Biological Process Design for Wastewater Treatment
Professor Vimal Chandra Srivastava
Department of Chemical Engineering
Indian Institute of Technology, Roorkee
Lecture 20
Coagulation, Flocculation, and Sedimentation - ll

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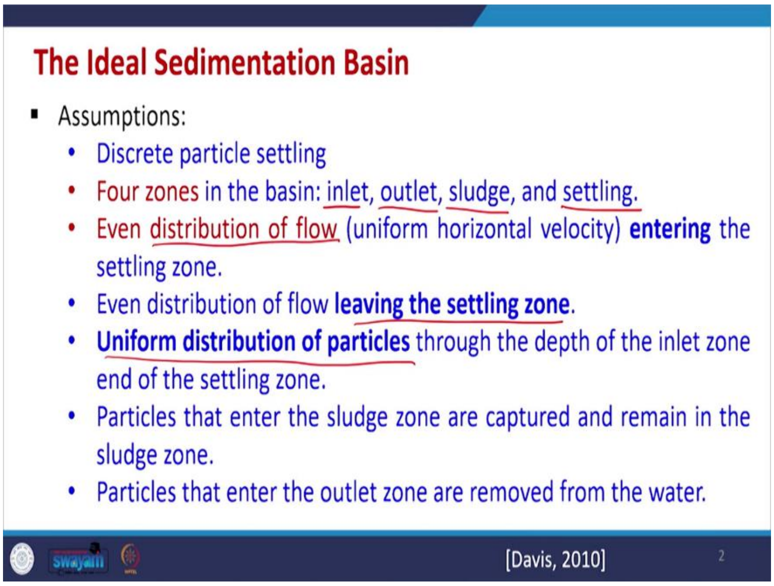

Welcome everyone in this NPTEL online certification course on Biological Process Design for Wastewater Treatment. So, in the previous lecture we studied regarding the coagulation, flocculation and sedimentation. So, we learnt that there are essentially four sections or parts in which the sedimentation may occur and those are the discrete sedimentation then flocculent sedimentation, then we have the suspension or sedimentation and then the fourth one which is the compression sedimentation. Now, in this the discrete particle theory actually helps us in finding out the terminal velocity that we calculated in the previous lecture.

Now, today we will continue with the same and study the flocculent sedimentation also. In biological process design generally up to flocculation settling it is a good enough for a study. Some amount of suspension sedimentation may also happen where the but it is good enough to understand the flocculent settling and it will be good enough for biological process design.

So, we will continue further with respect to the sedimentation. Now, what should we an ideal sedimentation basin we have studied the discrete particle theory and discrete settling up till now, what should be the ideal sedimentation basin? The ideal sedimentation basin should have a discrete particle settling that means, the particles settling down are not affected by each other and essentially in the sedimentation basin there are four zones one is the inlet zone and certainly the outlet zone is at the last then after an inlet we have a settling zone also a sludge zone in with the sludge is getting settled down our particles are going and then we have the outlet zone. So, we have four zones now in the flow regimes like in inlet and outlet the distribution of flow should be uniform. So, the uniform horizontal velocity for the fluid, which is entering the settling zone and similarly, we should have a even distribution of flow leaving the settling zone.

So, these even distribution of flow is very important. Otherwise disturbances may happen in the settling zone, then we have uniform distribution of particles throughout the depths of the inlet zone up to the end of the settling zone. So, this is also very important for ideal sedimentation basin, the particles that enter the sludge zone are captured and remained in the sludge zone. So, the they should not be going up and going in along with the outlet. So, once they are captured, they should remain in the sludge zone itself. So, this is the ideal thing, then particles that enter the outlet zone are removed from the water. So, if the particles are anyhow entering the outlet zone and they are not being captured, they should be removed from the water ideally.

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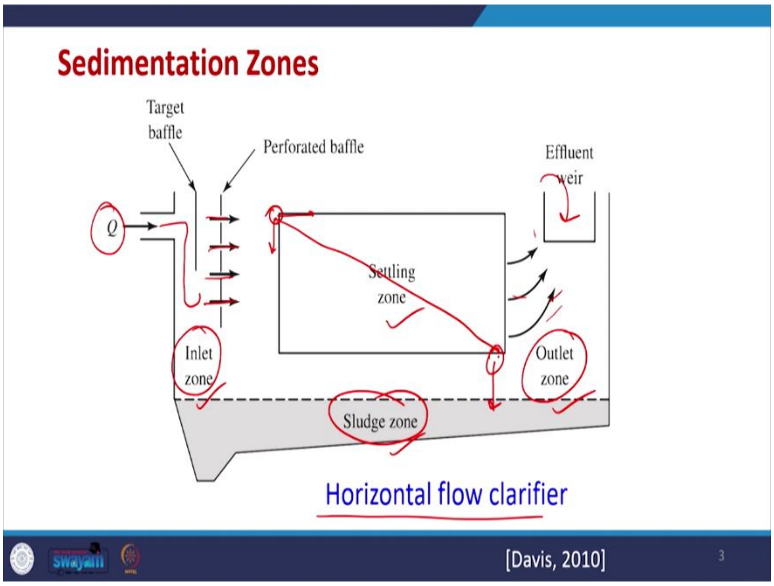

So, this is the sedimentation zones in a Horizontal flow clarifier So, we have the inlet. So, this is the inlet zone now we have Target baffle is there. So, that the flow which is coming out goes to the bottom and then we have Perforated baffles through which the flow is happening. So, now the flow has become uniform, then we have a settling zone suppose a particle is enters in this settling zone this particle is certainly moving in this direction also and it is settling down also. So, it should settle down before actually it reaches the outlet zone. So, it settles down here. So, it will go into the sludge zone which is given here and ultimately the particles which are not settled down and the flow will continue and the outlet zone from here the effluent will go out of the system. So, this is for Horizontal flow clarifier four zones inlet zone, settling zone sludge zone an outlet zone. So this is this is for horizontal flow clarifier.

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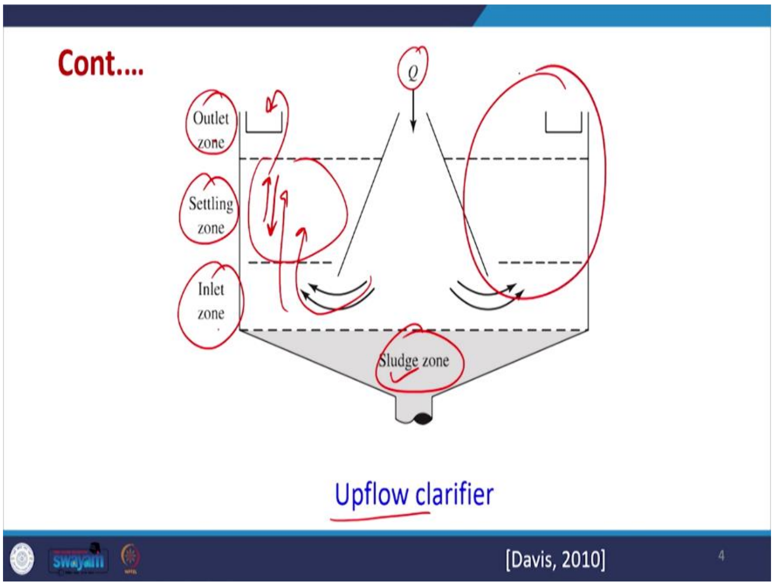

Now, similarly for Upflow clarifier, the water is coming in here and it is going here. So, the inlet zone is at the bottom because it is the water is going up then we have settling zone. So, in this case the water will go up, but the sludge will come down. So, this sludge will ultimately go into the sludge zone and then the water will ultimately reach the outlet zone which is given here. So, we have inlet zone here outlet zone settling zone and the sludge zone for upflow clarifier which is very commonly used in the industries for sedimentation. Now, settling in upflow clarifier suppose, that we are now concentrating on any of these one sections.

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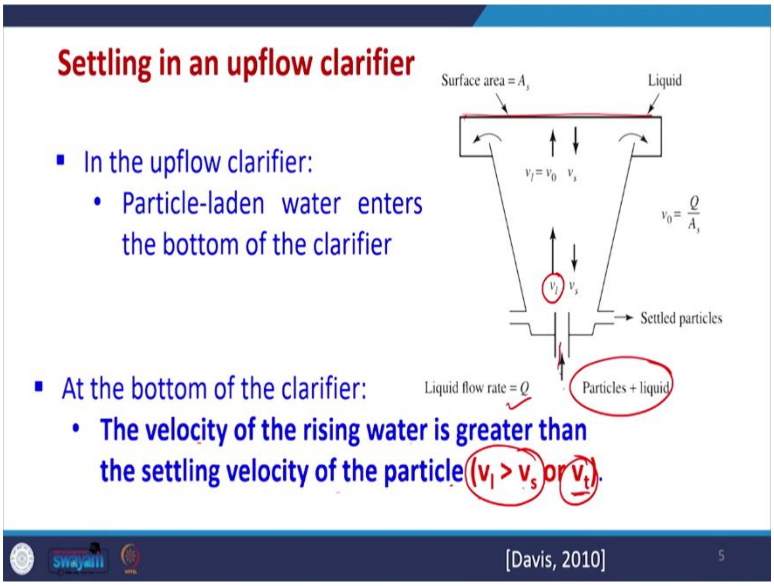

Now, here the particles are particle plus liquid with certain flow rate is going up. Now, under this condition the liquid is going up, but the sludge particles are settling down. So, this is there an overall the top surface area is and this is there now in the upflow clarifier the particle-laden water enters from the bottom of the clarifier at the bottom of the clarifier the velocity of rising water is greater than the settling velocity of particles. So, that means, this v_l is greater than v_s. So, it is trying to take up or v_s or v_t that means settling velocity of sludge or the terminal velocity of sludge particles. So, this is v_l is always greater than this.

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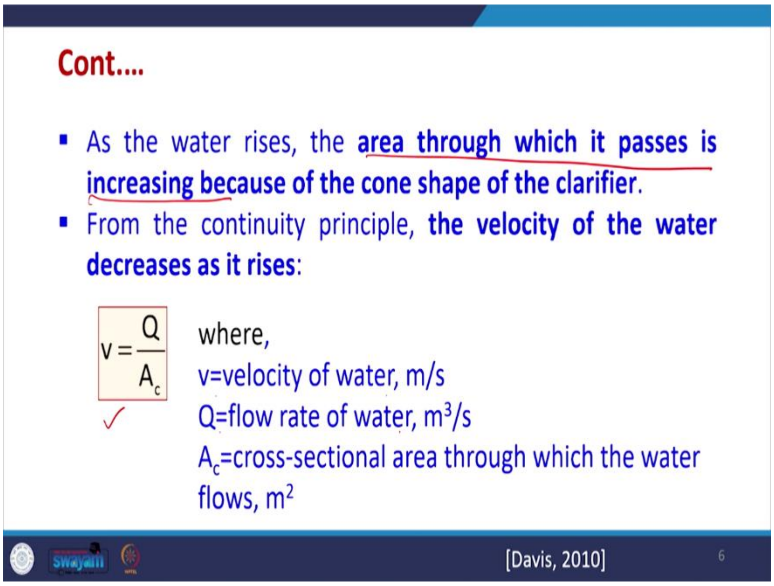

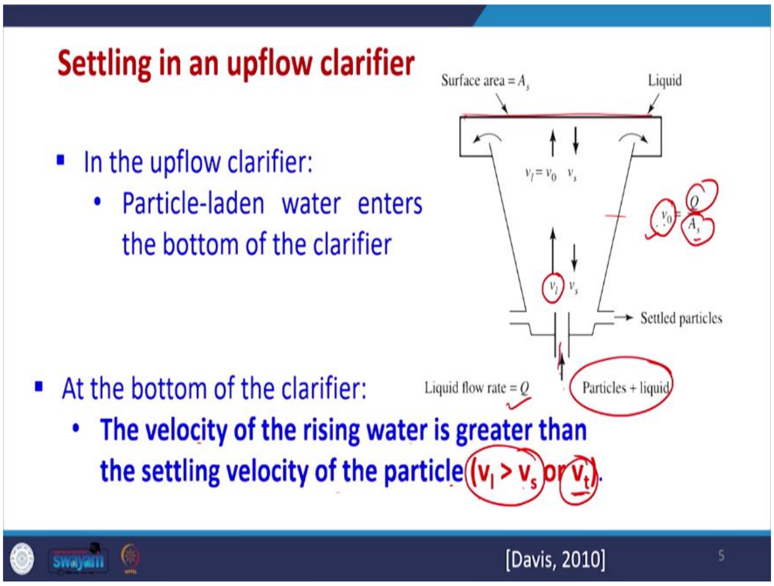

And since the area as the water rises, the area through which it passes is increasing because of the cone shape of the clarifier. So, we can see here the area is continuously increasing, because the flow rate is same, an area has become greater the velocity of liquid becomes lower and its ultimate maximum velocity is equal to the top surface area which is As. So, v_0 the maximum velocity which the liquid can reach is v_0. Now, we always want from the continuity principle the velocity of water decreases that it rises using this equation, where v is the velocity of water Q is the flow rate of water, A_c is the cross sectional area through which the water is flowing.

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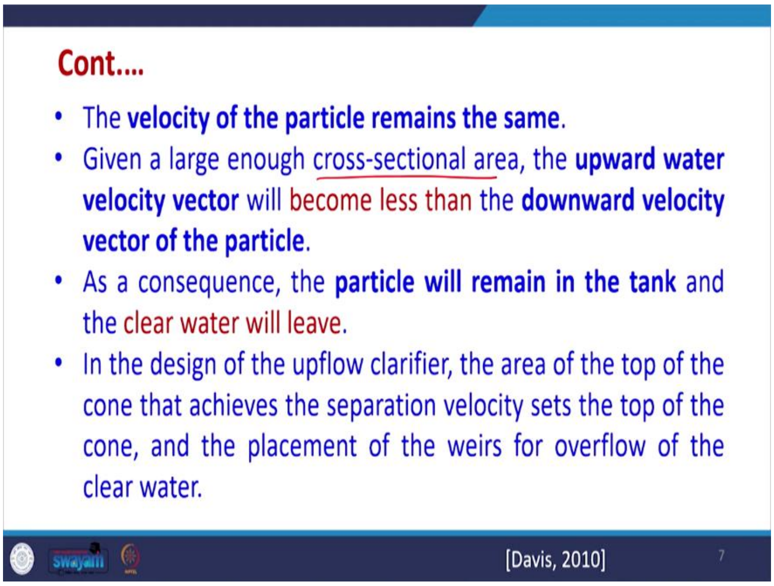

Now, the velocity of particle remains the same, the settling velocity of particle can maximum be same, given a large enough cross sectional area the upward water velocity will become less than that downward velocity of the particle. So, ultimately, because the area is increasing, the velocity of water will become less than the downward velocity of the particle as a consequence the particle will remain in that tank and then the clear water will leave and because of this region. In the design of our flow clarifier the area of the top of the cone that achieves the separation velocity sets the top of very important and the placement of weirs for overflow of the clear water is also properly designed and it should be clearly be noted.

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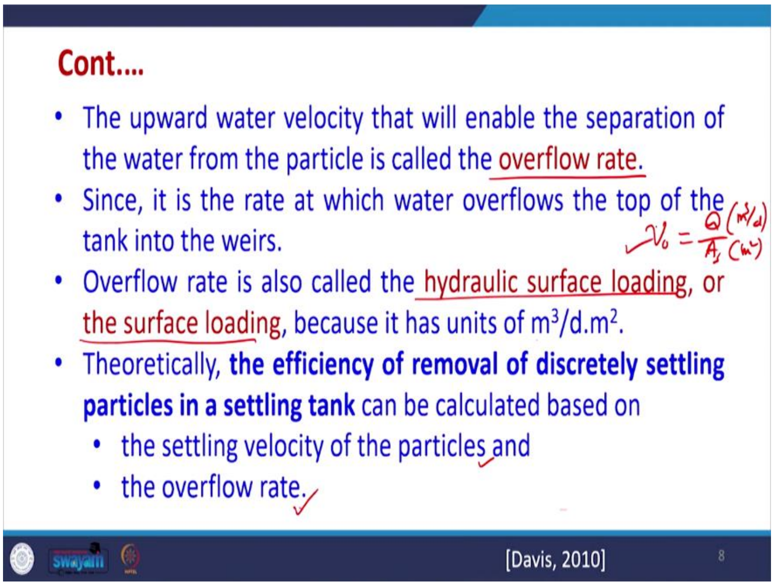

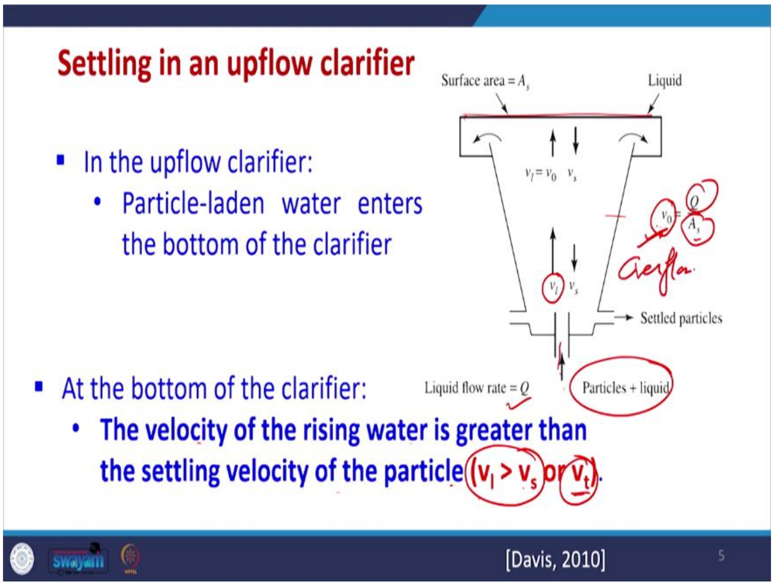

The upflow water velocity that will enable the separation of the water from the particle is called overflow rate. So, this is v_0, which was given here is called overflow rate. And this actually depends upon the maximum cross-sectional area of the clarifier. Since, it is the rate at which the water overflows the top of the tank into the weirs overflow rate is also called the hydraulic surface loading or the surface loading because it has the unit of meter cube per day per meter square. So, like v_0 is being given by Q upon A_s and Q is having you need to have meter cube per day suppose and this is having unit a meter square.

So, this is meter cube per day per meter square. Theoretically the efficiency of removal of discretely settling particles in the settling tank can be calculated based upon the settling velocity of particles which we determine the previous lecture and overflow rate which can be determined from this. So, this is how we calculate and design.

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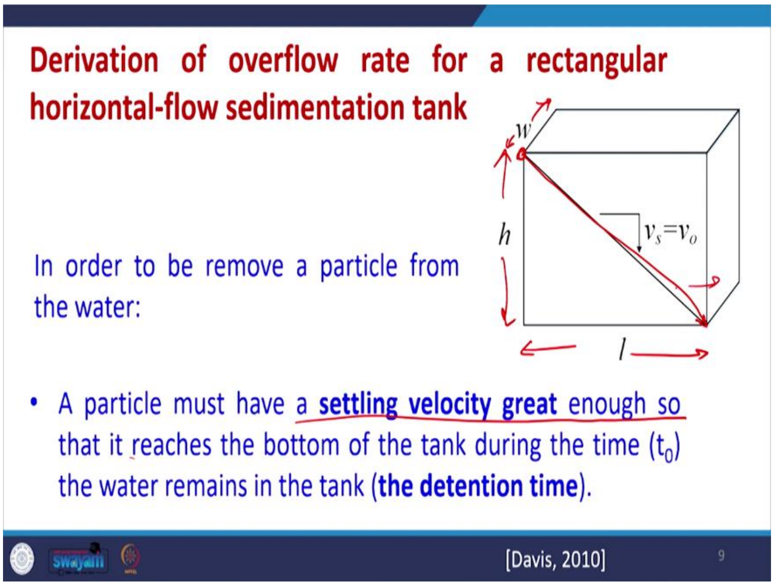

Now, derivation of the overflow rate for a rectangular horizontal flow sedimentation basin. So, in order to remove a particle from water, suppose this is a sedimentation basin, which is a having a length l height h. This is and the width is w this is width is w. Now, in order to remove the particle from the water, particle must have a settling velocity great enough so, that it reaches the bottom of the tank during that time t_0 the water remains in the tank that is the detention time that means, suppose any particle which is entering here, so, it should reach the bottom of that the settling zone before actually the water causes this zone, this is very important.

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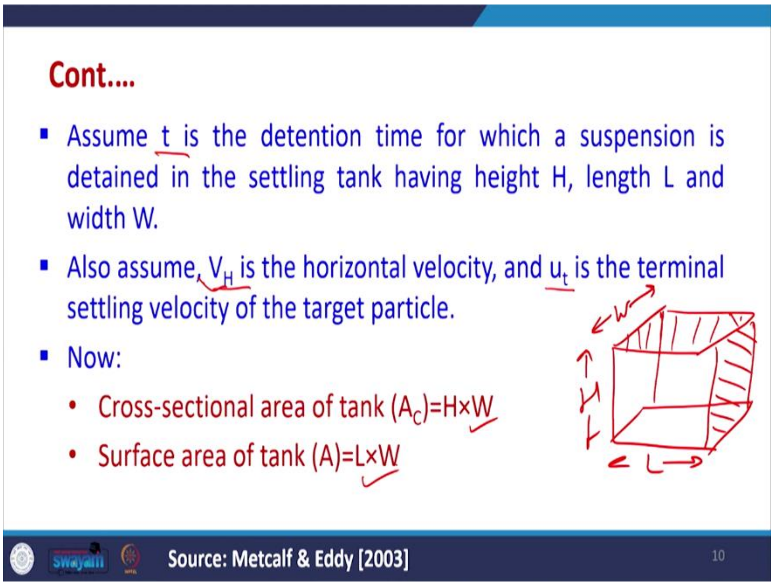

So, considering this as you mean suppose, that t is the detention time for which a suspension is detained in the settling tank that means, t is the time under which the water will remain in the tank and tank is having height H length L and width W Now, assuming the V_H is the horizontal velocity and u_t is the terminal settling velocity of the target particle now, we are assuming that V_H is the horizontal velocity and u_t is the terminal velocity. Now, the cross sectional area of a tank is H into w and the surface area of the tank is L into W this is very clear. So, we have this tank which is like this. So, this is the L and this is the H and this is the W. So, from here we can clearly see the cross sectional area which is like this, this one this is H the height into W so, that means H into W this is correct and the surface area the tank which is this one, this is this is W into L So, this is also correct.

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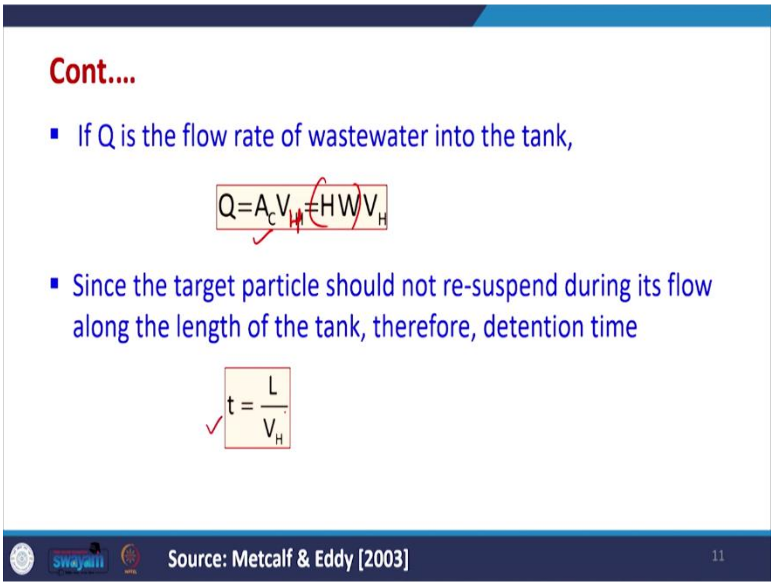
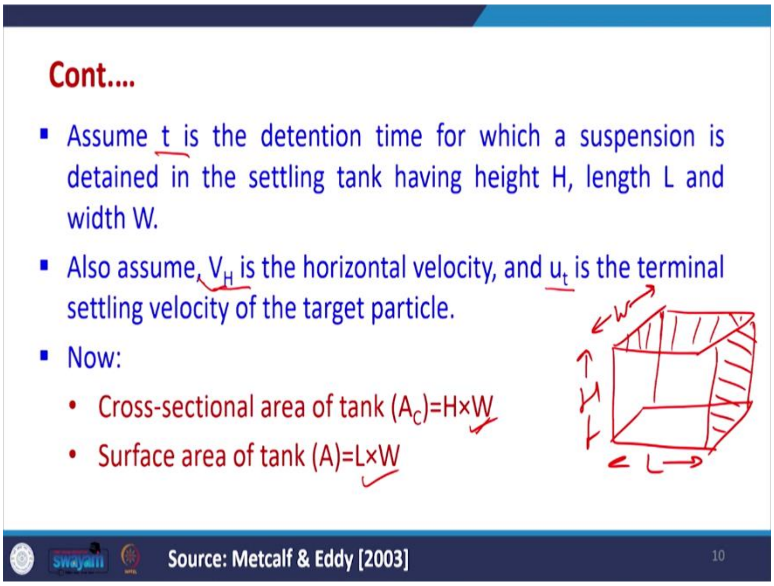


If Q is the flow rate of wastewater into the tank,

$$Q = A_C V_H = H\,W\,V_H$$

Detention time:

$$t = \frac{L}{V_H}$$



Now, going further if suppose Q is the flow rate of the wastewater into the tank. So, we can represent the Q into cross sectional area into horizontal velocity. Now, this cross sectional A_C can be written as H into W which was here the H into W into V_H since the target particles should not resuspend during its flow along the length of a tank therefore, detention time for the target particle like L is the length and V_H is the horizontal velocity. So, t is equal to L by V_H.

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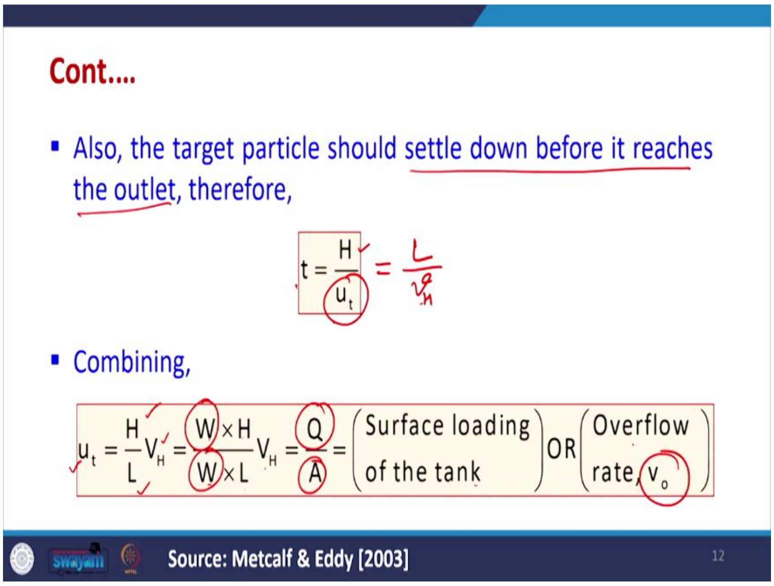

Also, the target particle should settle down before it reaches the outlet, therefore,

$$t = \frac{H}{u_t}$$

Combining,

$$u_t = \frac{H}{L} V_H = \frac{W \times H}{W \times L} V_H = \frac{Q}{A} = \left(\begin{array}{l} \text{Surface loading} \\ \text{of the tank} \end{array} \right) \text{OR} \left(\begin{array}{l} \text{Overflow} \\ \text{rate, } v_o \end{array} \right)$$

So, this is the detention time also the target particles should settle down before it reaches the outlet. So, that means, the t should also be equal to H the height divided by terminal velocity, which we determine in the previous lecture. Now, overall if we actually t is equal to L by V_H and t is equal to H by u_t So, we can write L by this horizontal velocity. So, we have two equations now, which are there and from this equation we can find out u_t is equal to H into V_H divided by L. Now, if we multiply both up and down by W for our case. So, this W into H into V_H is actually Q and W into L is the surface area. So, this is the surface loading our overflow rate that we determined earlier. So, that means, u_t and u_0 are the overflow rate they should be equal for the ideal condition.

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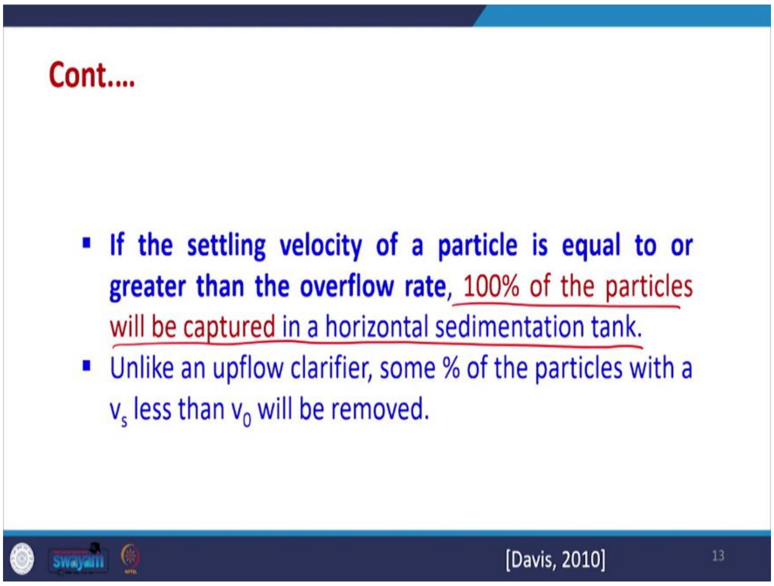

So, if the settling velocity of particle is equal to or greater than the overflow rate 100 percent of the particles will be captured in the horizontal settling basin unlike an upflow clarifier some of the particles within vs less than v0 will be removed also this is particle.

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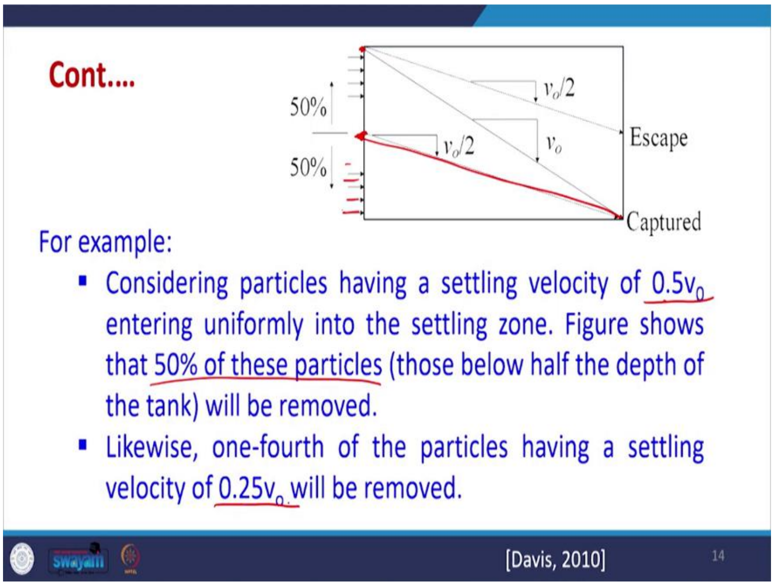

Now, for example, considering the particle having a settling velocity of 0.5 v_0 that means, the settling velocity is not greater than v_0 but it is only 0.5 v_0 and entering uniformly all throughout the settling zone. So, that means, this is the all part. Here when we are setting that the settling last is v_0 that means, the diameter will be less than the targeted actual diameter which have to be captured every particle greater than that diameter have to be captured. Now, it is not that only those particles will be captured, that particles less than point that particular critical diameter will also be captured depending upon the where they are entering. So, suppose they have terminal settling velocity of 0.5 v_0.

So, under that condition, the particle which is entering here actually it will be captured, but those entering above that they will escape that means, that figure shows that the 50 percent of those particles those below half the depth of the tank will be removed. Likewise, one fourth of a particles having a settling velocity of 0.25 v_0 will also be captured. So, all the particles above a certain size will 100 percent be captured below that size also the particles will be captured depending upon that, depending upon the position at which they are entering.

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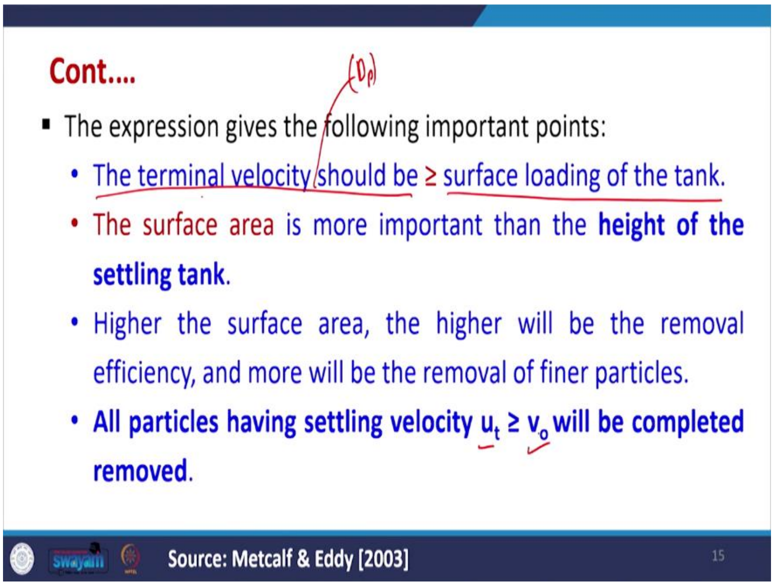

This is there the expression gives the following important points, the terminal velocity should be greater than the surface loading of the tank and this terminal velocity actually depends upon diameter. So, we have a particular diameter of particles which will be 100 percent be captured. Now, the surface area is more important than the height of the settling tank this is very important, the surface loading is important parameters that means, the surface area is important than the height after settling tank that is why many other settling tanks have very huge surface area higher the surface area higher will be the removal efficiency and more will be the removal of final particles all particles having settling velocity ut greater than the overflow rate will be completely removed.

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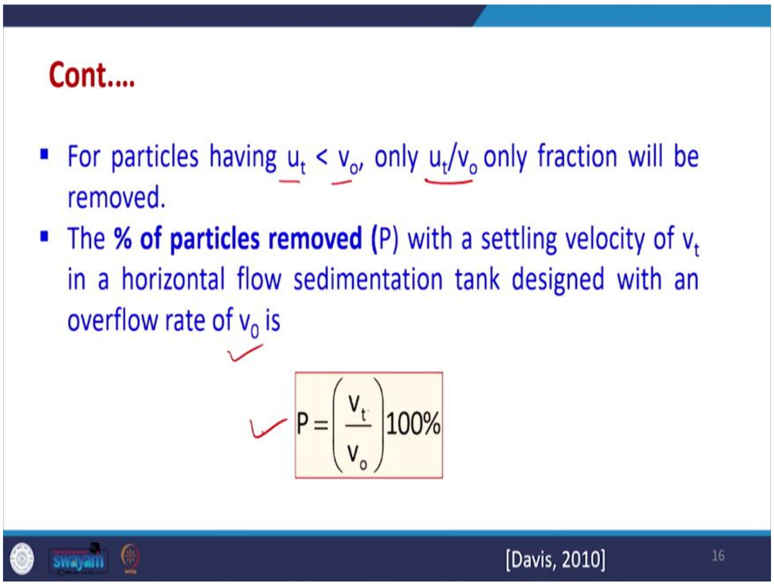

The % of particles removed (P) with a settling velocity of v_t in a horizontal flow sedimentation tank designed with an overflow rate of v_0 is:

$$P = \left(\frac{v_t}{v_o}\right)100\%$$

Also for particles which are having terminal velocity less than v_0 v_t by v_0 fraction will be removed still from less than that also the fraction will be removed, the percentage of particles P removed with a settling velocity of v_t in a horizontal flow basin tank design with an overflow rate of v_0 is v_t by v_0 into 100 percent this is the percentage of particles which can be removed from a horizontal basin.

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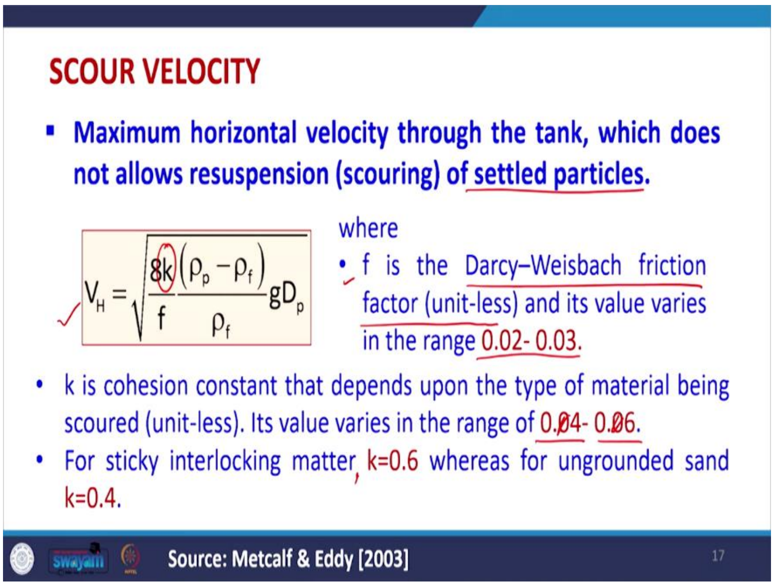

Maximum horizontal velocity through the tank, which does not allows resuspension (scouring) of settled particles.

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

Now, there is another time which is very important in the sedimentation basin is Scour velocity, the maximum horizontal velocity through the tank which does not allows resuspension or scouring of the settled particles. So, once they are settled down they should not be taken away. So, for that the horizontal velocity is given by this equation and in this case f is the Darcy-Weisbach friction factor it is unit-less and its value varies in the range of 0.02 to 0.03 this k is the cohesion constant that depends upon the type of material being scoured and it varies between 0.04 to 0.06. For a sticky interlocking matter the k value is taken to be 0.6 whereas for ungrounded sand material like it k value is taken to be 0.04. So, this is their now, actually this is 0.4 0.6.

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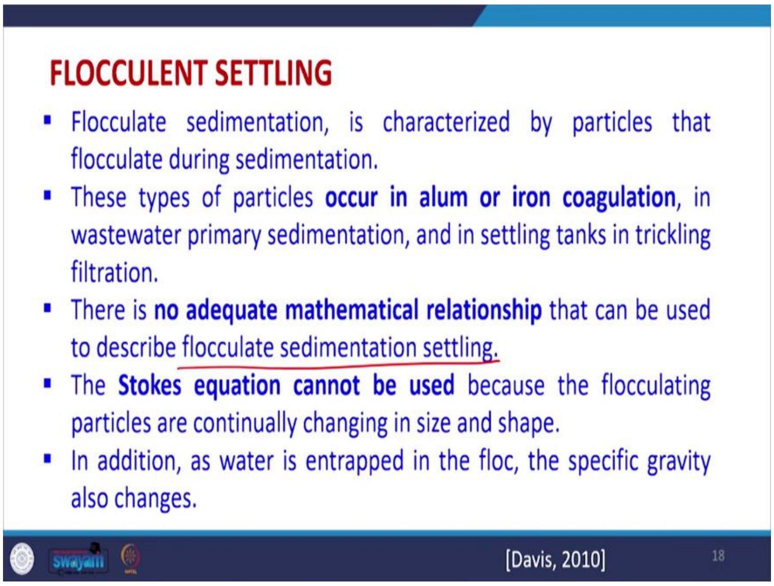

Now, going further, there is another case that I told that in place of discrete settling we have flocculent settling. So, flocculate sedimentation is characterized by particles that flocculate during sedimentation. These type of particles occur settling may occur in the case of like alum or iron coagulation which is very common, in wastewater primary sedimentation and in settling tanks in trickling filtration, there is no adequate mathematical relationship that can be used to describe the flocculate sedimentation settling.

The stokes equation cannot be used because the flow flocculating particles are continuously changing in size and shape in addition as water is entrapped in the floc, their specific gravity also changes this is their So, this is the flocculation technique.

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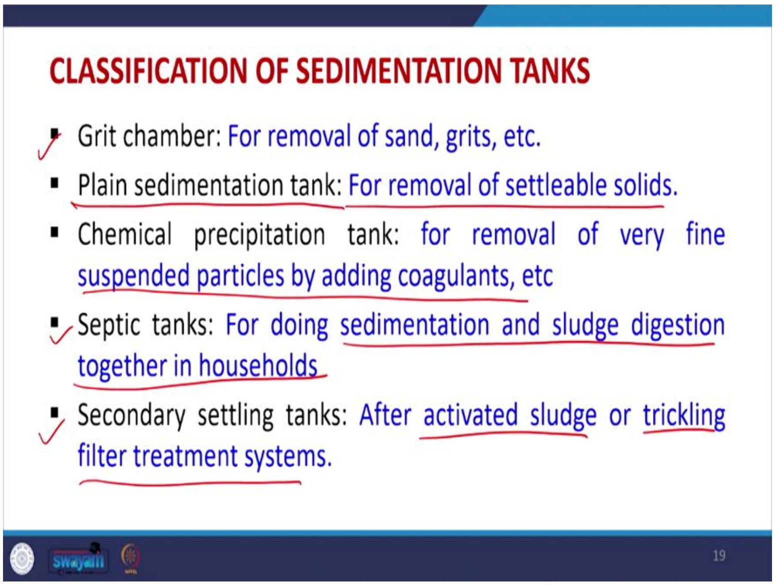

Now, there are different types of sedimentation tanks which may be used in the wastewater treatment. So, like first thing is that grit chamber for removal of sand and grits. So this is used in the initial stages itself. So, we know that settling is happening here or sedimentation is happening. So, grit chamber is very common. Then we have a plain sedimentation tank for removal of settlealable solids.

So, this is used for settlealable solid here we do not use any coagulant or flocculent because solids are by themselves bigger in size or they have very good density, so, they settle down. So, we have a plain sedimentation basin where the settling may happen, then we have a chemical precipitation tank for removal of very fine suspended particles by adding coagulant etcetera.

So, this is chemical precipitation tank for removal of very fine suspended particles etcetera. So, we can use them then septic tanks which are very common, what doing sedimentation and sludge digestion together in the household. So, this is in the residential residences where they have there is no common effluent capture.

So, for them the treatment has to be done within the residence. So, we have generally septic tanks, then these septic tanks sedimentation and sludge digestion occurs together, then we have secondary settling tank which is very important for biological process design. So, after activated sludge or after trickling filter systems are in the simple bonds also this settling happens, secondary settling happens after activated sludge or trickling filter treatment system.

So, this is the sedimentation basin our secondary settler is there and we actually use the sedimentation as one of the most basic method.

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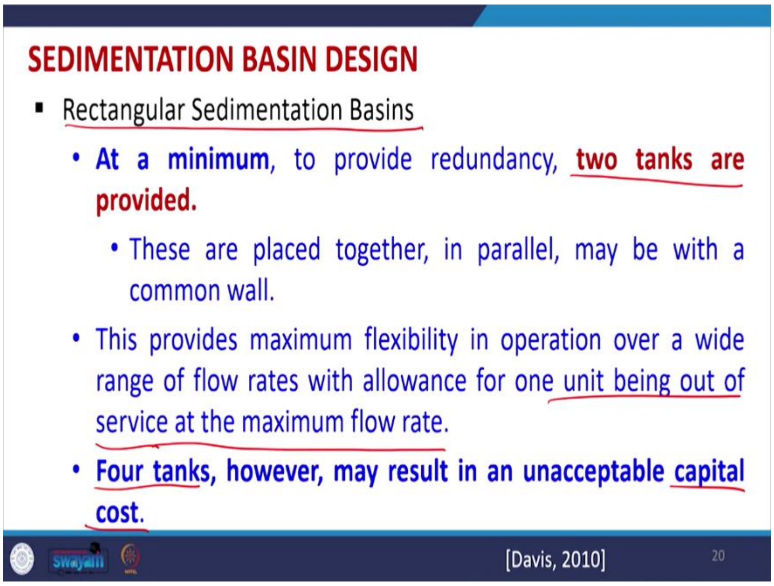

Then sedimentation basin design. So, for rectangular sedimentation basins, at a minimum to provide redundancy two tanks are used generally what we do is that for rectangular sedimentation basins, we may use two tanks or more these are placed together in parallel and maybe within a common wall also, this provides maximum flexibility in operation over a wide range of flow rates with allowance for one unit being out of service at the maximum flow rate.

So, it is possible that one unit the sludge have been captured a lot and that sub sludge removal has to take place. So, under those conditions that one way out. So, another maybe use many times please have two tanks, we can go for higher four number of tanks. However, as we go up the capital investment also happens. So, it may be possible that it may not be acceptable for the this the owner to have four tanks or otherwise, but two tanks are very common.

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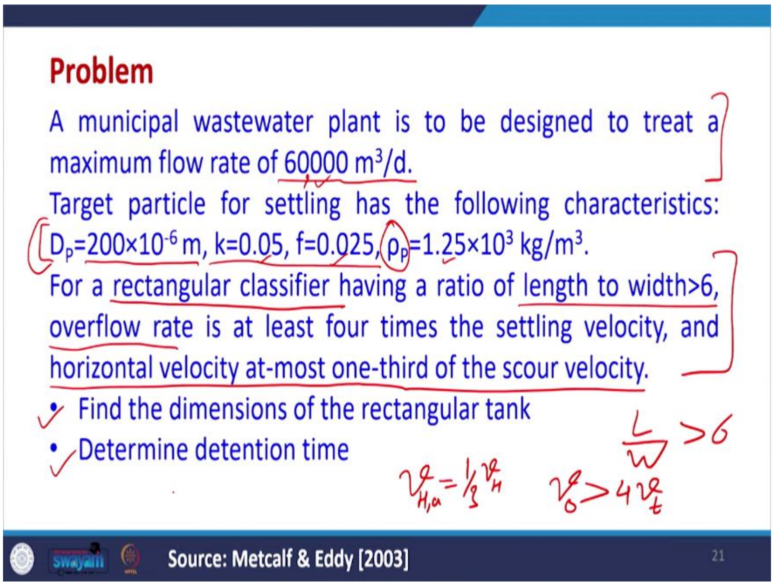

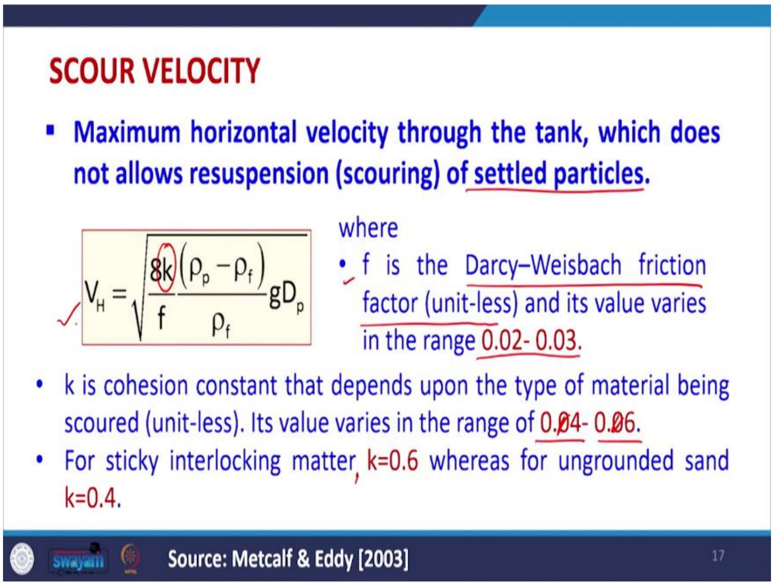

Maximum horizontal velocity through the tank, which does not allows resuspension (scouring) of settled particles.

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

Now, we will be solving some question here before ending the sedimentation thing. So, we have a problem a municipal wastewater plant is to be designed to a treat a maximum flow rate of 60,000-meter cube of water per day that in the settling basin or sedimentation basin, it is designed to remove all particles of diameter 200 micron or 200 into 10 raise to minus 6 meter and it is being given that for this condition that k value is 0.05 f value for is 0.025 and rupees the particle density is 1.25 into 10 raise to 3 kg per meter cube.

Now, we have to design a rectangular classifier having a ratio of length to width of greater than. So, the area which is available in such a manner that we can use the length to width ratio of greater than 6. Overflow rate in this case it is suggested that the overflow rate is at least four times the settling velocity.

So, that means, the v_0 is at least greater than the 4 times of the terminal velocity and the horizontal velocity at most one third of the scour velocity that means, the actual horizontal velocity actual V_H actual is one third of the scour velocity V_H which was given in the this is scour velocity. So, this is what is being suggested. Under this condition, we had to find out the dimension of the rectangular tank and determine that detention time also, this is being asked. So, at least in the actual condition, any treatment unit or any plant manufacturer will only give this data 60,000-meter cube per day.

So, we have to learn that from the particle size distribution we should know that what should be the target particle we should consider, then from the literature, we can find out these values or we can calculate then rho p also we have to determine the particle density these assumptions are based upon our own condition it they may change depending upon the cost the area available etcetera. And the efficiency which is desired. Now, for the present condition we will solve at this the data given.

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Solution

$$V_H = \sqrt{\frac{8k}{f}\frac{(\rho_p - \rho_f)}{\rho_f} g D_p} = \sqrt{\frac{8\times0.05\left(1.25\times10^3 - 10^3\right)}{0.025\times10^3} 9.81\times200\times10^{-6}}$$
$$= 0.08853 \text{ m/s}$$

Actual horizontal velocity $= V_H/3 = 0.02951$ m/s.

$$u_t = \frac{g(\rho_p - \rho_f)D_p^2}{18\mu_f} = 5.44\times10^{-3} \text{ m/s}$$

Source: Metcalf & Eddy [2003]

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$$V_H = \sqrt{\frac{8k}{f}\frac{(\rho_p - \rho_f)}{\rho_f} g D_p} = \sqrt{\frac{8\times0.05\left(1.25\times10^{3}-10^{3}\right)}{0.025\times10^{3}}9.81\times200\times10^{-6}}$$

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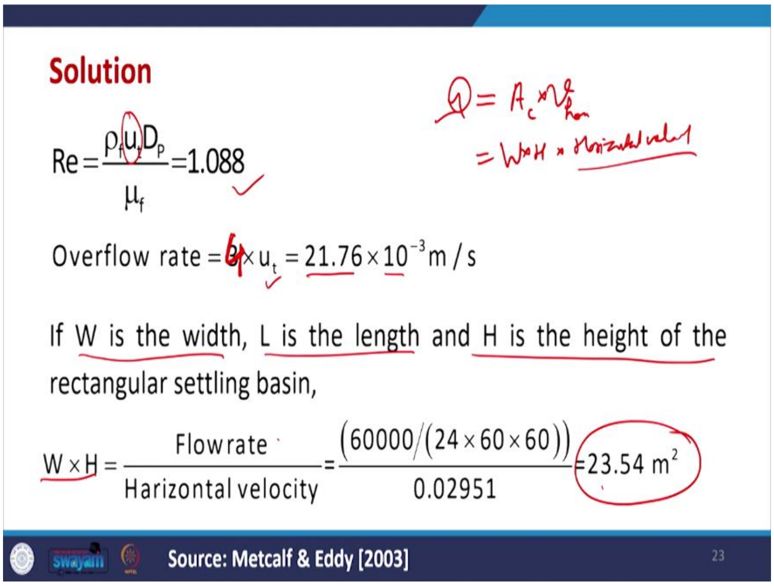

$$Re = \frac{\rho_f u_t D_P}{\mu_f} = 1.088$$

$$\text{Overflow rate} = 3\times u_t = 21.76\times10^{-3} m/s$$

$$W\times H = \frac{\text{Flowrate}}{\text{Harizontal velocity}} = \frac{\left(60000/(24\times60\times60)\right)}{0.02951} = 23.54 \text{ m}^2$$

Now, for this first we calculate the scour velocity. So, it is scour velocity is given by this formula V_H is equal to 8k by f under root rho$_p$ minus rho$_f$ rho$_f$ g into D_p. So, we keep all the here for density of fluid we are taking for the water. So, this is equal to 10 raise to 3 and we solve it using all the values which are given and ultimately the scour velocity comes out to be 0.08853 meter per second. Now, it is suggested that the actual horizontal velocity needs to be one third of that, so, that means, V_H by one third so, it is 0.02951 meter per second. Now, next we calculate that terminal velocity. So, for this the terminal velocity equation is given by this we are assuming that the laminar flow conditions are behaving that is why directly the

Stokes law equation has been used and we are using the viscosity of water for finding out this.

So, under this condition the terminal velocity comes out to be 5.44 into 10 raised to minus 3 meter per second this is given now, under this condition if we use this terminal velocity the Reynolds number comes out to be this, so, which is actually. So, that means that our assumption of laminar flow condition is okay and we can go ahead now, it is suggested that the overflow rate has to be four times this is four actually four times the u_t So, this is 21.76 into 10 raised to minus 3 meter per second, this is the overflow rate. Now, if W is the width, L is the length and H is the height of the rectangular settling basin. So, W into H should be equal to flow rate divided by horizontal velocity.

So, this is clear because Q the flow rate is equal to cross sectional area into horizontal velocity. Now, this is the cross sectional area is actually W the width into height and this is the horizontal velocity. So, from this equation we can calculate that W into H is equal to flow rate divided by the horizontal velocity which has been calculated already. So, from this the area the cross sectional area the height into width is coming out to be 23.54 meters square as per the present condition.

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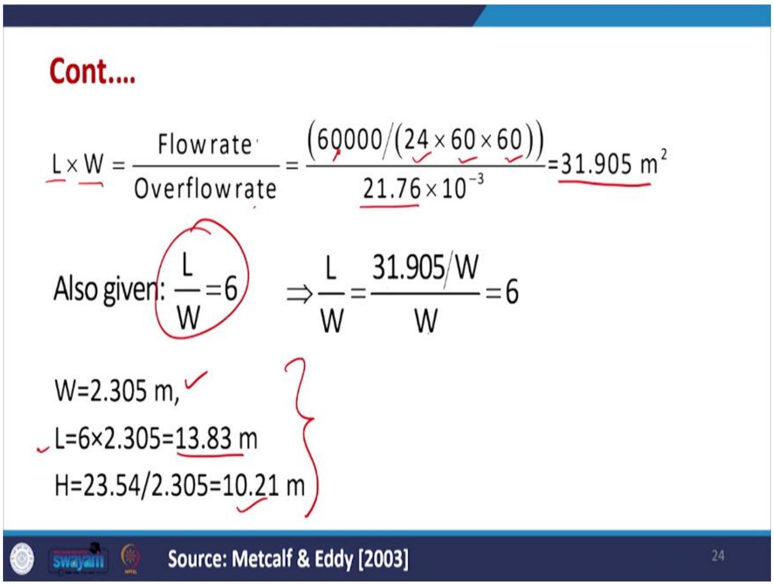
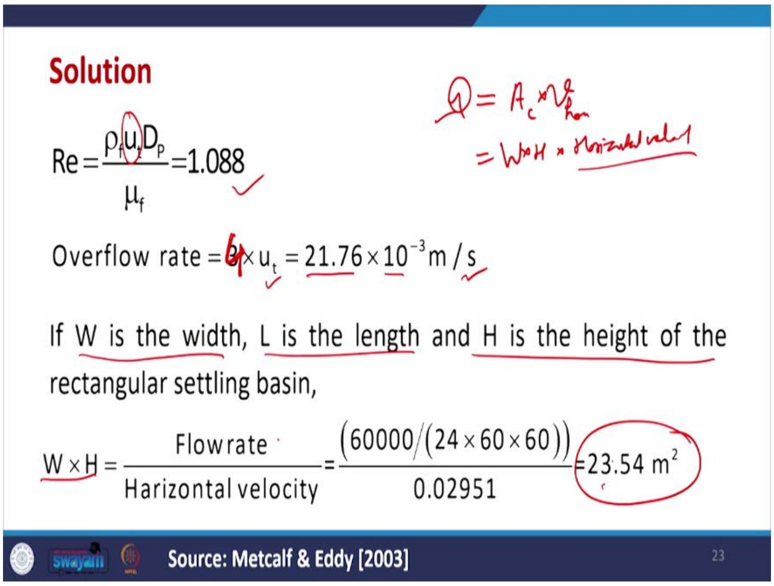


$$L \times W = \frac{Flowrate}{Overflowrate} = \frac{(60000/(24 \times 60 \times 60))}{21.76 \times 10^{-3}} = 31.905\ m^2$$

Also given: $\frac{L}{W}=6 \quad \Rightarrow \frac{L}{W}=\frac{31.905/W}{W}=6$

W=2.305 m,
L=6×2.305=13.83 m
H=23.54/2.305=10.21 m



$$Re=\frac{\rho_f u_t D_P}{\mu_f}=1.088$$

$$\text{Overflow rate}=3\times u_t=21.76\times10^{-3}\,m/s$$

$$W\times H=\frac{\text{Flowrate}}{\text{Harizontal velocity}}=\frac{\left(60000/(24\times60\times60)\right)}{0.02951}=23.54\ m^2$$

Going further similarly, we can calculate the surface area using the length into width is equal to flow rate divided by overflow rate, the flow rate is given to be 60,000-meter cube per day. So, now, it is converted into per second because the overflow units are in per second. So, we calculate 24 into 60 into 60 this is the unit will become in per second and overflow rate is given to be 21.76 into 10 raised to minus 3. So, that means, this area is coming out to be 31.90-meter square.

Now, it is also given that L by W is tentatively equal to 6. So, under this condition, so, here L by W was equal to this. So, L by W and here from here we are taking L is equal to 31.905 divided by W, again divided by w is equal to 6 that means, if we solve this the W value will be coming out to be 2.305 meter, the length will be coming out to be 6 into W.

So, this will be 13.83 meter and the height will be obtained from In the previous equation, which was given here 23.5 four L into W into H. So, this from here 10.21. So, we have all the dimensions are obtained to us, so, we will cross check with respect to the available area whether it is fitting to our conditions or not otherwise we can modify this condition. So, as to further change these dimensions and it still it should work out.

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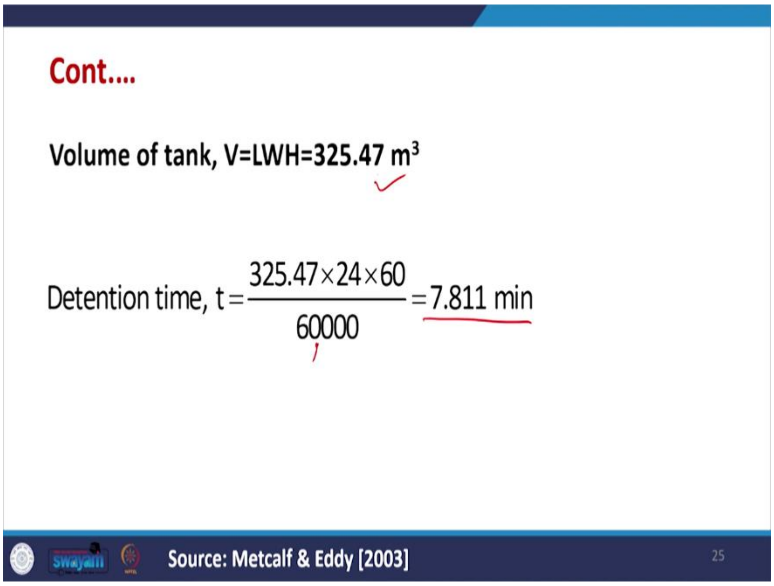
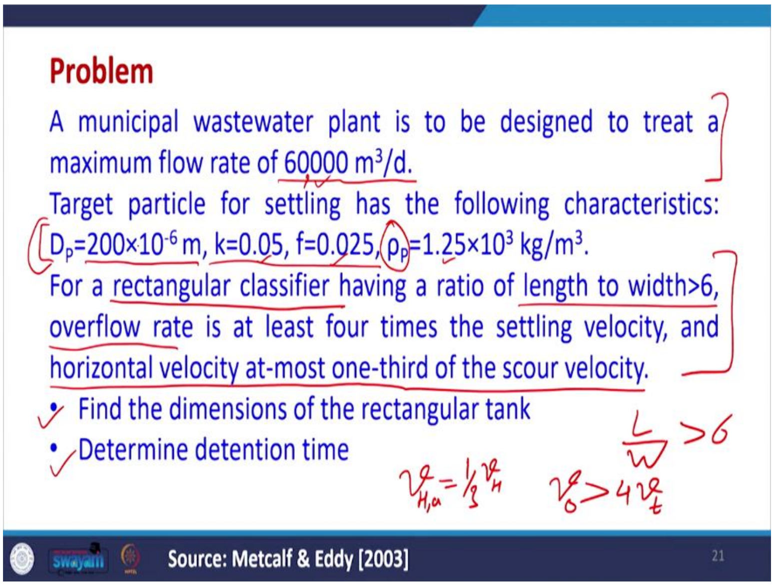


Volume of tank, V=LWH=325.47 m^3

$$\text{Detention time, } t = \frac{325.47 \times 24 \times 60}{60000} = 7.811 \text{ min}$$



The volume of tank is coming out to be 325.47-meter cube, that detention time will be because this is the meter cube and this is the flow rate which was desired. So, if you solve it, it will be coming out to be 7.811 minute. So, this is the way we can design a settling tank for treatment of wastewater for a particular target of particle.

So, this is how we go ahead certainly we have to assume a lot of data and we can change these data depending upon the requirement and space available, the cost of treatment, the efficiency desired etcetera. So, this is how to design. So, we will go further ahead with the learning other methods related to biological process design in the next lecture. Thank you very much.