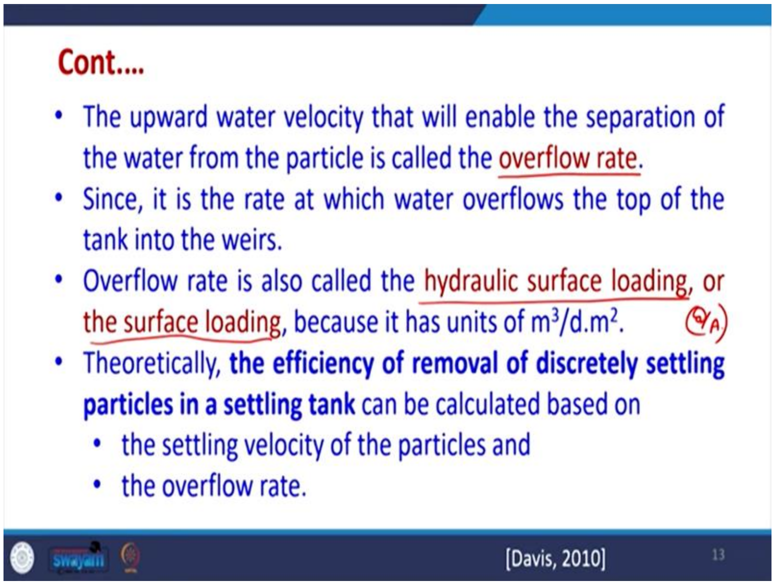

So, the upward water velocity that will enable the separation of the water from the particle it is called as overflow rate so will be further discussing this. Since it is the rate at which the water overflows the top of the tank into the weir so that is why it is called as overflow rate. Now, overflow rate is also called as the hydraulic surface loading or the surface loading so there are different terms. And it may have the unit like it has a unit a meter cube per day per meter square in place of per day it may be anything it is like Q by A the area is of Q by Q where Q is the flow rate and A is the area. So, this is the hydraulic surface loading or surface loading how it is called the overflow rate.

Theoretically, the efficiency of removal of discretely settling particles in a settling tank depends upon the settling velocity of the particle and the overflow rate. So, these two become very important parameters in the sedimentation basin design. Now, we will study understand that how overflow rate can be calculated for a rectangular horizontal flow sedimentation basin. So, this is being assumed.

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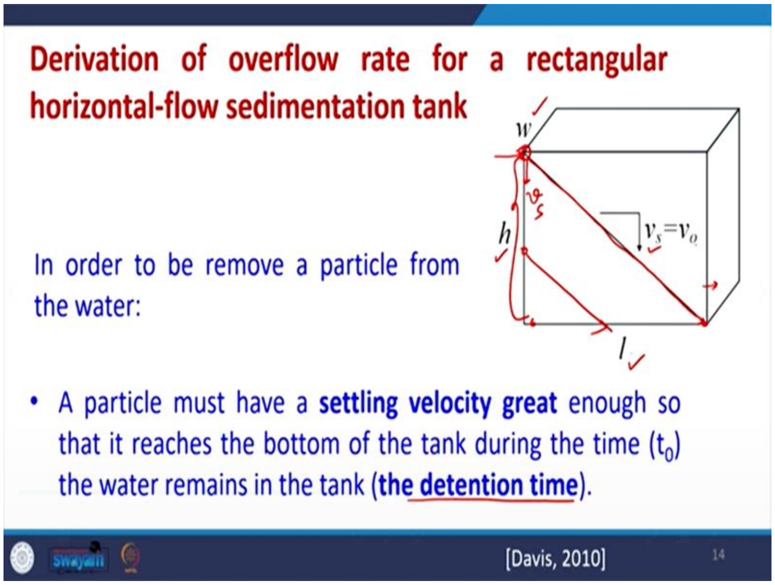

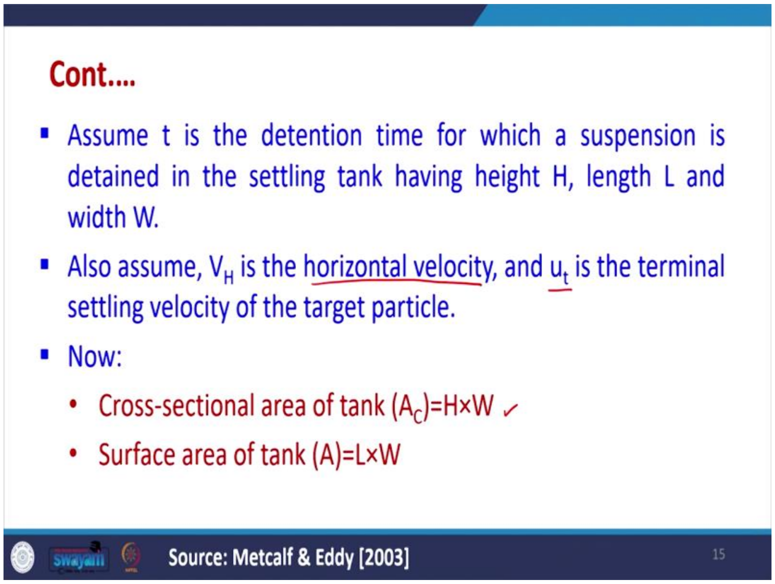

So, we have a sedimentation basin which is having a height h length l and width w so this is there so this is height this is length and this is width which is w. Now, it is having a settling velocity of Vs, so we are assuming that the particles the target particle which we are trying to remove. Suppose the target particle is 100 micron, so for 100 micron we can calculate the settling velocity. So, we want it to be settled down so for that condition assuming that Vs is the settling velocity so a particle must have a settling velocity enough what is the basic criteria.

So, a particle must have a settling velocity great enough so that it reaches the bottom of the tank during time t0 in which the water remains in the time. So, suppose this term logic is called as detention time so suppose there is some time within which we want the particle to settle down. So, suppose the particle is entering at that top of the tank if and we want the particle this is the particle so we want this to be settle down this much distance within the time the particle reaches the length l.

So, any will be having two velocities one is the settling velocity another is the whatever is the flow velocity of the particle inside this basin. So, we want this particle to reach the bottom that means it will move like this it is settling down and moving also. So, we want to reach the settling zone before actually it comes out so this particle will 100 percent get removed. If any this particle size enters in the middle of the tank also then then also it will certainly get removed so this is possible. So, we always start from the top of the tank so the basic design is for this condition where it enters at the top of the tank but we want to settle it before it reaches out of the it goes out of the settling zone so this is there.

Now, assume t is the detention time for which the a suspension is detained in the settling tank which is having height H length L and width W already we discussed this. Also assume that VH there will be some confusion there is a another term which is kept as VH later on but that is called scour velocity we will discuss it later.

But right now, we are assuming that velocity is horizontal velocity is VH the Vt or vs is the terminal settling velocity of the target particle so these are the two assumptions we are making. Now, what is the cross-sectional area of the tank so this cross-sectional area is like H we are assuming sorry capital so we are here H into w so that will be the cross-sectional area whatever is the height into width. And similarly, surface area of the tank is length into W so this is length and this is into W so this is the cross sectional this is the surface area of the tank.

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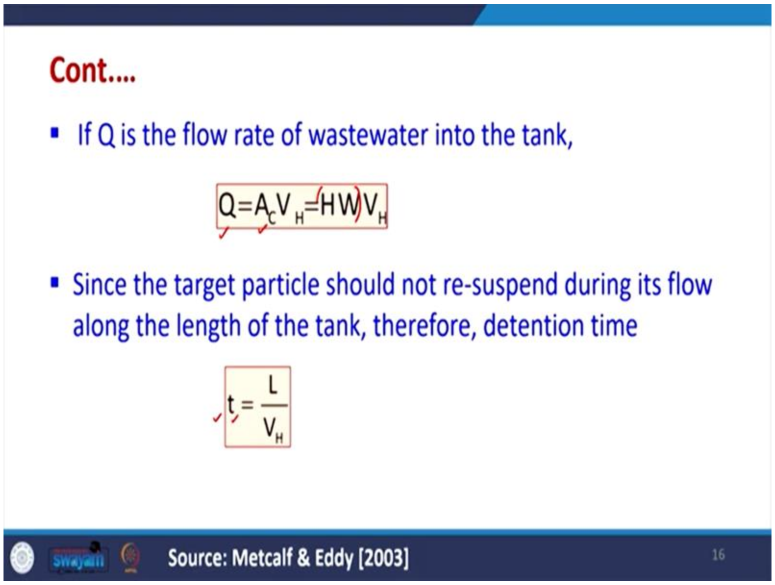

Now, let us start so if suppose Q is the flow rate of the water or wastewater into the tank. So, Q is the flow rate so we can write like this A cross sectional area into horizontal velocity so that means and this cross-sectional area is like height into width into horizontal velocity. Since the target particles should not re-suspend during its flow along the length of the tank so that means it should be that the tension time can also be calculated as t should be equal to length the length which is moving. So, this is the length that we saw so this is the length so for time of detention the length should be can time of detention can be calculated as L divided by horizontal velocity so this is the time in which it will remain in the horizontal direction like.

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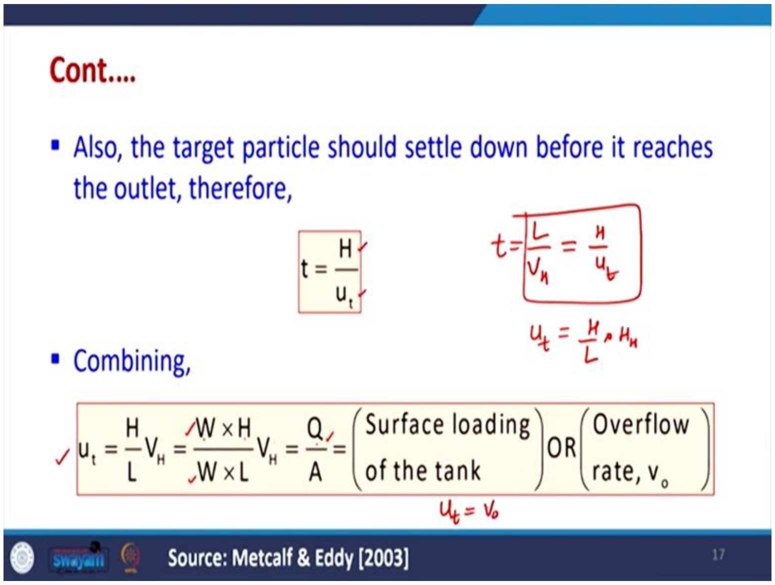

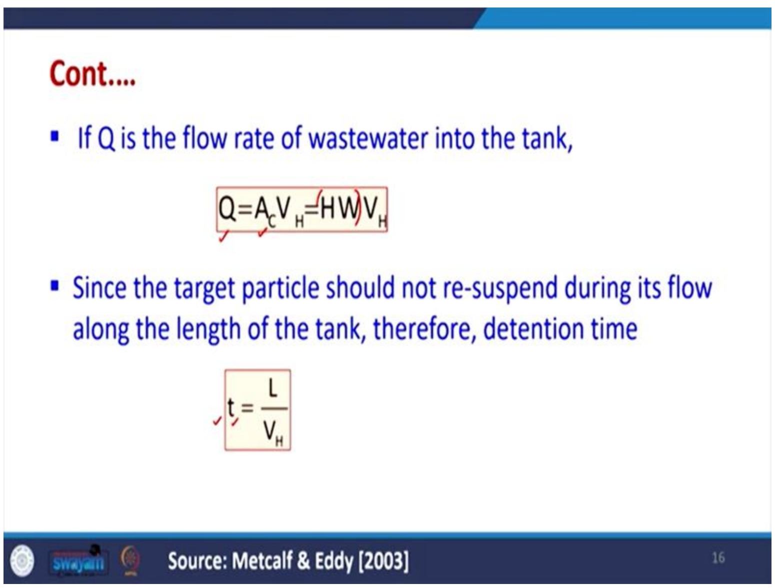

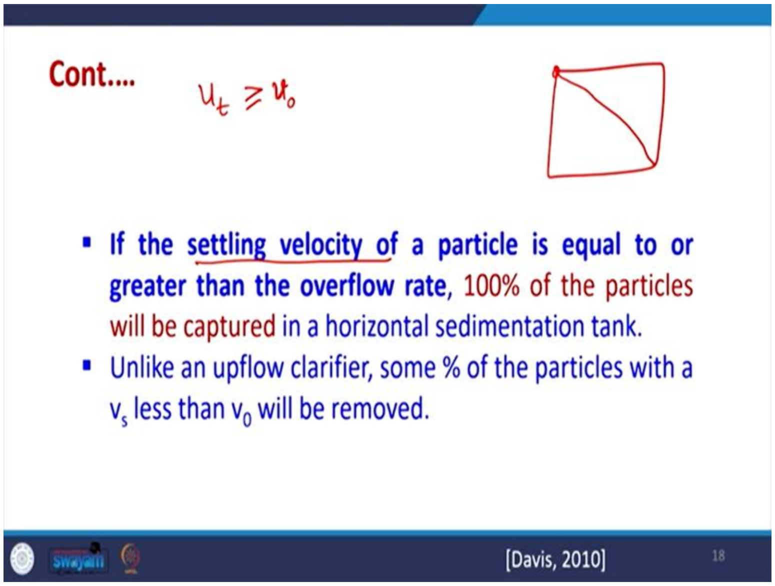

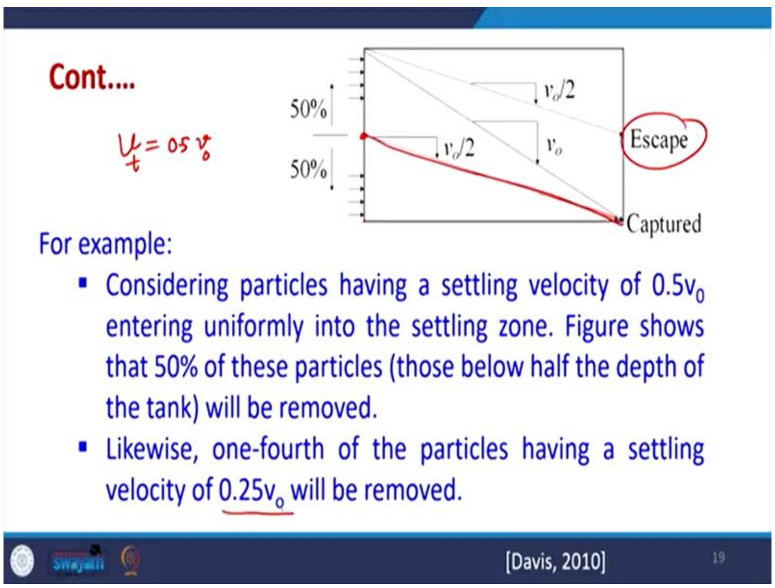

Similarly, the target particle is settling down also so during that time before it reaches the outlet zone its detention time can also be calculated how it is settling down so H is the height and Ut is the terminal velocity so we divide H by Ut to get the terminal velocity so this is there. Now, if you combine together both t together this t and this t, so we have two t together one is t is equal to L by VH so L by VH the horizontal velocity this is equal to H by Ut terminal velocity. The same has been given here and from this equation we can calculate the Ut to be equal to H by L into VH which is given here so we are starting with terminal velocity is equal to H by L into VH.

Now, what we do is that we multiply numerator and denominator both by width so if you multiply by width we get this particular equation. Now, remember width into height into horizontal velocity is equal to the flow rate which we derived earlier so this is like same so we have kept Q as here and W into L are the surface area of the tank. So, this this we did earlier surface area of the tank is L into W so if both are there so that means the terminal velocity should be equal to Q by A and which is actually the surface loading of the tank or overflow rate V0.

So, this is like we can keep it as V0 so we can write Ut should be equal to V0 for the target particle for which we have a diameter fix and which is having a particular density. So, if both are known we have a target particle which is known. Now, if the settling velocity of the particle is equal to or greater than the overflow rate 100 percent of the particles will be captured in a horizontal sedimentation basin as we did earlier we are targeting that. If suppose the what is this meaning that in the previous equation we find out Vt is equal to if Ut is greater than or equal to U0 or V0 sorry overflow rate.

So, under that condition this particle will settle down hundred percent before actually it reaches out of the system so we have hundred percent removal of the particles from the water whatever is the target particle for a horizontal sedimentation basin. And the same idea is expanded to the upflow clarifiers as well so that is unlike an upflow clarifies some of the particles within a Vs less than V0 can also be removed. But this is the case ideally we will assuming that any target particle which is having a dense part settling velocity greater than the overflow rate will 100 percent get removed.

Now, what will happen to the other particle suppose the terminal velocity is not equal to V0 suppose it is only 0.5 of V0 so or over flow rate. So, under that condition at least if it is only 0.5 so the target particles up to half of the height they will get removed so they will settle down above that they will not settle down they will escape.

But all those particles which are up to this zone they will get captured, so considering that particles have are having a settling velocity of only 0.5 V0 entering uniformly into the settling zone. Figure shows that fifty percent of these particles those below half the depth of the tank still will get removed so this is there. Similarly, we can go further extend and one fourth of the particle suppose 0.25 V0 so one fourth of the particle will get removed in the settling if in the settling zone so this is how we can calculate.

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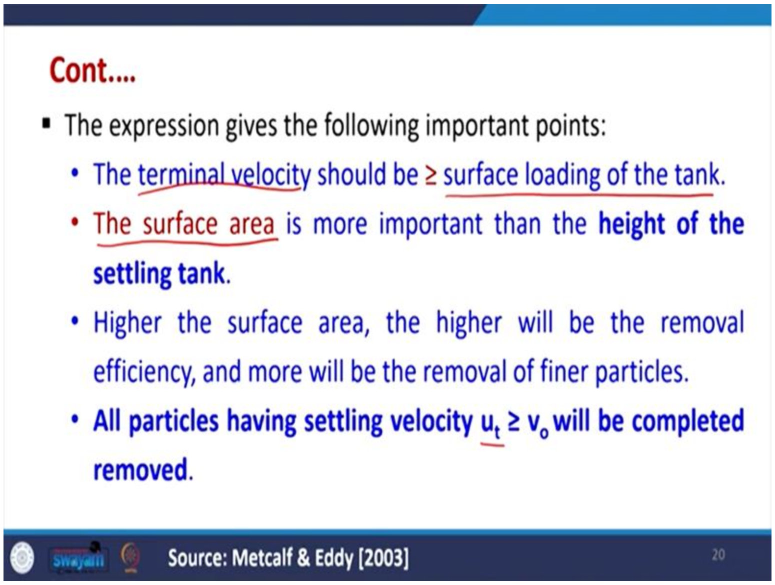

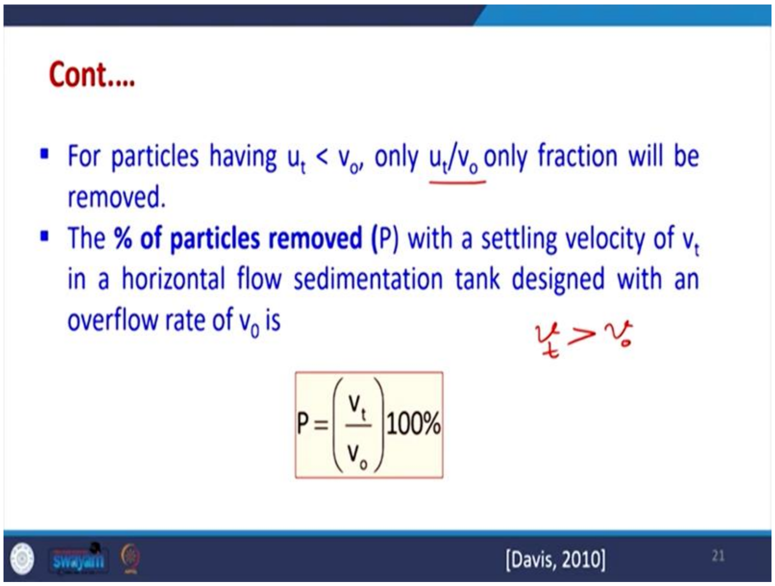

So, there are some of the important points we can learn from this one thing is that the terminal velocity should be or greater than the surface loading of the tank. So, if we can keep this otherwise vice versa we can do this so terminal velocity of the target particle is calculated. Now, we should design a tank in such a way that surface loading should always be less than the terminal velocity. If we can do this will capture the all the target particles, now whichever suppose 100 micron is the target particle now above 100 micron also some of the particle will get captured because at least half the height so it is possible that will capture up to 100 micron all the particles above that also will capture lot of particles so this is there.

The surface area is more important than the height of the settling tan when we are designing any system higher the surface area higher will be the removal of if removal efficiency and more particles will get removed all the particles which are having settling velocity Ut greater than 0 some of them will get captured but some of them will get removed also. So, there will not be 100 percent efficiency for target particles which are having a overflow rate greater than V0. Some of the particles which are actually up to half of the zone up to one fourth of the zone they will get removed still.

For particles which are having Ut less than U0 only Ut by V0 fraction only will be removed so this is there. So, suppose the target particle is having velocity greater than 0 so V0 so we calculate the ratio and the removal efficiency the percentage of particles removed for this condition will be divide will be like Vt divided by V0 into 100. So, this is how we calculate for a condition where the settling velocity is greater than the V0 so this is there. Going further we have a condition which is we have a velocity which is called as scour velocity.

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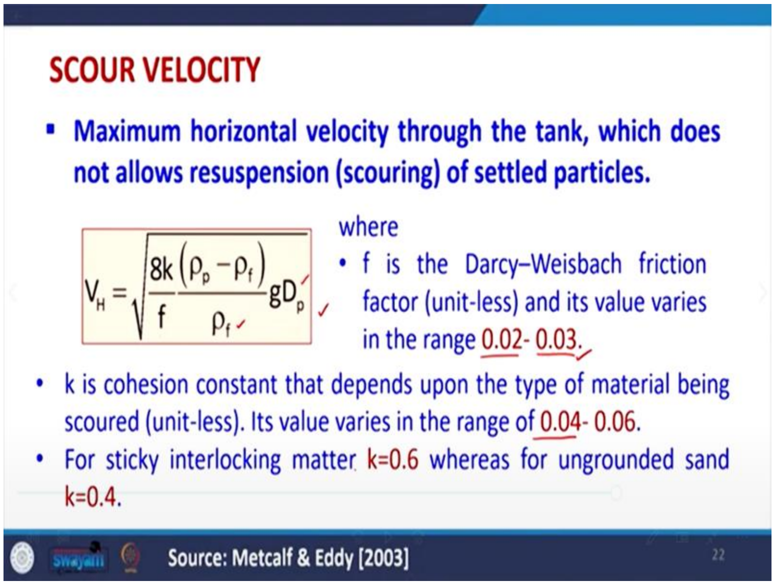

Maximum horizontal velocity through the tank, which does not allows resuspension (scouring) of settled particles.

$$V_H = \sqrt{\frac{8k}{f}\frac{(\rho_p - \rho_f)}{\rho_f} g D_p}$$

where

- f is the Darcy–Weisbach friction factor (unit-less) and its value varies in the range 0.02-0.03.

So, what is scour velocity it is like the maximum horizontal velocity through the tank which does not allow the resuspension or scouring of the settling particles. What does it mean that, suppose if we have very high horizontal velocity so what it will do is that it will re-suspend the particles from the settle zone so we do not want to keep that also.

So, always when we are designing any sedimentation basin horizontal floor overflow rate is one of the important criteria then we should also take care of the maximum horizontal velocity through which we should allow the water to enter into the system. Otherwise if VH becomes more than this the particles which will actually settle down to the sludge tank they will also become re-suspended which is never desirable.

So, that is why scour velocity or maximum horizontal velocity is very important and that can be calculated by this expression which is given here. So, this maximum horizontal velocity is like under root of 8k rho p minus rho f and then further divided by the bulk dense this density of the fluid and then it is a function of like diameter of the particle as well.

Here f is called the Darcy-Weisbach friction factor it is unit less and its value may range from 0.02 to 0.03. If we do not know it is better to keep the value highest possible so that we know that our maximum horizontal velocity is the lowest possible so this is very important. Similarly, k is the cohesion constant that depends upon the material being is scoured.

So, its value varies from 0.04 to 0.06 if we do not know it is better to keep the value lowest possible. In the f case it is highest possible in the k case we can keep it lowest possible because we want to have the lowest possible her maximum horizontal velocity. So, for sticky and interlocking matter k is equal to 0.6 whereas for ungrounded sand particles like it is k is equal to 0.4 so we can calculate the scour velocity.

So, now three important things have happened till now, we have a terminal velocity which is very very important to calculate then we have a overflow rate that is very important and from overflow rate actually we can calculate the area of cross section surface area which is more important.

So, Q will be generally fixed because we can tentatively if the flow rate is too high the amount of water getting generated in the plant is very high. So, we can divide we can have three four settling tanks five six set link tanks like this so we have some idea of Q. Now, Q is known so only design factor is a and also during this Q calculation we can take care of the maximum horizontal velocity that should be allowed.

So, three important factors terminal velocity overflow rate within your flow rate surface area is important and also depending upon Q we have to take care of the maximum horizontal velocity so that resuspension of the settled particle does not happens so three important things that are there in the settling and sedimentation in the basics.

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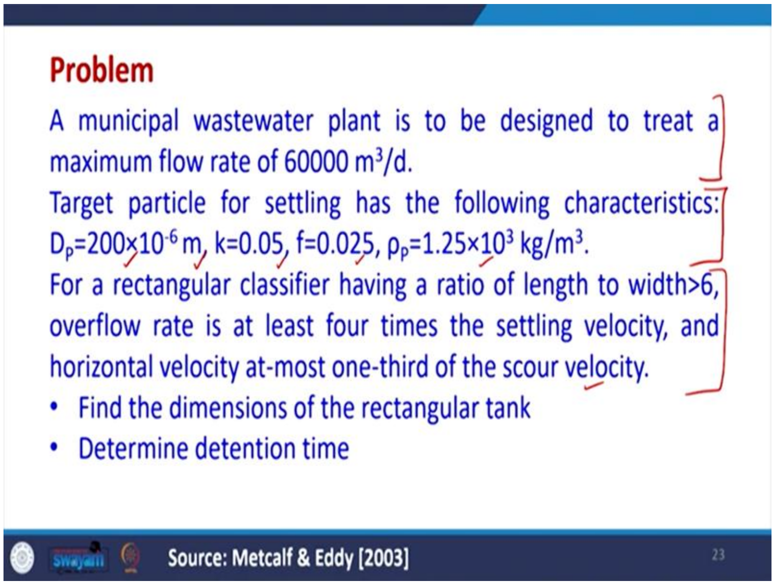

Now, one question is given here a municipal wastewater plant is to be designed to treat a maximum flow rate of 60,000-meter cube per day. Now, the diameter of the particle is given as 200 micrometer k is given as 0.05 and the specific factor is f is given the particle density is also given it has been calculated. So, in actual scenario this will be only the known thing then we have as a design engineer or something we have to determine this from the literature or we have to calculate this using various methods sophisticated instruments etcetera.

Now, we have to assume also something so this is given in the problem but in the actual case this condition we may have to decide by ourselves. So, we are designing a rectangular classifier here we are assuming that the ratio of length to width has to be kept greater than 6 overflow rate we are assuming that will keep at least 4 times the settling velocity so that whatever is the target this particle everything of that gets removed. And horizontal velocity is at most one third of the scour velocity.

So, we are keeping the horizontal velocity also much lower we are keeping the overflow rate very high so that everything settles down so we are assuming. And there is some assumption with respect to length width also that we are assuming. Now, we have to find out the dimension of the rectangular tank and determine the retention time. At these conditions we can worry and we can cross check with respect to like what will be the total cost etcetera these things we have to decide from literature or try to get the values by from some other source. So, this is there and this will be the actual condition which will be given by any industry or otherwise so this is there.

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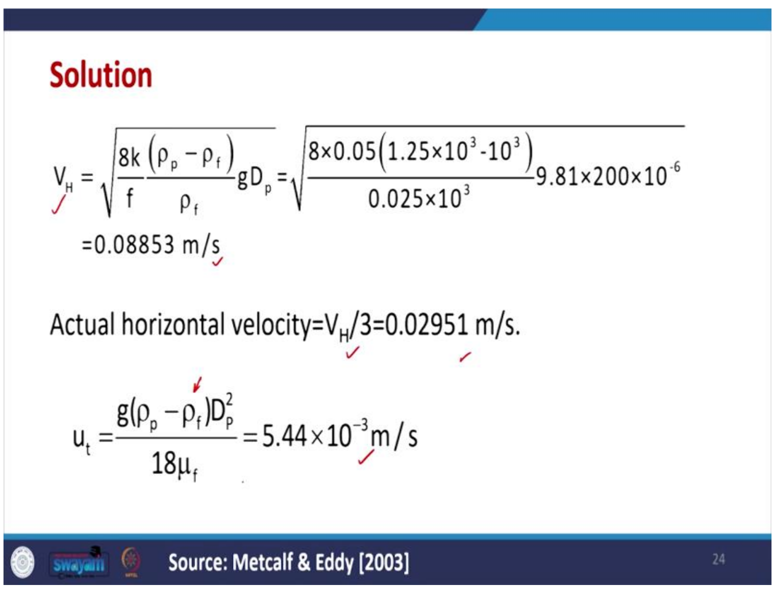

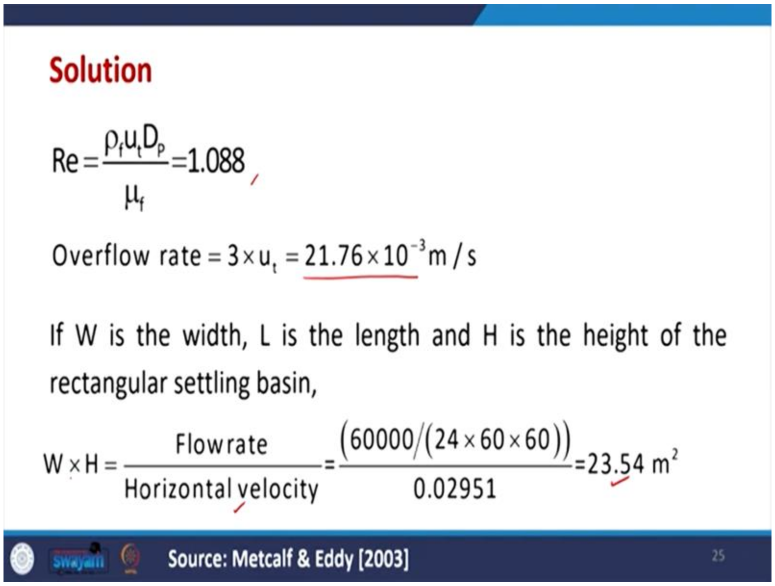

Now, we first calculate the horizontal settling velocity using this scour velocity so it comes out to be 0.08853 meter per second so everything is kept here. Now, the actual sorry horizontal velocity we are going to take is less one third of the scour velocity so that has been taken. Now, the terminal velocity has been calculated and here we put all the for fluid we are assuming to be the water. So, for that condition here already 1.25 is the specific gravity of the particle so we are assuming for liquid to be 1. And under that condition the terminal velocity is found out 5.44 into 10 raised to minus 3 meter per second.

And then we cross check that whether we are assuming this using the stokes law reason whether it is correct or not. So, Reynolds number comes out to be 1.088 so we can assume to be. Now, we are assuming overflow rate we are taking three times of the terminal velocity so it is calculated this is the overflow rate. Now, if W is the width and L is the length and H is the height of the rectangular basin. So, the W into H so that means width into height which is like the cross sectional area of the section will be equal to like the flow rate divided by the horizontal velocity. So, since horizontal velocity is fixed flow rate is already fixed we get the W into H is equal to 23.54-meter square.

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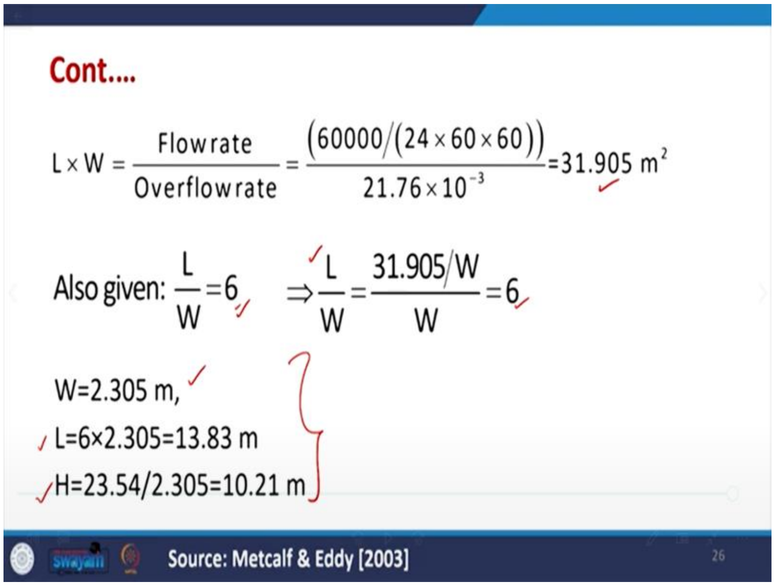

Now, going further similarly the surface area of the tank is equal to flow rate divided by overflow rate and that comes out to be 31.905-meter square so we calculate it. Now, since L by W was taken as 6, so L by W is equal to what we do is that we put the from here the term for L so from here L will be equal to 31.905 divided by W so this is there.

And we have assumed it to be 6 so solving we get W, once W is known we can calculate the L and once L is also known we can calculate the H so all these parameters we get the dimensions. So, here certainly we have assumed this and but under all these conditions all the target particles will get removed. So, through this we end this lecture we will continue the settling section in the next lecture as well, so thank you very much.