Wastewater Treatment and Recycling
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Lecture - 26
Wastewater Treatment Units: Primary Sedimentation

Hello friends. So, in this lecture we are going to talk about Primary Sedimentation. Earlier we discussed about some of the preliminary units in the form of screening grit removal and if needed one can go for a equalization tank. Now, primary sedimentation is one of the very basic units of any sewage treatment plant and is employed in fact, quite a few of the industrial wastewater or industrial effluent treatment plant as well.

Now, it is a primary unit as we discussed earlier that there are preliminary units or primary units which often or some people club as a primary unit everything. So, this is a primary unit and this is typically one of the last stages of primary treatment and beyond this or post this primary treatment next step is the secondary treatment which are the basic biological systems.

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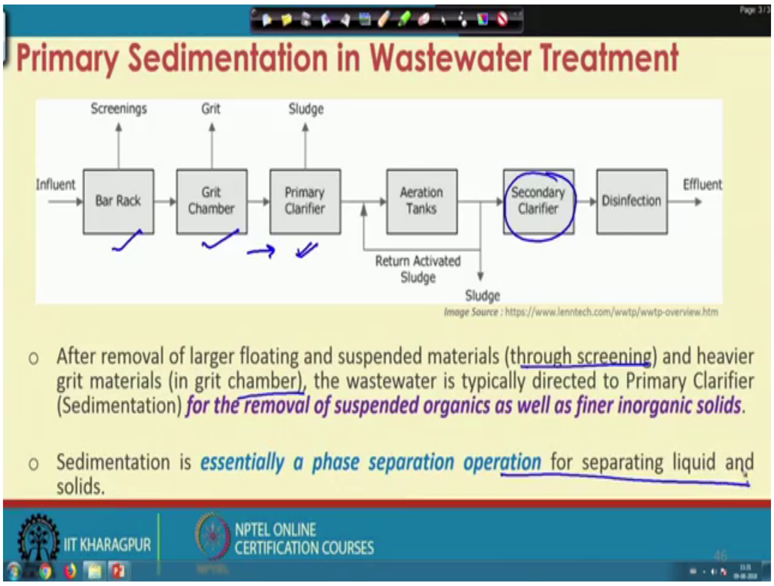

So, we are going to see the sedimentation, details of sedimentation in the next couple of lectures and the first thing is to basically see where this unit is placed in a treatment plant in a sewage treatment plant for sale. So, if you see the screening we discussed earlier, grit chamber we discussed earlier and if needed we can provide a equalization depending on this. But as we said that particularly in the sewage treatment plant and large sewage treatment plant because, the flow is adequate because the kind of inflow comes from the domestic or commercial circles. So, there is not much of the variation in terms of quality as well as in terms of quantity and equalization is avoided.

So, we can actually the outflow from the grit chamber could be connected to the primary clarifier or primary sedimentation. Why we use primary term is because there is another sedimentation which is typically used in the typical sewage treatment plants in the form of secondary clarifier. So, in order to distinguish between which clarification we are talking about, which kind of sedimentation we are talking about we prefix them with primary sedimentation or secondary sedimentation or secondary clarification.

Now, in a sewage treatment plant when we have received the water we have removed the larger floating and suspended materials through screening and the heavier grit materials in the grit chamber. Then what is left typically is the further suspended materials in the form of some of the organic solids because, organic suspended materials are not removed in the grit chamber because of their lighter nature or lesser specific gravity. And there are fines in organic, finer inorganic sediment in inorganic sediments or inorganic particles which are also not removed in the grit chamber because of small size and as you recall we provided very little time in the grit chamber retention time of say a minute or under a minute.

So, in that time period the settling of the final particle does not take place and those finer sediments weathered inorganic or whatsoever in the nature are settled in the primary clarifier. As well as some of the organic solids, organic suspended materials may also get settled in the sedimentation basin, so that is the basic objective of your primary clarifier to settle out the sediments.

Now, this is achieved essentially by a phase separation process. So, what happens that a sedimentation is basically your typical unit operation where a phase separation takes place and as a result of that the solid phase, which is there present in the water earlier in the suspended form gets settled by the virtue of gravity and the water or aqueous phase becomes free of those particles which get settle down and then the overflow of the water is collected and processed further. So, that is essentially the separation of liquid phase and solid phase that is what typically takes place in a primary sedimentation basin it. In fact, valid for all the sedimentation even the secondary sedimentation also there is a phase separation takes place.

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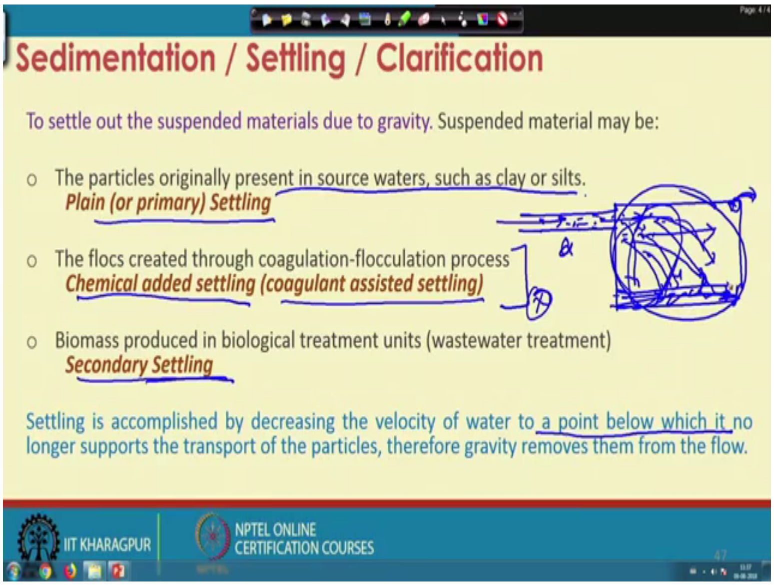

But, why we are calling it primary or then secondary that kind of thing, depends on what is the intent of the or what is the basic objective, what exactly we want to remove. So, as we said if we want to remove some of the let us say finer sediment particles, which has not settled in the grid chamber or some of the organic suspended particles of relatively lower specific gravity. Lower means not lower than water, if it is the specific gravity is lower than water it is not going to get settled, lower here we are in referring with respect to the grit. So, grit as we took the specific gravity of say 2.65 or something, so some particles which come with the lower specific gravity of 1.2 or 1.3, 1.5.

So, they typically do not settle in a grit chamber, but they can be settled in the primary sedimentation basin, so typically if we see the idea is to settle out the suspended materials due to gravity. Now this suspended materials could be the particles which are originally present in the surface waters or the particles which are present in the surface water such as silt, clay those kind of thing. So, when we intend to settle these we call it plane or primary settling it could be flocs which are created through coagulation flocculation process. When we do that we call that as a chemical added settling or coagulant assisted settling. Because, we first had a coagulant and then the formation of flocs takes place, the colloidal particles gets destabilized, they attach, they from the flocs and then they settle. So, this type of settling we typically refer as covalent assisted settling or chemical added settling; this has a very less application in the wastewater treatment.

Generally in water treatment because when we get the sources there is a lot of colloidal particles which we essentially want to settle down, here in the wastewater treatment typically coagulant addition is avoided particularly the sewage treatment.

For some industrial processes we may go for the chemical settling depending if there is a high dose of metal concentrations heavy metal concentration, so through neutralization or through chemical precipitation of the metals we intend to basically settle down or reduce the some of the concentrations of those metals. However, in typical sewage treatment plants the coagulation flocculation process is not performed because, anyway these finer suspended are settled in the primary settling. And then it is the secondary settling or biological which is typically adopted after the biological processes takes care of the rest of the material, even including the colloidal particles if available.

So, that is generally not there in the wastewater treatment processes, then we go for we can use this settling concept or settling phenomena for the settling or phase separation of the biomass which is produced from the biological treatment units. Which are there in the secondary treatment typically in the wastewater treatment so this is called secondary settling. And secondary settling is also one of the important steps or important units in the process of the wastewater treatment.

Now, this settling or this what whether we can call this settling or clarification or sedimentation they are essentially considered like as synonyms particularly in terms of the waste water or water treatment processes. So, the settling is typically accomplished by decreasing the velocity of water. What happens that we are having a tank; now, there is a water which actually comes in the form of a channel or through a pipe the cross sectional area of this channel or pipe is very low, so we get discharged at a significant velocity and this velocity keeps these particles in suspension. But when this flow is released in a tank like this for say, what happens that the cross sectional area of the tank becomes very high and as a result the velocity decreases substantially.

So, the velocity through this tank; velocity of water through this tank is decreased and it is decreased beyond the point or it is decreased to a point below which it no longer can support the transport of the particles. So, what happens those particles which were present over here when they are released in the tank so since the velocity of water has decreased, so these particles actually settle down. These particles get settled down in the tank itself depending on their way, depending on their specific gravity, depending on the residence time provided in this chamber.

Since, these particles get settle down they get removed, because if they settle down here and you collect; let us say overflow from this point forward. So, water which is overflowing from this tank will be devoid of these particles which will be collected eventually towards the bottom of the tank. So, that way this is the basic concept of settling, the basic idea of settling is that the velocity is reduced to a point, below which the particles does not move along with the water but rather settle down.

So, the settling is essentially by the gravitational forces because, the particles have their weight and if there is specific gravity is higher than the water, if there is specific gravity is higher than the water they will have gravitational force which is exceeding buoyancy forces. And as a result they will have a net velocity in the downward direction which makes these particles settle. There might be lighter particles also coming in which are lighter than the water, though those particles when you reduce the velocity of the flow and water even cannot support the movement of those particles. So, those particles which are lighter than the water will actually float up.

So, if in case you are having say oil or grease; oil or these kind of things present in the water or some other lighter lipids or those kind of materials which are present in the water in unsolvable form, so they will eventually float on the top. So, like sedimentation is the process through which these particles settle at the bottom, there is another process which is skimming, so skimming is further in oil and grease removal typically.

So, the particles which are lighter when you allow them to retain in a tank they will float at the top and then from the top you can collect all the material all such materials a top layer you can collect and your water is divided or is free of those kind of impurities. So, a skimming tank is another optional step like equalization tank we discussed, so it skimming tank if your impure if your water is having these sort of impurities, generally your municipal wastewater does not have too much of such impurities.

So, skimming is avoided in municipal wastewater treatments, but in some industrial effluent treatments the skimming becomes the important step if it is having let us say those kind of lightweight materials, light weight suspended materials, so that can be collected that can be captured in a skimming device where from where you remove oil grease and all these things from the top. Coming back to the sedimentation process, so it is as we say that light weight may move up the particles which are having higher specific gravity then the water will settle down and this is the concept that typically is used in the process of sedimentation.

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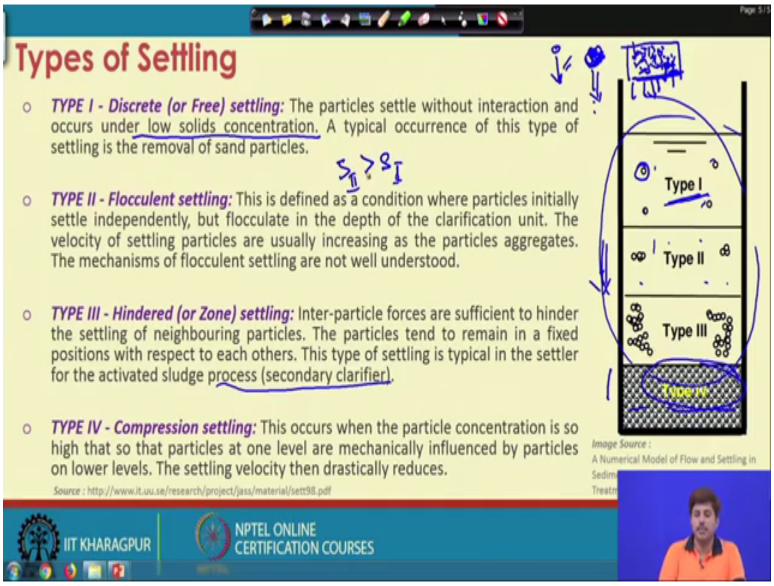

Now, if we see there are four types of settling; there are four distinct types of settling, the first one which is called discrete settling or type 1 settling or some people also refer it as free settling is actually a type of settling. Where the particle settles without interaction, each particle settles as one single discrete entity, one single particle or settling is free from the interaction with any other particles. So, this type of settling is called basically your discrete settling which are under when there is low solid concentrations, when there is not enough interaction between particle to particle. So, that kind of things and this typically occurs in a settling, if you let us say have a sand particles or those kind of things you leave, so each particle settles by it is own.

So, those kinds of settlings is called type I settling or discrete settling, then we have another type of settling which is called flocculent settling or type II settling. So, this is a condition where the particles initially settle independently, but in the process as soon as they come down, so let us say you are having a system like this so particle is initially what is happening is settling independently. But when they move down their concentration say increases little or their, then they may have a chance of interacting with each other and that results in the particles agglomerating and forming flocs.

So, what happens that they flocculate, when they settle; when they go deeper in the clarification unit or in the clarification basin and the velocity of these settling particles increases because, the when they form flocs, when they form a larger aggregates the size of the particle or the weight of the net particle increases and as a result they settle at a relatively faster speed. So, the exact mechanism is not well understood, but for the design purpose we follow the major concepts of the discrete settling for the flocculent settling as well.

Then there is another type of settling which is called types 3 settling also called hindered or zone settling. So, in this process there is a the different particles settle as a zone, that is why this is also called zone settling. So, what happens you see in the discrete settling the particles were settling independently, so one particle is settling at a time that is your discrete settling when you have formed the larger flocs. So, a clump of particles settling together this is your propellant settling and since the mass of this particle or the weight of this particle is higher; size of this particle is higher, this settles relatively at a higher settling speed as opposed to that free settling or as opposed to the discrete particles which were settling under type I.

In type III what happens, type III also a lot of particles settle together similar to flocculent settling, but they do not form flocs. So, if there are let us say these many particles over there and all of them are settling together, but their intra particle distances are not changing. So, there is specific gravity and their weight or those kind of things are not changing and the net thrust which is applied on this becomes relatively higher. So, what happens that since inter particle forces are; since inter particle distances are not changing their inter particle forces are sufficient enough to hinder this process of settling pay of the other particles.

So, if this particle is settling this particle will have some intramolecular forces with this, so this avoids this and in process this also has to be settle down. So, entire thing settles as a as a zone, but because of this up thrust or because of them not agglomerating and finding a larger mass rather they are settling as a zone. So, we call that as a zone settling or we call that as a hindered settling where the velocity of settling is lesser as opposed to the flocculent settling or discrete settling.

This is typically case when we settle biomass in the activated sludge process or secondary clarifier, we will discuss that in the next week, what happens in the secondary clarifier and then there is type IV settling which is also referred as compression settling. So, this occurs when the particle concentrations is so high that the particle at one level are mechanically influenced by the particle on the other levels.

So, the particles which are at the bottom will get mechanically influenced for them from the upper particle and as a result the settling velocity is drastically decreased because, the settling is due to the compression of those particles and that is why this is called compression settling and very limited scope of compression, since the scope of compression is very limited. So, the velocity of settling is very limited and the scope of settling also is very limited because, it is the physical compression of the particle it is not that the particle are settling in the water in fact.

So, because the particles are being compressed because of the huge mass on top of them and that leads to some sort of partially getting compressed resulting in the compression settling. So, these are the 4 different types of settling. Now, if you see the velocity wise so you have let us say settling velocity in type I something. Now, since your type II when the particles are forming agglomerate they are having the agglomerate or this as a bigger particle size with a high higher weight. So, they settle at a faster speed so what you will see that the settling velocity of the type II settling is higher than the your is actually higher than your type one settling; velocity we can refer it as V also.

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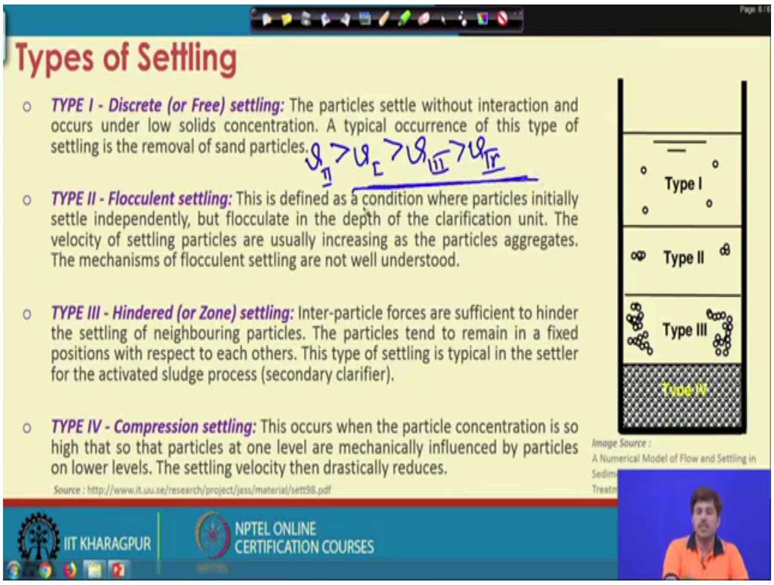

So, let us say the settling velocity of the particle in type I is lesser or settling velocity of the particle in type 2 is greater than the settling velocity of particle in type I. Whereas in type III when there is a hindrance occurs, when the zone settles and a hindrance occur the settling velocity is reduced. So, the settling velocity under type III is smaller than the settling lost in type II as well as settling velocity in type I or the discrete settling particles.

Because, of these intramolecular forces, putting disturbance in the settling process and the least velocity is actually the settling velocity in type IV when there is a compression. So, since there is not much settling under compression so the settling velocity is also least. So, this is the typical order of settling velocity under these different 4 types of settling.

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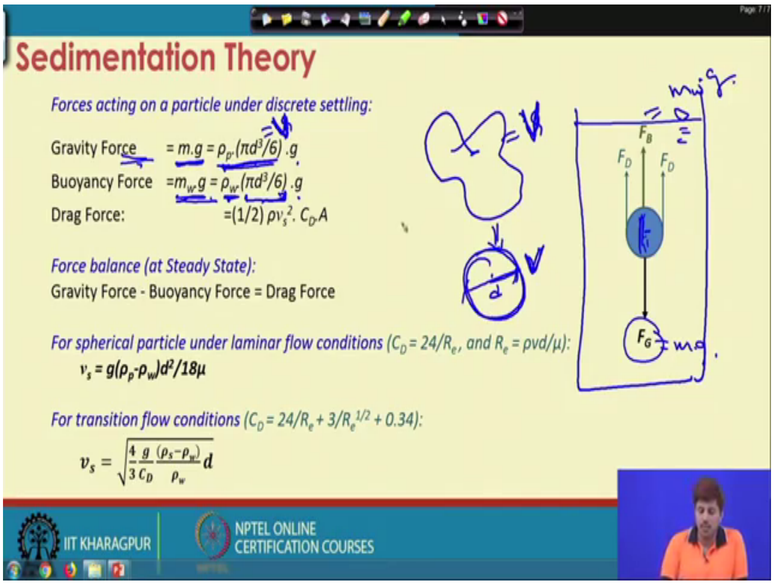

Now, if we see the theory of settling or sedimentation theory what typically has, so if we have a particle, let say this is a particle which is settling in a column or in a fluid. So, in a fluid this is a particle which is trying to settle down, now what kind of forces act on a particle, there is some weight of this particle or mass of this particle which will lead to the gravitational force which will be in the downward direction. So, there is a gravity force acting in the downward direction and this gravity force is equal to the mass of particle into the gravity. And mass of particle can be given as the density of the particle into the volume of the particle. So, if it is a spherical particle, consider it as a let us say spherical particle, so it is volume become pi d cube by 6. So, normally for settling purpose we consider spherical particle or if the particles are not a spherical we determine equivalent spherical dia.

So, we the entire volume of the particle, let us say you have a particle of this shape the total volume is V of this particle. So, we take an equivalent spherical particle of volume V and take the dia of this particle, that is how we represent the settling of the particle. So, if the equivalent is spherical dia is d, so pi d cube by 6 becomes the volume of the spherical particle. So, density into volume will be give you the mass into g will be the total gravity force on this particle which is acting over here which is equal to m into g.

Now, then because it is settling in a water it is settling in a fluid, so it is in the process, it has displaced some fluid it is inside the fluid. So, the amount of fluids it has displays equal to the mass of the fluid into gravity there will be a bouncy force acting on that and if it is a spherical particle, so the place where buoyancy force acts and gravity force acts are going to be the same. So, there will be a bouncy force acting which will be equal to the mass of water displaced into g. And mass of water displaced is going to be equal to the density of water into the volume of the particle, because a particle is going to displace the mass of water equal to it is own volume.

So, there is the volume of the particle displaced volume of the particle into the density of the water which is displaced into g will give us the buoyancy force, which is equal to mass of water into g and then there is a drag force acts. So, if a particle is trying to settle in a water this thing, if a spherical particle is trying to settle, so let us say this is my spherical particle, let us clear these things up.

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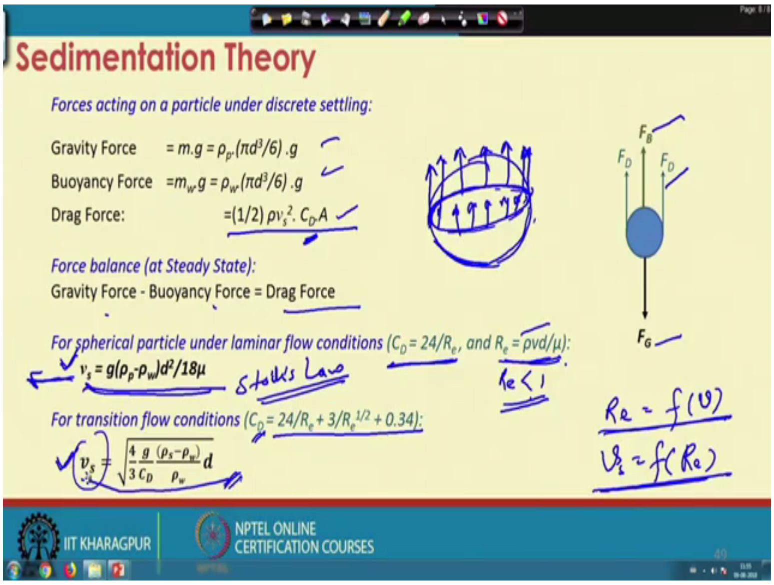

So, if this is my spherical particle and say this is the cross sectional area of this. So, when this is settling in the water as opposed to the motion of the particle because particularly if it is settling down, so there will be drag force acting on the particle where it is being in contact with the water, where there is a drag applied in contact with the water.

So, drag is applied where? Drag is applied on the surface which is getting dragged when the particle is settling and which surface is getting dragged it is not these surfaces which are getting dragged, it is actually the equivalent circular surface which is getting dragged. So, there will be drag force applied on basically the entire surface, when this particle is getting down. So, this will be the direction of kind of drag force and this drag force applied is equal to half rho v s square C D into A where C D is the coefficient of drag.

So, that way we can have these 3 forces that act on this particle, so there is drag force, there is bouncy force and there is gravity force and this is how we get these 3 forces.

Now, what happens that under a steady state if we allow this by water in some time or if your inflow outflow and dimension of the tank are all same. So, your particles are bound to reach steady states at some stage so and in the steady stage we can achieve a force balance, so there will be gravity force minus buoyancy force is going to be equal to the drag force.

So, if we follow this principle, if we equate these forces, so what we can see is that the particularly here we have a C D component which is a drag component, now this drag component defines or governs how we are going to get the velocity of the particle. So, by equating these forces we can get the settling velocity equal to 4 by 3 g by C D, density of particle minus density of water divided by density of water into d. So, that is the velocity settling velocity we are going to get, this is the typical settling velocity that we will be getting from equating these forces.

Now, there are some simplified cases, if we have let us say a laminar flow condition where your Reynolds number is less than 1 say. So, Reynolds number which is expressed as rho v d by mu and for laminar flow condition this coefficient of drag is typically taken as 24 by Re. So, 24 by Reynolds number so we can take this as 24 by rho v d into mu and we can actually replace this thing C D along with this and what we get is the typical stokes law what we call as. So, this is your stokes law of settling velocity. So, a particle settling under laminar flow condition in a water will have a settling velocity equal to v equal to g density of particle minus density of water into d square divided by 18 mu. So, we earlier saw this while discussing the grit chamber in the previous lecture.

So, this is how we get the settling velocity of particle under laminar flow condition, if it is a turbulent flow condition we will use the transition flow this thing where C D equal to 24 by Re a plus 3 by Re to the power half plus 0.34. So, that way we can actually compute the based on the Re we can compute the drag coefficient and based on drag coefficient we can compute the velocity. Now, this becomes little tricky because installation of Re needs Re is actually or a function of velocity and your velocity is actually a function of C D which is eventually a function of Re, so that way velocity becomes a function of Re.

So, Re is a function of velocity and velocity is a function of Reynolds number. So, that way we will have to do a trial and error if it is not following stokes law where we can state forward determine the settling velocity of the particle. If it is not under laminar flow conditions, so let us say we started with the stokes law we determine the settling velocity and once we know the settling velocity for a given size of particle or this thing we determine the settling velocity. And once we know the settling velocity we computed the Reynolds number and we find out that Reynolds number is less than 1 that then our the estimate of the velocity that we have estimated is correct.

But, if we figure out that Reynolds number is more than 1 is not actually less than 1; that means, the estimate of the velocity that we made is incorrect. So, what we do we still use that estimate of the velocity and compute the Reynolds number and use the Reynolds number to find the C D and then estimate a new velocity. So, we get another estimate of velocity, again even this estimate of velocity may not be correct because we have used a drag coefficient based on a incorrect Reynold number because, Reynold number was derived from the earlier velocity.

So, since Reynold number was incorrect our drag coefficient would be incorrect and our said estimate of settling velocity would also be incorrect. But what we do, we do several trials and error that, so we do we now take this settling velocity compute the Reynold number, compute the drag coefficient and recompute the settling velocity and we do it n number of times say 4 5 times. By which we get the value of v is not changing much are almost stabilizes the value of v as value of Reynolds number and value of that coefficients when they become more or less consistent or constant, that estimate we take as a estimate of the settling velocity. So, that is how we can basically estimate the settling velocity in such system.

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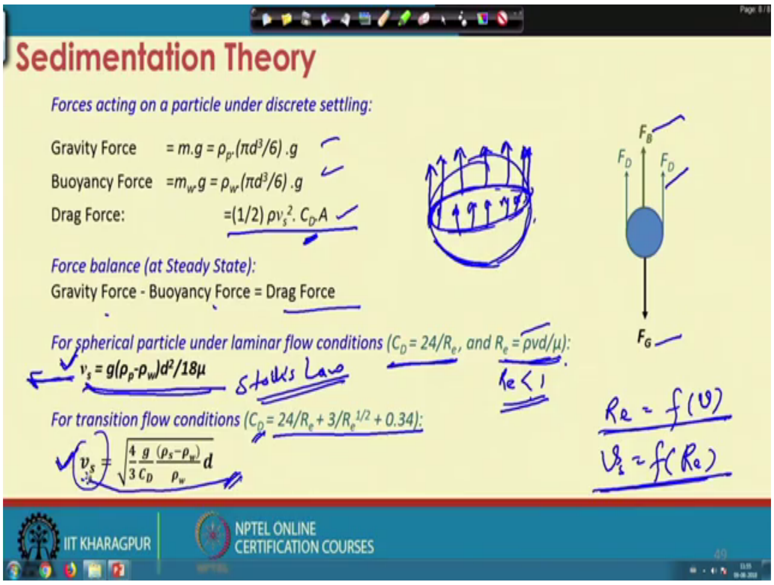

Now, if we see the how settling takes place in ideal settling tank, so what happens that there is a water which is say coming through an inlet and then we have mechanism through which typically we will talk about those mechanism. But we have a mechanism through which this water is because water is coming here at relatively higher flow. So, this flow is subsidized, this turbulence is reduced over here and water is allowed to enter through baffle or through perforated system at different heights in this zone that way. So, we can have a say perforated this thing or that kind of system or we can guide the water through the bottom that way.

So, there are these mechanisms through which the water is allowed, to first it is collected in the inlet zone and then from inlet zone it is allowed to pass through. So, typically there are 4 zones in a settling basin, zone means there is no separate zone as such, there is not a concrete walls parties like partitioning these zones. There may be separate zones like based on conceptual as well. However, for inlet zone we can have certain arrangements also at times in order to partition different, but otherwise also even in a simple single tank there would be 4 distinct or different zones which are needed for the entire sedimentation process. So, what happens the water enters first in the inlet zone and then from inlet zone it is guided to the second zone which is called a settling zone. So, it is the settling zone where this settling process takes place.

Now, if let us say different particles are entering at different levels, one particle is entering here one particle is entering here or say one particle is entering here. So, based on the size of the particle they will have their own settling velocity component and their own horizontal velocity component and that will result to a net velocity magnitude and it is direction, which direction the particle will move and with what velocity the particle is going to move. So, what happens that the particle moves will obviously be moving in the angular direction here. So, it will be coming downward what happens that if it is a little begin a particle which is having higher content, this may come here at the same point a small particle entering may have a lesser gravitational pull.

So, that the trajectory of that particle may not be that is steep and it may actually come here. Then similarly, one particle of say very fine is of this size is actually guided through here, while the another particle entering at this point a very small particle may have a trajectory like this. So, these different particles may have different trajectories over there and depending on the size of particle that one we want to remove we will have to dimensionalize the tank. Now, what happens is that when this particle actually takes a trajectory, so either it will hit the bottom somewhere. So, if let us say you are having heavy particle over here that will quickly come down here or the particle here, which will be coming down here.

So, the particle eventually either may hit this bottom zone or may hit this zone somewhere here depending on it is trajectory. So, the one which are hitting this bottom till this point are considered to basically moving into the sludge zone and then are considered to be removed.

So, there is this is the another zone third zone which is sludge zone, where the mass of the part where this particles that settle are get collected in the sludge zone. So, that is my third zone or sludge zone. And then I have a fourth zone which is outlet zone so, the particle outlet zone is from where the particle actually moves out of the tank. So we consider that any particle which has actually gone into the outlet zone which has not hit the bottom till this point, which has not entered into the sludge zone will go into the outlet zone and will that will be washed out from the or that will be basically move out along with the effluent from the tank.

So, these are the 4 distinct, 4 different zones of a settling basin, where there is inlet zone the particle comes and the initial turbulence is subsidized, then settling zone where settling process takes place. the particle which settles comes to the sludge zone and particles which do not settle, which actually moves into the outlet zone will be basically going along with the outflow of the water.

An ideal settling basin works on certain assumption that the first assumption is the flow is laminar, the impurities particles are evenly distributed in the whole area of the tank, the entrance and exit does not affect the sedimentation efficiency of the settling zone and the settled particle, the particles which are settled does not re suspend or does not come back in the system. So, these are the certain set of assumptions on which an ideal settling of the discrete particle works.

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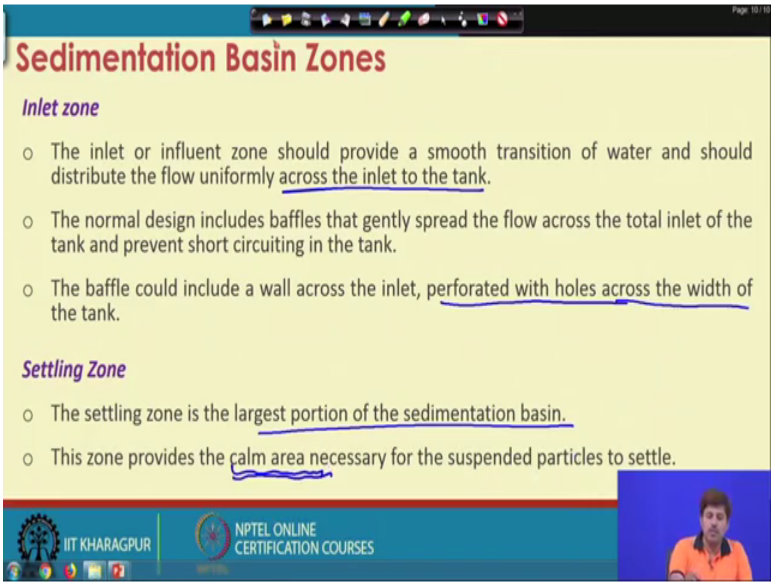

Now, the different zones that we were discussing so they have all these different aspects, so there would be inlet zone which is your responsible for taking the water in the tank and a smooth transition of water and should distribute the flow uniformly across the inlet of the tank. Then there is normal design includes baffle which are gently spread across the flow our, we can have basically perforated this thing with hole across the width of the tank which leads the smooth transition. The settling zone is the where the particles settle in the sedimentation basin and this zone typically provides that this static or calm area necessary for particles to settle. So, these are the things that happen in the settling zone.

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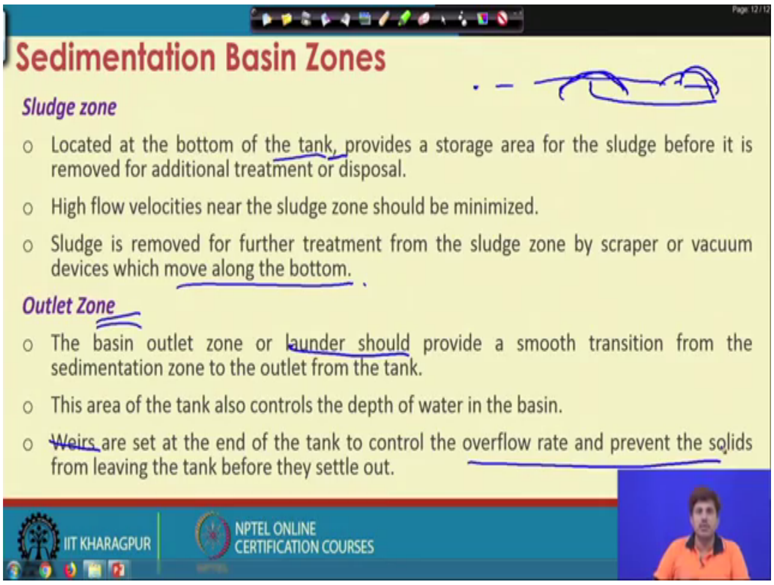

Then in the sludge zone what happens that, which it is typically located at the bottom of the tank, it provides a storage area for sludge before it is removed from the for additional treatment or for disposal purpose. The velocities or high velocities near sludge zone should be minimized, because if there is a high in a velocity in the sludge zone we will see the lot of particles coming into the resuspension. The sludge is removed for further treatment by a scrapper or vacuum devices which move along with the bottom in this zone. And outlet zone is typically your sort of weirs or launders which provide the smooth transition from the sedimentation zone to the outlet zone of the tank and this area of the tank is typically controls the depth of the water in the basin, how much is the depth of the water.

Because, if you have provided a weir so your depth of the water will be up till that weir because overflow goes into that weir or overflow goes into the launder if you have provided. So, it is eventually this zone which will govern the depth of the water in the tank and it will control the overflow rate and prevent the solids from leaving the tank which have settled out.

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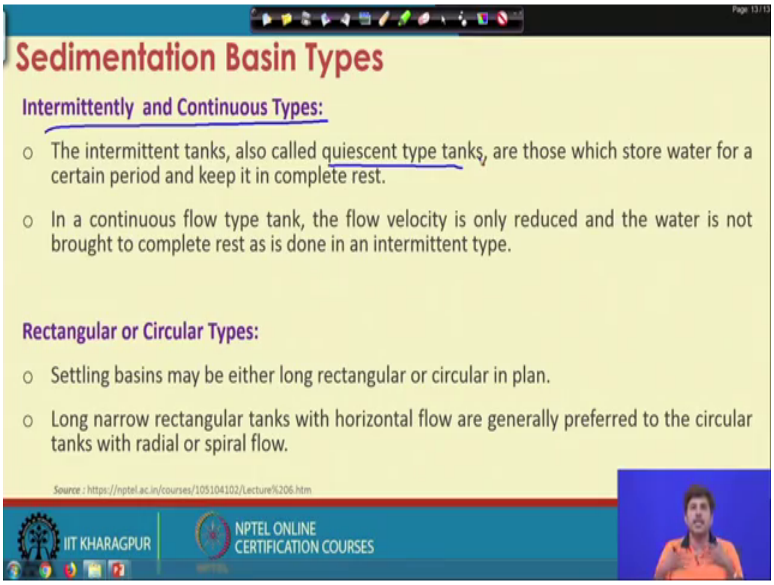

So, these are the, these 4 different type of zones in a sedimentation tank. Now, there are different types of sedimentation basins, so based on the flow regime we can say there are intermediate, intermittent type and continue type sedimentation basin. So, the intermittent tank which are also called quiescent type tanks, these are those who store water for a certain period and then keep the water at complete rest when the sedimentation takes place the water is overflowed.

While in continuous type of tank there is a flow connected there is an inflow and there is a continuous outflow and because of the dimensionalization of the tank the flow velocity is reduced such that the particles tend to settle down. So, it is usually continuous type of tanks which are more preferred because, batch operation or intermittent operation of the settling basin is difficult particularly in the large systems.

The classification or the different types of tanks may also be classified based on the shape of the tank. So, there are 2 shapes generally there rectangular shapes and circular shapes. So settling basin may either be a long rectangular type or in a circular type in the plan. Now, long narrow rectangular tanks are preferred over the circular tanks generally because, it avoids short circuiting or it sort of, in circular tank you may have radial or a spiral flows which intend more of mixing or from that kind of thing.

So, the efficiency of sedimentation may be reduced in such tanks, whereas in long rectangular tanks the flow regime is such that it is basically avoid short circuiting and provide good enough time for the fluid or for the particles in the tank, so that the settling can be appropriately take place. So, we will stop this last this lecture here only and in next class we will talk more about the putting through different arrangements concepts and some of the design aspects of the sedimentation tank.

Thank you.