Water Supply Engineering
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Lecture-28
Coagulation and Flocculation: Theory

Welcome back friends now we have moved to the sixth week for this course water supply engineering. And as we have started talking about water treatment so we will be continuing water treatment for couple weeks more and in this particular class we are going to start with coagulation and flocculation theory.

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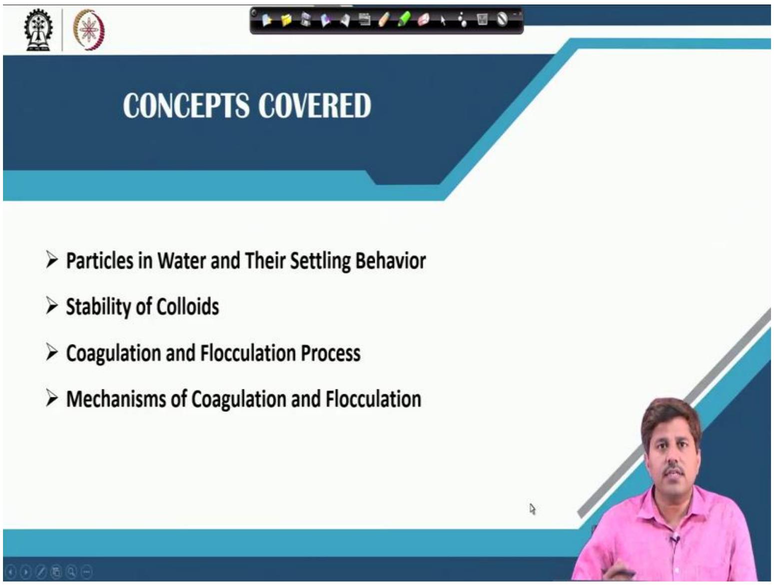

So, we have been discussing conventional treatment system and so far we did talk about the sedimentation and aeration units. This particular class will be focused on coagulation flocculation process and more sever will be discussing theory of the correlation flocculation process. So, what we are going to discuss is what are the different types of particle in water and they are settling behaviour. And we will talk about the why it is difficult to remove collides why they are considered stable in water.

And then we will move on to the coagulation and flocculation process and the mechanisms through which the particles are removed or particles are processed in a correlation flocculation process.

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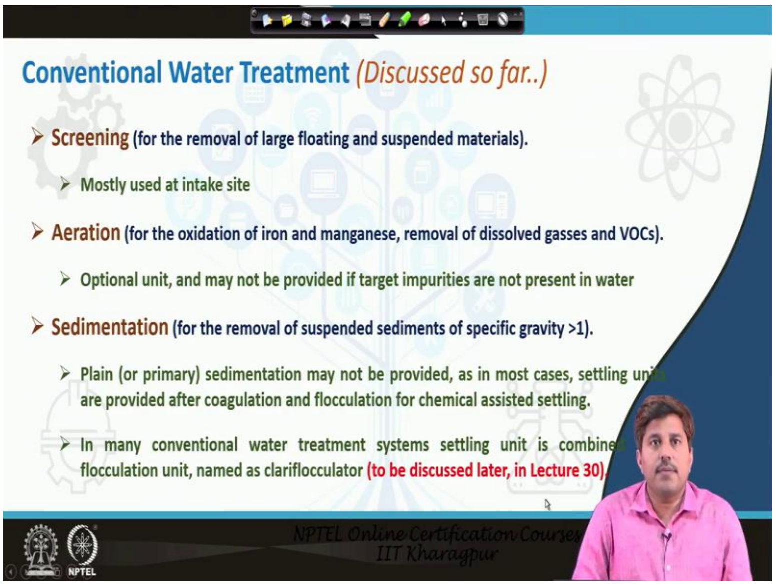

So, to begin with let us discuss what we read so far. So, the screening process which is basically for the removal of large floating and suspended materials and it is mostly used at intake site and not the treatment plant as we discussed earlier. We did study aeration also in the previous week which is an optional unit and may not be provided if target impurities are not present in the water.

And what are the target impurities for that it is basically the color and order producing the organic compound VOCs or some of the dissolved gases like CO2 H2S etcetera or if we want to have the oxidation of iron and manganese then we can aim aeration. So, if we are not having these kinds of impurities we may in fact avoid aeration as well. What else we studies is sedimentation which is for the removal of suspended sediments of generally specific gravity greater than one so which are heavier than water so that they can settle in the water.

Now we did study the concept and application of sedimentation units but in fact the plane or the primary sedimentation is generally not provided in most of the cases in conventional water treatment systems. It is not that sedimentation is not provided sedimentation is one of the very important units of any water treatment facility but what we are saying is that plane or primary sedimentation is generally not provided.

Instead settling unit is provided after coagulation flocculation process which is basically the chemical assisted settling. In many conventional treatment systems in fact the coagulation flocculation not copulation in fact the flocculation and the sedimentation basin is combined.

So, we do combine the flocculation unit and the settling unit and then we call that as a Glary clariflocculator which we will be discussing in one of the later lectures in lecture number 30.

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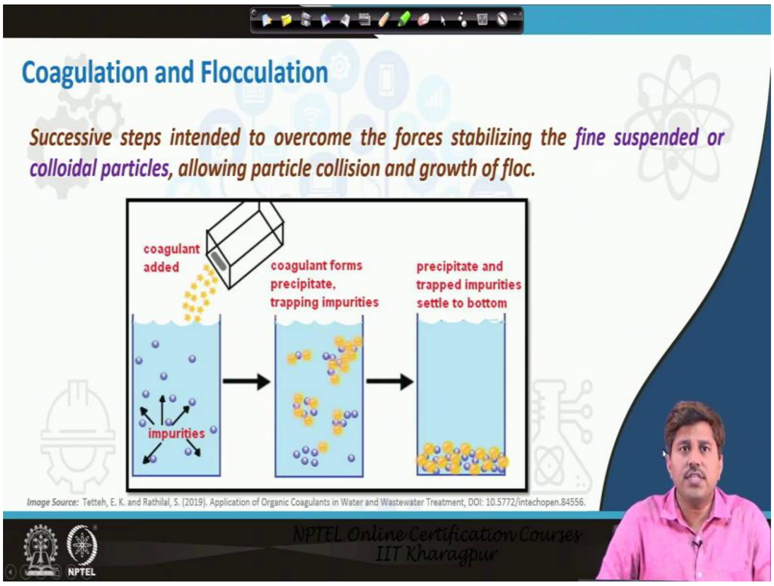

So coagulation flocculation process we generally name them together because these are successive steps although these 2 are the different processes coagulation is separate thing flocculation is separate but since these are done in succession because without going for a flocculation step there is no point of coagulation. And flocculation cannot be done without any sort of assistance either in the form of some additional chemical or polymer or those kind of means we have to kind of in most cases needs an additive for enhancing the chances of the flop of formation which is known as flocculation.

So, we do need a covalent for the process of flocculation and there is absolutely no point in adding coagulant if we are not going for flocculation. So, essentially the coagulation and flocculation process are complementing to each other we need coagulant for flocculation process and we need a flocculation step if we want to add coagulation because otherwise it does not serve the very purpose.

So as a result we basically study and combine usually combine them together for study purpose so we call that coagulation and flocculation process which is in fact successive step. And they intend to overcome the forces that are stabilizing the fine suspended and colloidal particles and then allow them to settle. So, what eventually happens that we in the correlation flocculation step we add a coagulant there are there are impurities or solid particles very fine solid particles or colloidal particles which are present in the water they do not interact each other they do not combine with each other.

And since their sizes are very small so they remain in the suspension what this additive does is it enhances the opportunity for particle-particle bridging so that the particles which were moving freely can bridge together in a larger mass so that their weight can increase and then they can actually settle. So, settling process is different what we have studied earlier. The sedimentation process or clarification process same may be used after coagulation flocculation process for allowing the flocks which are formed to settle.

But essentially the correlation collaboration process is addition of covalent and providing the opportunity for formation of flocks. So, these are the processes that we are going to study.

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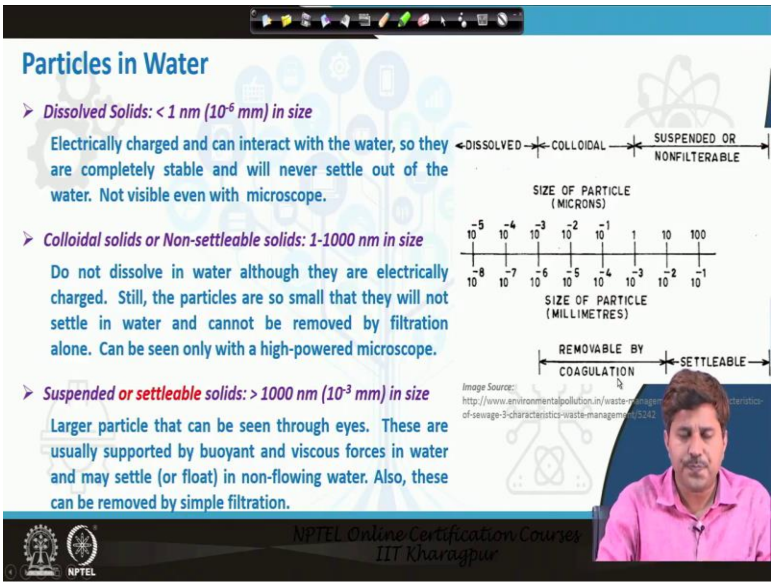

Now before we go on to studying the coagulation flocculation process let us see the basic objective of a coagulation flocculation process. The objective is the removal of the very fine suspended particles or colloidal solids. Now why we intend to remove the colloidal solids are fine suspended particles with coagulation flocculation basically because they cannot be removed by other simple mechanisms like settling.

So if we see the different type of particles that are present in the water so we have we can divide them into three different classes. We have dissolved solids which are of size less than one nanometer or say 10 to the power -6 millimetre size which is in if you see in the scale of microns so it is 10 to the power -3 microns. So, solids lesser than of this size is known as dissolved solids, these are electrically charged and can interact with the water so they are basically in a completely stable state and they will never settle.

Even if we leave water for years they are not going to settle. Say if you take a pinch of color and add that in a water the water becomes coloured it is not that if you leave that water for 10 days or say 10 months it is going to go colourless. It will go colourless only if that compound decomposes it is not that it will actually set the colour is generally not going to settle down. So, there is no possibility of removal of these solids by settling purpose.

They are generally not visible even with the microscope you cannot see them in the solid form. Then the second category is the colloidal solids and or which is also known as times non settleable solids. So, these are typically of the size of one micron or smaller particles. So, they are of kind of 1000 nanometer which is say 1 micron size. They do not dissolve in water so they have they remain in a distinct solid phase in the water but they are electrically charged and as a result they have a repulsive forces which does not allow them to basically form agglomerates.

So, because the size is so small they will not settle in water and they generally cannot be removed even by simple filtration alone they can be seen only with very high-powered microscopes. So, if you are using very high-powered microscope we can see the collide like simply if you see the dust particles so you can see that the water may looked a bit because the colloidal particles give increases the turbidity of water. So, water will look turbid you can distinguish a water which is not having colloidal solids with a colloidal solids by turbidity or even by seeing through it.

In most cases but the turbidity part is but you cannot distinguish the clear solid particles you cannot see that a separate single solid particle is floating in the water for that you may need a high-powered microscope. And then third type of solids which are basically the suspended solids or they have generally non filterable solids. So, they are the solids of size greater than one micron or greater than 10 to the power -3 millimeter in size. So, these are generally larger particles and like we can see them through eyes may be the smaller section of this may not be visible like close to 1 micron or so.

But as the particle size go grow bigger it is easier to see them through eyes. These are usually supported by the buoyant and viscous forces in the water and they will settle or float depending on their relative density they may settle if it is that if the specific gravity is higher than that of water they will settle. If it is specific gravity is lower than that of water they may actually float in non flowing waters.

If water is moving so that additional force keeps them in suspension but if we allow water to remain still they can actually settle or flow depending on their specific gravity. Also they like Midori these can be removed by the simple filtration depending on what filter sizes we use. So, these are suspended solids we often say them as a set eleven solids as well those settleable solids the solids that can usually settle are of size of 10 to the power -2 mm or higher if we go to the like 1 micron size particle that again is very difficult to settle.

Although it is a suspended form of solid or non filtrate form of solid so it cannot be simply filtered the like; now if we see the settleable solids which are generally of the size greater than 10 to the power -2 millimeter or 10 micron can easily be settled and we can plan the removal of these particles in the sedimentation basin. However the smaller size particle needs to be removed with the other mechanism and we usually opt for coagulation flocculation units for removal of these size of particles.

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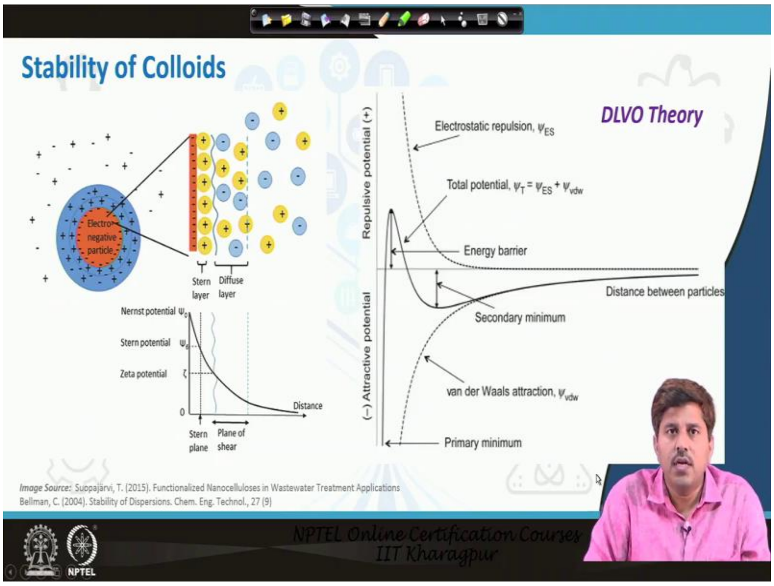

Now why these size of particles do not settle or do not interact or why they are stable in the in the aqueous mediums is generally ah because of the charge that they have and discharge make them particle make these particles like repel each other so that it the particle cannot bridge together cannot come cannot basically come and form flops or agglomerates together. So, if you see this typical particle like take an example of clay. So, clay particles the surfaces of clay particles are traditionally negatively charged so we will have electro negative recharge particles over here.

Now the particle if you see the surface of particle that is negatively charged and then there is a stern layer formed which is of kind of positive charged ions over and above that and then there is a diffused layer which is basically the again mixed of positive and negative. So, this because of the two different layers the stern layer and diffuse layer we call this a double layer formation. And this double layer is such that it does not allow the particles of or more than one particle to come and bridge together.

Why does not allow is basically given by DLVO theory. DLVO were named after 4 scientists whose last name were initiated with the DLV and O. So, this theory is named after those 4 scientists and it is very common theory considered for the stability of dispersions or colloidal particles in the in the solution. Now as per this theory if you say this is say your midline and these are the attractive potential and this is the repulsive potential.

So, if the particles are to be bridge they have to have the higher attractive potential than that of repulsive potential. Now if say we have one particle here whose surface is say this and we have one particle here so the distance between the two particle is this and in that case it like there is no as such if you see very little potential there is no repulsion between these two particles and very little attractive forces for them to basically come in together.

Now if by say kinetic motion of the fluid or random motion of the particle these particles comes together let us say this particle has moved here now. Now if this particle has moved here from this place if from this place this particle has moved here still you do not see any repulsive forces and then there is a little attractive forces which will try to bring these particles closer. Say this particle come here again you see that almost very little no repulsive forces and attractive forces are increasing as the particle is getting together.

So, these are basically wonderful forces of attraction and as we know that as we are as close to surface the van der Waals forces of attraction will be highest and as we move far the van der Waals forces of attraction decreases. So, the particle comes here it will have higher forces of attraction it will move closer but now because of this double layer formation now this starts this basically causes repulsive potential and does not allow particle to come closer.

So, what happens let us say in the next stage for say if we are bringing the particle to this level, let us say if you are bringing the particle to this level. Now what happens that the van der Waals forces of attraction is this much. The repulsive forces at that particular time is this much so still the forces of attraction is leading and if you see the net potential over there, if you see say this is your one particle.

Now you have bought it to here you have bought your second particle to this point now still the the solid line here this dotted line is wonderful forces of attraction this dotted line is electrostatic repulsion however the solid line is the total potential line which is the resultant of the two. So, when this force is 0 it is actually equal to the van der Waals forces of attraction and when you have start getting a repulsive forces as well so this force basically encounter covers for that as well.

So at this point still it has forces of attraction dominating the forces of repulsion it will move further closer now say it moves to a newer location over here the particles say has moved to this location. Now at this location we have certain van der Waals forces of attraction and we have certain forces of electrostatic repulsion. And these two forces are more or less same. So, as a result when these two forces are more or less same when the particle is at this point it is not having any net potential of attraction or repulsion because the attractive forces and repulsive forces are balancing each other.

As a result there is no net attraction or repulsion a however if particle moves further closer say if the particle has moved now more closer. So, this is your original particle and says particle has moved here. Now once the particle has moved here now you see the corresponding forces of attraction might be this much but corresponding forces of repulsion are far higher and as a result if you see the net potential, so now there is a net repulsion.

So, the ripple these repelling forces are dominating or the repulsive potential is dominating over attractive potential and then the particle starts repelling each other and then they will never allow this particle to come close and come close to this one and stick this. So, this possibility is ruled out. The attraction between the two particles are the two particles coming extremely close so that they can bridge is ruled out and because of these repulsive forces these particles will remain at the kind of distance and they will never come close.

So, if this particle is here this particle is here they are going to remain like this because of the repulsive forces. They are repelling each other and as a result there is no possibility of bridging. And as we discussed the particle sizes are very small and if they are not bridging they will remain in suspension because they do not have enough weight to settle. So, the gravitational forces are not enough to cover for the buoyancy and drag forces so that it can settle and as a result they remain in the suspension for very, very large period of time because of this size issue.

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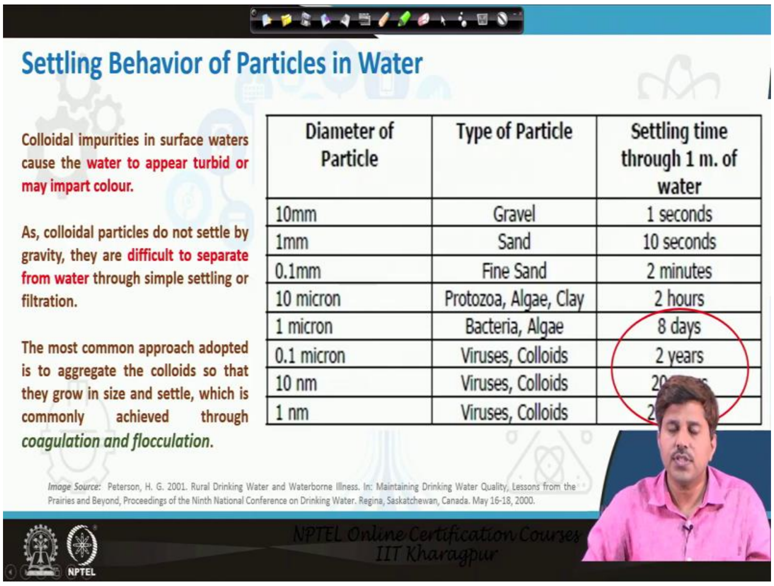

So, if you see like the settling behaviour of different size of particles in water. So, the particles of say if you typically take a spherical particle, so, spherical particles of diameter which is say the nature of particle is gravel will settle very quickly and just as in the in a second it is likely to settle. For particle of size 1mm say this is sand particle will typically settle in 10 second, settle means covering one meter distance this is the approximate time that will require for covering one meter distance vertical distance in the water for the settling process.

We go to the fine sand or a further smaller particle of 0.1 mm daya it will typically settle in 2 minutes the 10 micron size which are protozoa algae and some clay particles will typically settle in 2 hours. But if we go less than this the settling period increases very, very much like these algae they will typically take 8 days to settle between a and algae and the colloidal particles are viruses because of their size range they takes years to settle ok.

The size of 0.1 micron particle which is 100 nanometer particles will take approximately 2 years to settle 10 nanometer particle will take approximately 20 years to settle and 1 nanometer particle will take around 200 years to settle. Now if we want to remove these particles say if you want to remove up just 1 micron size particle for say or the particles of size between 1 micron and 0.1 micron.

Let us say if your intention is to removal of this size of particle the amount of time that we require if we just go for simple settling process is 8 days to 20 years. Now it spray I eight days to two years now it is practically not possible to design a reactor with so high residence time. The size is going to be very, very big like practically it is called almost like impossible or non feasible we can say.

So, it is a non feasible to design a system to remove these particles with the simple settling. Now why we need to remove these particles because of course they are a contaminant they make water appear turbid and may impart colour as well in the water they might not be good for health and because of this process they are in fact difficult to separate. So, the most common approach that is adopted for the separation of these type of particles by gravity is that we allow them to aggregate.

We allow them to aggregate and then grow in the size and settle and how we are allowing them to aggregate through the process regulation and flocculation.

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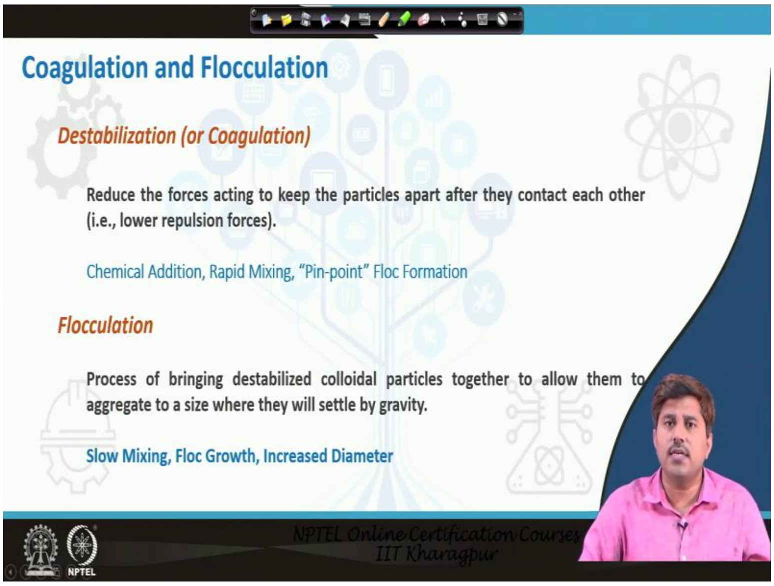

So, this is why the coagulation flocculation is considered an important step in the conventional water treatment plants. It is almost like any conventional water treatment plant will have a coagulation flocculation treatment units, if it is if it is a in fact water treatment plant in extreme cases people just provide disinfection and nothing else no treatment no sedimentation no coagulation flocculation.

But if we are talking about a treatment of water or water treatment facility then coagulation flocculation is normally a kind of a must you need to have it there. So, what our population and flocculation? Coagulation is practically the destabilization of these colloidal particles. We just discussed that they are stabilized in than water they do not come close enough to say agglomerate and form flocks because of the repulsive forces that are there.

So, the idea is we lower the repulsive forces so that the particle may come closer and basically they contact each other so that is done through the destabilization. So, we destabilize these repulsive forces in a coagulation process. So, coagulation process is not the binding of the particle it is just the destabilizing the forces that are keeping the particles apart. So, it is basically lower the repulsive forces are destabilizing the particle.

What we call the particles are stable in nature in suspension we destabilize them so that there is possibility of them joining together. How it is achieved we add chemical for that we then go for rapid mixing and this basically pinpoints the floc formation. So, this is a starting point for the formation of floc. Formation of floc is the process of flocculation. So, coagulation facilitates the formation of flocks it is basically provides an environment in which the flocks can form.

So, making a taking a stabilized system to a level where the flock formation can start or basically pinpoints the flock formation is the process of coagulation which is typically achieved by adding a coagulant. After that we go for flocculation process which is the process of bridging these destabilized colloid particles together to allow them to aggregate to a size where they will settle simply by gravity and this is achieved through slow mixing then growing the flocks and maybe we can increase the diameter.

So that like when the flocks grow the particle daya overall particle daya increases and then settling velocity increases and they can settle together.

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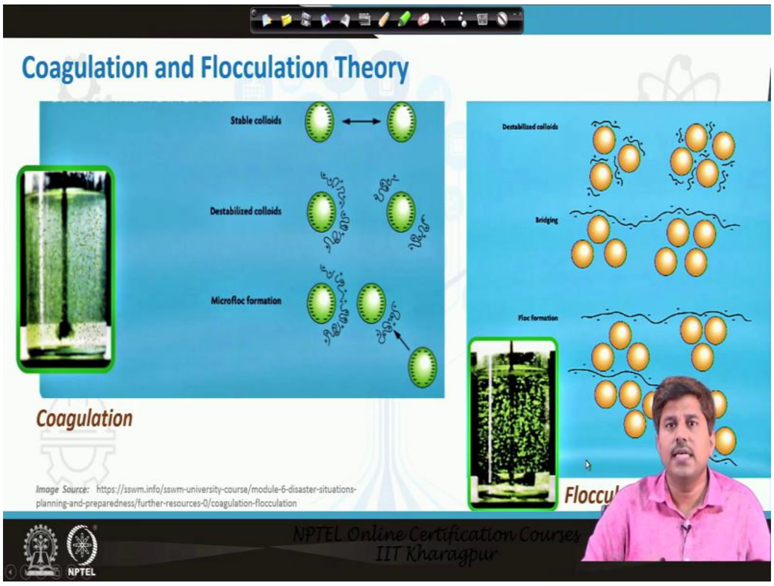

As we were just we discussed in earlier lecture that flocculent settling has higher settling velocity. So, if we see the coagulation and flocculation process essentially, so the coagulation process is there are stable collides which are which are basically not having an opportunity to bridge. So, what coagulation does is it destabilizes these collide particles and then allow them to basically start formation of the flocs.

And the flocculation process so we have the destabilized colloid particles they do breach and then they combine in a larger mass and form floc so that is what is the flocculation step.

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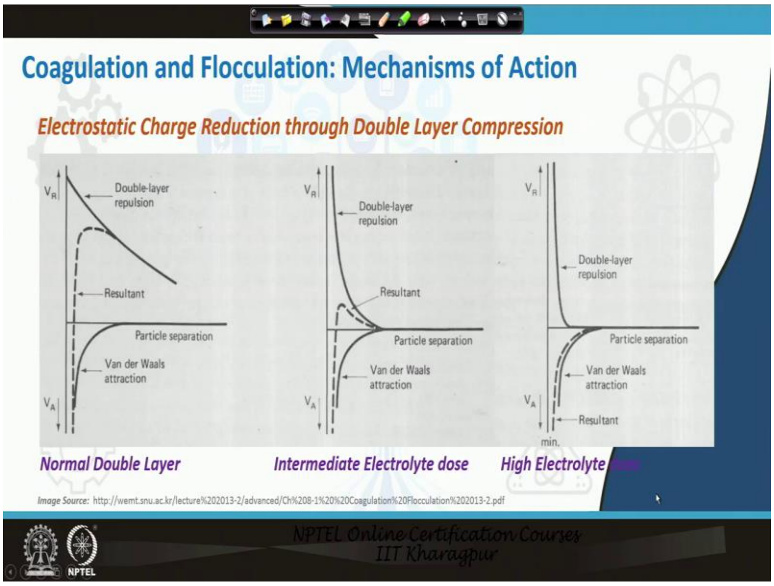

There are different mechanisms through which this destabilization and attachment of particles takes place so the coagulation and flocculation takes place. So, there are 4 major mechanisms which are considered for the coagulation and flocculation process and one of them first of them is basically the electrostatic charge reduction through double layer compression. Now we were just studying that in the normal circumstances there is a double layer form.

And that double layer if you see the resultant forces so resultant forces are repulsive and that is why the particle does not reach together. So, this is van der Waals forces of attraction this is the double layer of repulsion. So, the net forces at any point of time if you see it is actually the forces of repulsion are dominating then the particles will not are not going to go together. Now when we add electrolyte doses when we add electrolyte in the system so what that electrolyte does because you are having a potential and then there is once you add electrolyte which will create it is the reverse potential.

And as a result it is able to suppress that double layer. So, this process is known as the double layer compression. So, the double layer is going to go compressed and that depends on how much it will be compressed depends on what kind of electrolyte we are using and how much dose of electrolyte we are providing. Electrolyte here in a way you can say that the coagulant impact. The coagulant of what coagulant we are using and how much coagulant dose we are providing.

If we add simple electrolyte like let us say sodium and these things there they have limited capacity if we add because their charge is just one. The potential is much lower if you are adding iron or LM kind of electrolyte or that kind of coagulant. So, because of the high cationic potential +3 potential they are far more able to reduce this double-layer and that is why they are much more used as a coagulant as opposed to the other options.

So what happens when we add these coagulants it will basically be double-layer is suppressed. The double-layer which is formed so the distance of double air is suppressed and as a result you are still having the same van der Waals forces of attraction but these suppression forces is or the repulsive forces is reduced and as a result the resultant force profile which you are having earlier like that now you are having that.

So, if you are having a particle here earlier it used to have this high potential of repulsion. But at the same location if you have say a particle now it is having much lower like if you see the forces of repulsion is much lower. So, that is when you add intermediate electrolyte dose. So, if you add too much of electrolyte very high electrolyte doses then in fact it can almost like take the double layer effect completely off it can suppress the double layer too much like.

If you see the earlier double layer like was thickness was like this it has reduced like this and then if you further add it will be reduced like this and as a result you can see that van der Waals forces of attraction become more prominent and then that will allow the particles to bridge together. So, that is the case of high electrolyte doses.

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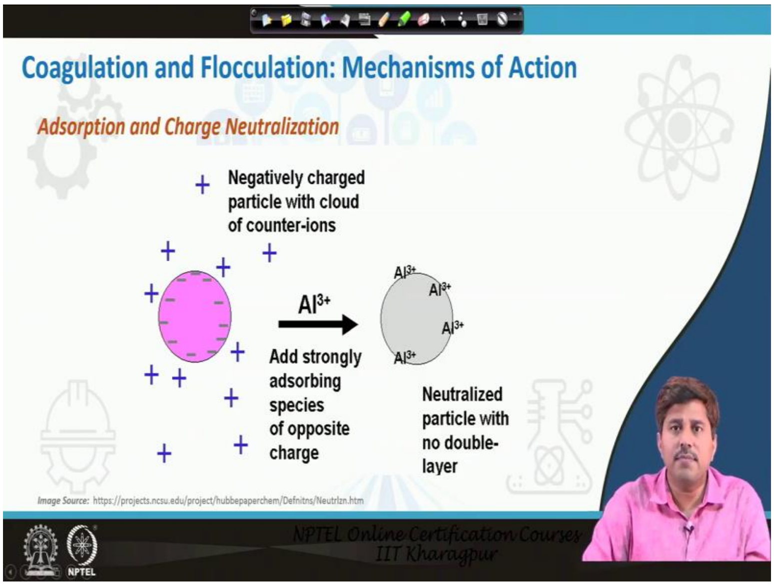

The other mechanism is the adsorption and charge neutralization. So, what happens like if say for say example we add LM doses aluminum + 3 ions we add now these are the cationic ions. The these are your clay particles which are negatively charged. So, these will basically attach to the clay particle surfaces these will get adsorbed to the clay particle surfaces because of the attraction and then once they get adsorb on the surface they will neutralize the charge.

So because when we add coagulant it will immediately get dissolved in the water it can produce certain ionic species which may form an ionic interaction with the surface and as a result it can get adsorbed to the surface and once it get adsorbed it is a cationic thing which is getting adsorbed with the surface and forming an ionic interaction and that ionic interaction what will help is neutralize its charge.

So, the neutralized particle will not have any double layer because the charge has already been neutralized. So, this is also in fact kind of a mechanism for the repulsion of double layer ok the reduction of double layer.

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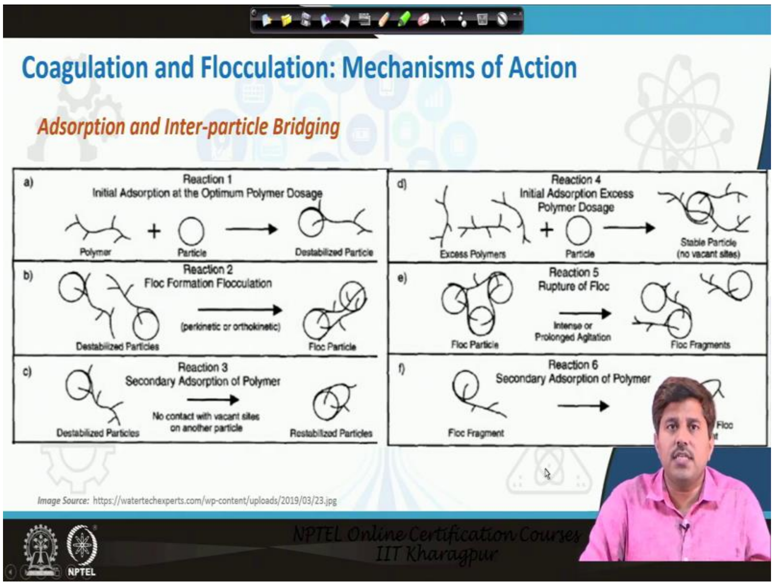

Then another mechanism is the adsorption and inter-particle breezing. This is more effective for polymer cases so if we are adding say a polymer if you are adding a polymer and we have a particle. so, this polymer many times like we use cationic polymers for a purpose of as a coagulant purpose of floc formation. So, this cationic these particles are negatively charged these are the cationic charge polymer they will interact with this and they will form a bridge thread.

Now similarly like we may have further these kind of destabilized particles this stabilized particle become destabilized and then more than one destabilized particles can bridge together. There is another possibility that destabilized particle because of the polymer thread actually they can go on the secondary adsorption on the polymer and as a result they get destabilized.

So, there are various reaction various mechanisms which are possible the more important one are these two the neutralization and the bridging part. If we add axis of polymer again we get a stable particle with various thread and then it can actually interlink more than one particles together and that we also floc formation is possible. There is a possibility of rupture of floc if this flock becomes too big so the like again there is a positive there floc and get fragmented and then these fragmented flocs can again actually turn to restabilized.

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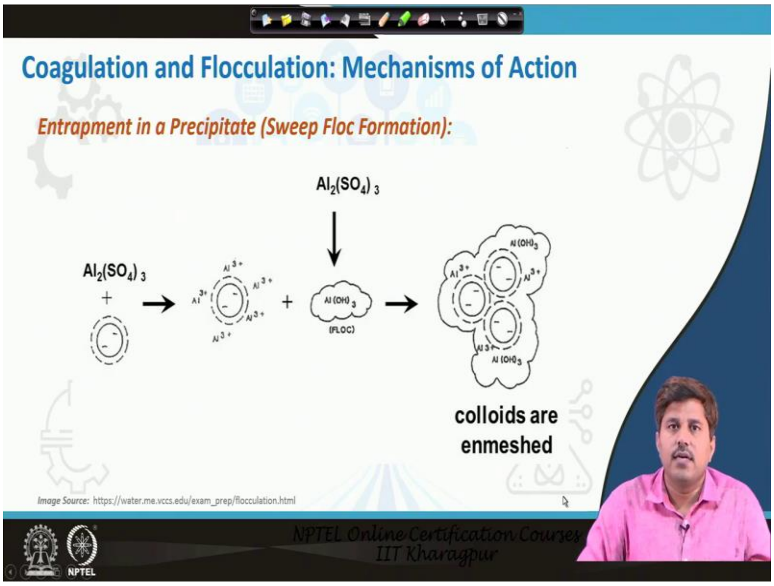

So, this is the one another mechanism which is through inter particle bridging and the last one whereas one of the most important one is the entrapment in a precipitate which is basically the sweep floc formation. So, the sweep floc formation is as such like if we are say add too much of collide particular too much of coagulant. So, these coagulant also form precipitate and a large mass of precipitate will be formed in the water.

If we say add aluminum it will form ALOH wholes size, if we add fed iron so if it will form a Fe whole thrice. Now these are the like precipitates and these are when basically in a say basin you add the coagulant and large amount of precipitate is formed. Now because of the heavier nature of these precipitates they tend to settle. And once they tend to settle whatever the turbid particles or colloidal particles are coming in their way they will actually get entrapped or enmeshed in this floc.

Once these flocks are formed in the water, so they will first thing is like when the formation starts there will be lot of surfaces available. So, there might be these collides getting adsorb on the surface. Even if they are not getting adsorbed when these come together and form bigger and bigger particles or whatever; whatsoever impurity or whatever the collide particles present they will get enmeshed in that basically flocs.

So if this is say or floc mass it might have various collides within this, even if those colloids are not destabilized. And when these flocks try to settle a larger mass try to settle say so in between if we are getting some colloid particles so it keeps on enmeshing those in trapping those particles and keeps on growing bigger and bigger and by the time it settles everything will actually settle along with these flocs.

So as everything is getting settled along with these flocks that is why it is known as free flock formation like sweeping action. So, if we have lot of dust and these things we like we take a broom and sweep it together. So, this this kind of the flocs that is formed when it settles it acts as a boom broom because there is a lot of mass and then it basically sweeps all these small colloidal particles that are coming in its way.

So, that is what is sweep floc formation and this is one of the very important mechanism through which basically the flocs are through which these flocks get settled.

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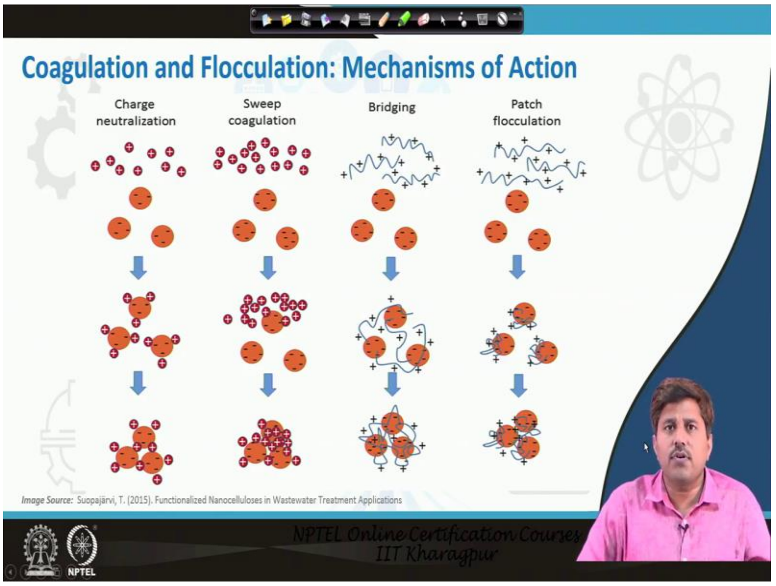

So, these are the major mechanisms for coagulation and flocculation we have charged neutralization we have sweep coagulation, we have bridging and we have kind of we may have patch flocculation kind of processes working on. So, with this will conclude this particular lecture we will talk more about the application. Now how we do these processes we have so far talked about the theory how what are the coagulation and flocculation mechanism and what is the carbonation flocculation process.

In next class will discuss how the coagulation flocculation units work how they are implemented in the field. So, the application part will discuss in the next class. So, see you in the next class thank you for joining.