Water and Waste Water Treatment

Prof. Bhanu Prakash
Department of Civil Engineering
Indian Institute of Technology – Roorkee

Lecture - 33
Overview of Water Treatment

Hello everyone, welcome back to the latest session. In the last 2 sessions, we looked at how much water to, what do we say, designed for and then we looked at the kind of quality of water that we want to achieve. So, now, we are going to look at how to achieve the quality of water that we want to achieve. Let us move on.

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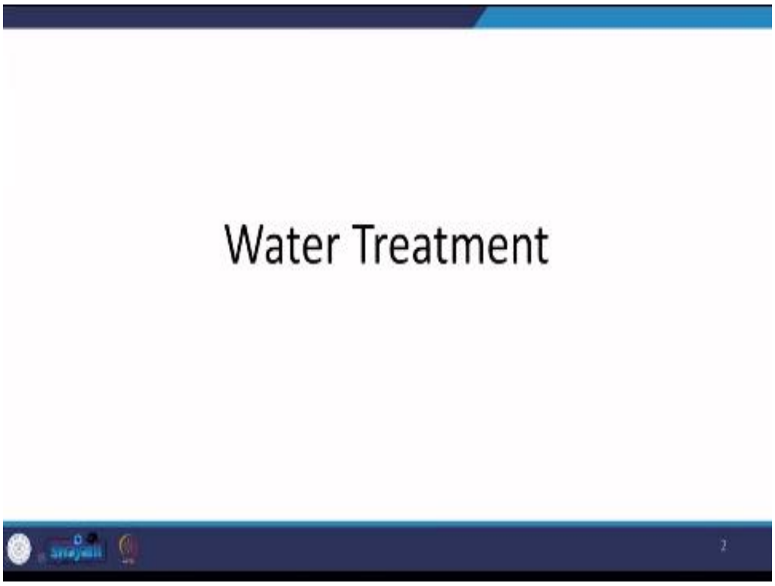

Water Treatment

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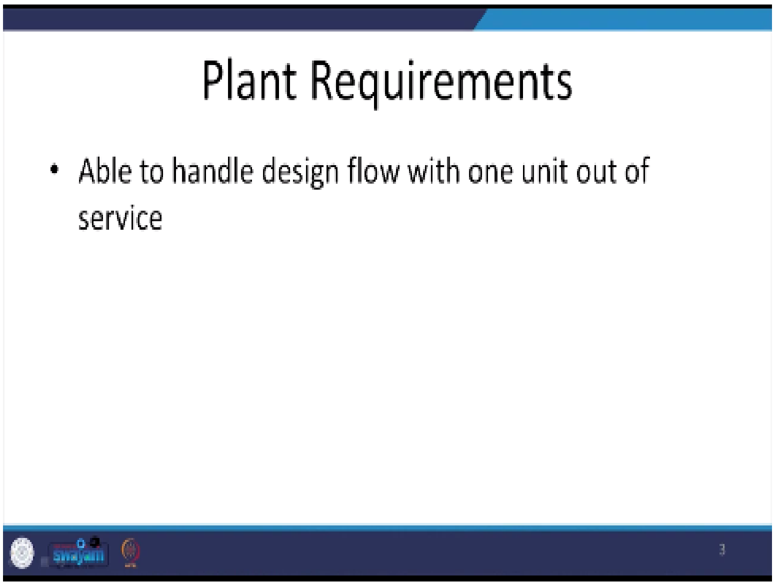

Plant Requirements

- Able to handle design flow with one unit out of service

So, water treatment. So, plant requirement in general ideal case depending on how well you design it and the capital costs, you want to design such that even when one of your unit process, , sedimentation tank, one is out of service. The other said there should be understand by sedimentation tank to be able to you know cater to the needs of the population. So, that is what we have here.

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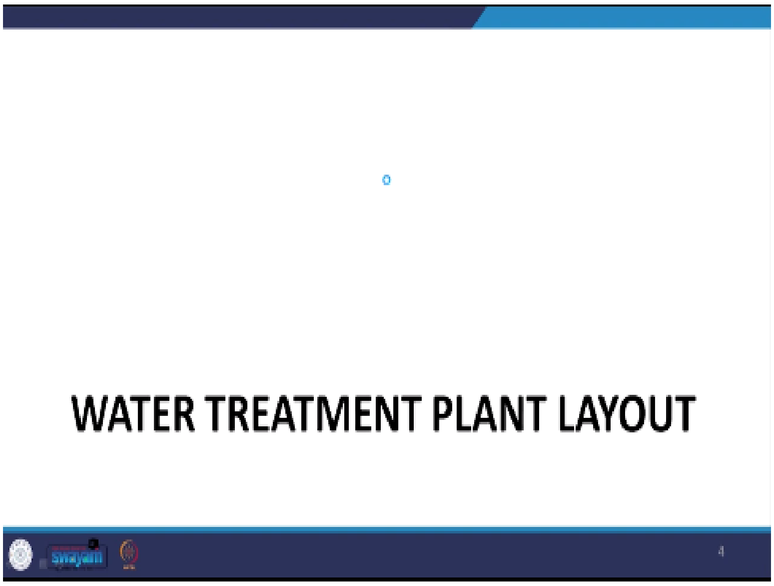

WATER TREATMENT PLANT LAYOUT

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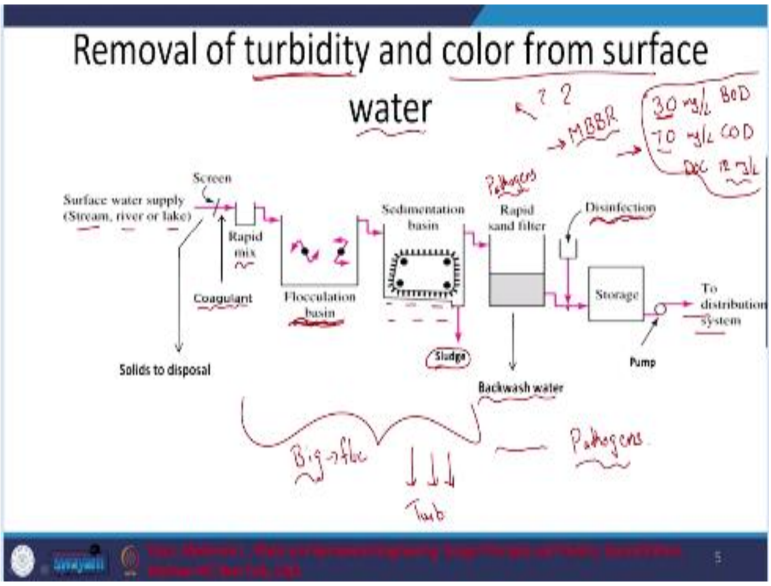

Removal of turbidity and color from surface water

So, ability to handle design flow that design flow with one unit out of service. So, typical water treatment plant layout, let us look at this. So, here we are concerned about removal of turbidity and colour from surface water. Why is this important? As I mentioned, depending on the kind of water intake, you know water treatment process will change. For example, if it is groundwater you know the aquifer groundwater or subsurface aquifer or ground aquifer, groundwater aquifer will act as a filter.

So, third stability will be relatively less in groundwater in general, unless it has great levels of what we say influence due to surface water or such but rarely that will be the case. So, then I will choose a different mechanism. Why? Because groundwater typically higher hardness, I will need to look at removal of hardness , but if it is surface water typically turbidity will be high. Turbidity in the sense suspended particulate matter or such will be high. So, I need to look at that.

So, in that context, I would like to mention river Yamuna, we have plants or water treatment plants, huge water treatment plants 150 million gallons per day or such I believe. One gallon is equal to 2.3 or 2.7 litres. So, you have these huge plants in Mathura and Agra. So, one built earlier is based on the traditional technique. And we will look at that later or rather I want to mention that later.

And the other one they are using a waste water treatment process based system to be able to treat this surface water. Why is that? Because river Yamuna, you know, depending on when you sample, you are going to have BOD to be this and maybe COD to be 70, 80 milligram per litre COD. And here the issue is, if you look at the dissolved organic carbon, it will be around what 8 to 9 to 12 milligram per litre, milligram per litre dissolved organic carbon.

So, it is almost not almost at under the category of sewage, , so that is why they were using MBBR, moving bed biofilm reactor based plan to treat the water and then supply it for drinking water. So, that is the kind of process or different kinds of unique process that people have to employ based on the kind of water that they take. But that is a unique case river Yamuna, though it caters to a large population.

Typically, we have what do we say, other, what do we say, reverse to and we are not going to have those rivers being as polluted as Yamuna. But that is something that they wanted to mention. MBBR I think you remember I showed a media and one of the previous sessions and that media will act as a surface for the microbes to grow on that those microbes will degrade my organic content which will lead to this high BOD, enough of that.

Let us come back to this. In this case, I am just concerned about surface water which has relatively high turbidity. So, what is it that I want to do, let us go through step wise. So, surface water is coming in from stream, river or lake, screens. You will always going to have screens because you will always have different kinds of stuff thrown into the water and you can have a coagulant added, yes, we will look at why a coagulant is required.

We will look at that later. For mixing it well and for coagulating the particles and so that the initial coagulation starts, you are going to have rapid mixing. And then you will have a flocculation basin where you want to form the flocs. So, here the turbulence and thus, the mixing intensity will be less. Once the bigger flocs are formed, you will have a sedimentation basin where we use gravity, often to be able to remove these bigger particles or bigger suspended particles or the flocs from the water.

And here, we are decreasing the turbidity. Those particles that are too small to be settled out. What do we want to do? We want to form flocs to form flocs; we want to see to it that the particles come together. But typically, you know they need to overcome their what do we say, force of repulsion so, for that we add quadrant. We will look at the relevant reasons later. And then after that is done, the flocs can be formed.

And once the bigger flocs are formed, they will be removed in these sedimentation tanks, . And after that even then you will have some particles which will still be suspended but might take too long to be removed in a sedimentation tank. So, you will have a sand filter and then sand filter itself, you will have quite a few pathogens that can be removed . And the last step is always disinfection.

You want to kill the pathogens that are left. And that is why you add pathogens, not pathogens pardon me, you will not add pathogens; you are going to disinfect the water by adding a disinfecting agent which is typically an oxidising compound or UV. Why UV? It will damage the DNA or the RNA of the pathogens and then we are also going to ensure residual chlorine levels or residual disinfection levels.

So, that in the distribution system, you have chlorine that can tackle or take care of any microbial growth or re-entry into the distribution network and what else so, from time to time these filters will be chopped, so you want to have to backwash it; back, wash. So, if (07:03) during the screen solids are, what we say, form you have to dispose them and sedimentation basin the sludge that comes down.

You are going to have to dispose it; typically inert if it is surface water. So, this is the case. What is it? We are doing here in all this process; we are forming bigger particles, flocs and then we are removing them from the water by letting them settle down. Here, we are filtration rapid sand filter. , suspended particle and then we are killing the pathogens. So, in effect, here we are removing the turbidity and here we are dealing with a pathogen. So, that is what we have.

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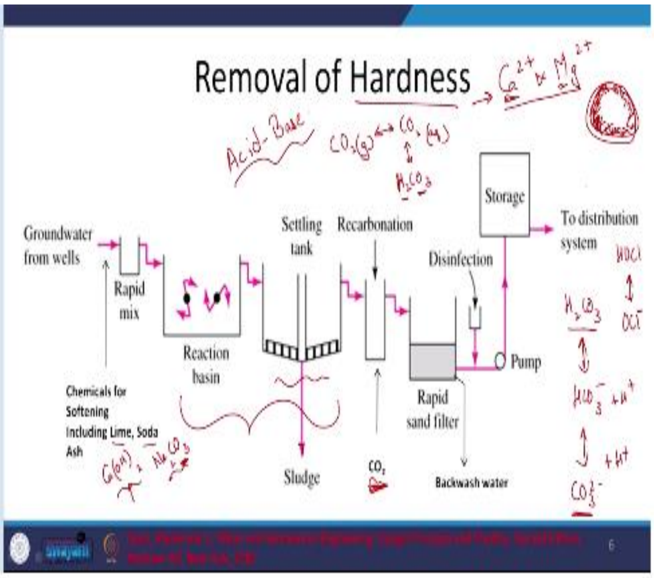

Removal of Hardness

But if it was groundwater, which has hardness; hardness is due to calcium and magnesium, we will look at this later, but just an introduction to help understand the issues. So, this will affect. I will get pictures later at least. If this is my pipe, you know, almost this section will be scaled up. For example, you would have seen this earlier at least when you used to boil water for hot water, to have a hot water bath or to drink one should.

We have disinfection is boiling the water to drink. We used to see that over time this vessel had what we say, scale being formed and over time I had to supply energy at a greater intensity or heat the water for a longer time to be able to achieve the same level of what we say, final temperature. So, my heating efficiency is decreasing there. And you know why is this, due to big, it is because you know, precipitates of calcium and magnesium precipitation earlier they were dissolved, dissolved in the relevant solution.

When I heated it you know, some of it, some forms will precipitate out. So, we have permanent and temporary hardness based on how they can be removed but we will look at that later. And what else other than this precipitation, calcium and magnesium they will affect the ability or the amount of soap I require to be able to clean myself, the utensils or the clothes, .

So, that is one of the aspects. It will stain all your bathroom what we say, where like pipes and they will break. So, these are aspects that need to be considered. Thus, we need to remove or look at removal of hardness. So, groundwater from wells; so, we can add different chemicals like lime or soda ash, lime CaOH twice soda ash Na_2CO_3. So, here we are adding line to increase the pH here to add CO_3^{2-}.

So, that you can precipitate the compounds in the form of calcium carbonate or magnesium carbonate . We will look at that later and then we are mixing that pretty fast rapid mixing and then we have the reaction basin here and then the settling tank, we are letting that settle down and the sludge will be taken out settling down and because the pH is in increase, you want to decrease the pH.

How do you decrease the pH by adding carbon dioxide? So, I think in this aspect, I need to look at the or briefly talk about acid base chemistry because that plays a role and then it will be easier to understand the relevant aspects rather than looking at it in what do we say, pieces. For example, carbon dioxide is a gas. When I dissolve it into water, some of it will dissolve in water but will not stay at CO_2; it will stay as H_2CO_3.

H_2CO_3 has this 2 protons H^+, so it can donate that. It can donate H_2CO_3. H_2CO_3 will be in equilibrium with HCO_3^- and CO_3^{2-} and in each process, it can give out one H+. If you see, they know, we are having acid dissociating. So, this is the acid and this is the most deprotonated form. For example, earlier too, we looked at this HOCl being in equilibrium with OCl^-.

So, this ratio of HOCl to OCl will depend upon the pH and pKa of the solution. We looked at that earlier. But we will come back to that. Why is that relevant? Because CO_3^{2-} well, you know, precipitate out some of the calcium and magnesium that is why you need to add $CO3^{2-}$.

At least that is what we are adding here. And here we are adding CO_2 to bring the pH down because during this step, we increase the pH a lot.

High pH water, we cannot drink. So, we are going to add carbonate to also increase alkalinity and decrease the pH. That is what we have. And then , rapid sand filter. Finally disinfection, storage and distribution. So, different ways to go about it. So, when we say your drinking water treated, how are you going to treat it? It is going to depend upon the kind of water that is being treated.

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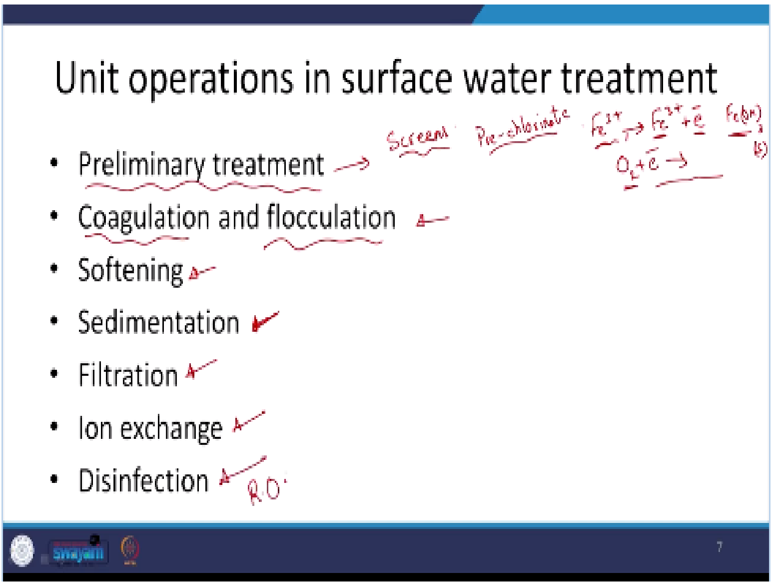

Unit operations in surface water treatment

- Preliminary treatment
- Coagulation and flocculation
- Softening
- Sedimentation
- Filtration
- Ion exchange
- Disinfection

Screens

Pre-chlorinate

$Fe^{2+} \rightarrow Fe^{3+} + \bar{e}$

$Fe(OH)_3$ (s)

$O_2 + \bar{e} \rightarrow$

RO

So, unit operations, different operations that we are going to look at in this particular class or during the other half of this course. So, preliminary treatment, we will not discuss much, but in general, it is screens. And what else at least in Agra and Mathura what do they do, if they directly have these sedimentation tanks microbes grow all along the sidewalls or there is microbial growth white, because there is a lot of organic content wherever there is organic content, the microbes will thrive. So, sometimes they pre-chlorinate the water.

So, that is one kind of preliminary treatment, . Another case is when you have high iron content in your water, , if Fe^{2+} or manganese or such, so you want to precipitate that out. How do you do that? Iron in the form of Fe^{2+} is very soluble, meaning it wants to stay in water, but if you oxidise that to Fe^{3+}, so, how will it go plus electron or if you see to it that the electron is removed, then Fe^{3+} will typically precipitate out as a FeOH thrives the solid pretty easily.

But, how do I do this? To do this, I need to accept this electron. So, what is a common electron acceptor? You know, oxygen is a common electron acceptor, . Anyway, we do not, we are not going to balance it now. So, that is how you can go ahead and do that. , you are going to aided the water so that iron is oxidised to Fe^{3+} and precipitates out. So, these are some of the preliminary treatment steps that are used, but we will look at that later.

But we are typically concerned with turbidity or suspended particles and relatively heavier particles they would, what do we say, come out. But there are some that will not, yes. So, how do I take care of this? So, what do I need to do? I need to first understand why are these particles not coming together by themselves. If there are different particles, why do not they come together by themselves and make my job easier.

First, we will understand why and then we will see how we can, you know, start this, what we say, issue of coagulation. When we destabilise the solution, now solution is stable, the particles do not want to come together and settle out. They are very stable. So, coagulation I am adding coagulants to destabilise the system. So, that the initial coalescence can take place it. Initially, the particles can start coalescing or I want to be able to neutralise the charge on the coagulation.

, we will see why. And then after this, we want to promote formation of bigger flux, bigger flux. Flux, we also came across in that wastewater secondary treatment after biological treatment, the kind of microbes, we want to form you know, they will settle down. So, that is something we looked at. So, over the next 2 or 3 lectures, we will be looking at coagulation and flocculation.

Then we will look at softening of hard water, hard water meaning the one that has calcium and magnesium sedimentation we looked at earlier, but maybe now we will look at the design aspects. Filtration different types of filtration, ion exchange a relatively recent one and disinfection, I should have also had RO and what do we say, under nano-filtration, we will look at; under filtration, we will look at nano or ultra filtration. So, these aspects we will look at.

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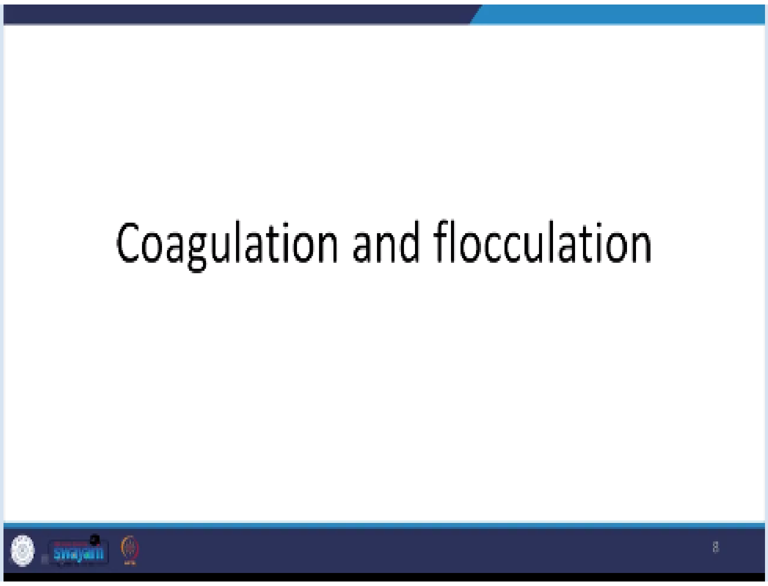

Coagulation and flocculation

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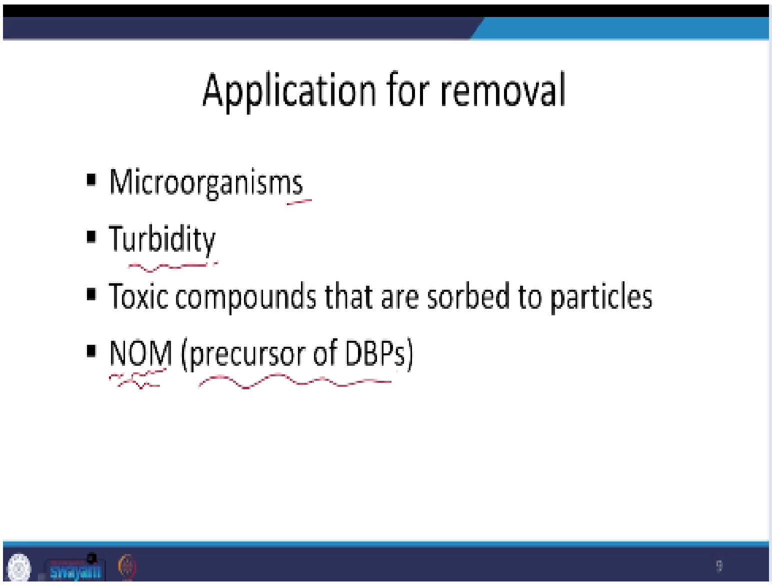

Application for removal

- Microorganisms
- Turbidity
- Toxic compounds that are sorbed to particles
- NOM (precursor of DBPs)

So, let us move on and look at the aspect at hand which is called coagulation and then flocculation. So, first, application for removal, where is it coming into the picture . So, I have microorganisms that are suspended on the relevant or in the relevant water. I have turbidity due to relevant particles that are out there. The toxic compounds that are adsorbed onto these particles and environment.

So, water , I have a river water and if there is a thriving system aquatic system or ecosystem or , there is rain and it comes in contact with the dead leaves and plants and you know, the leech organic matter, organic matter cells and that comes into the river. So, all this builds up and you have natural or otherwise you will have a lot of organic matter. And these are as you know, precursors to DBP. So, I want to be able to remove these and how do I go about that or such?

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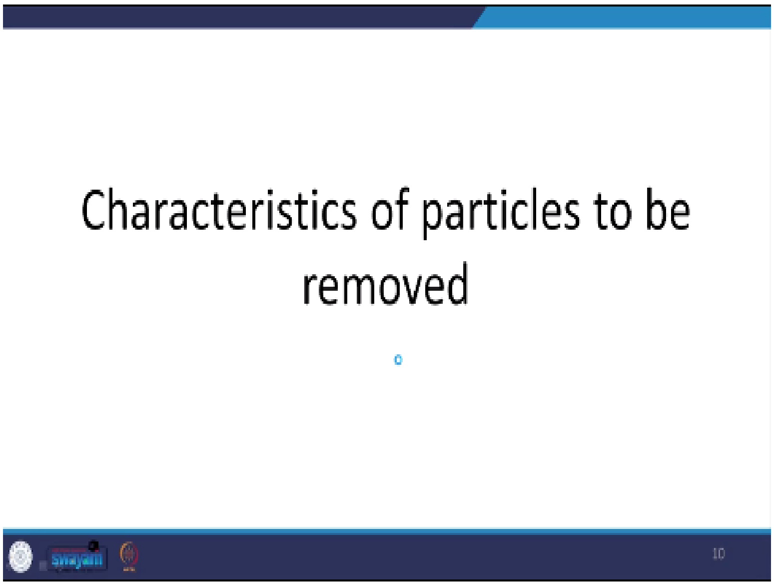

Characteristics of particles to be removed

So, the first aspect is the, what are the characteristics of the particles that I want to remove. , why is it that they do not come together by themselves? I skipped a bit.

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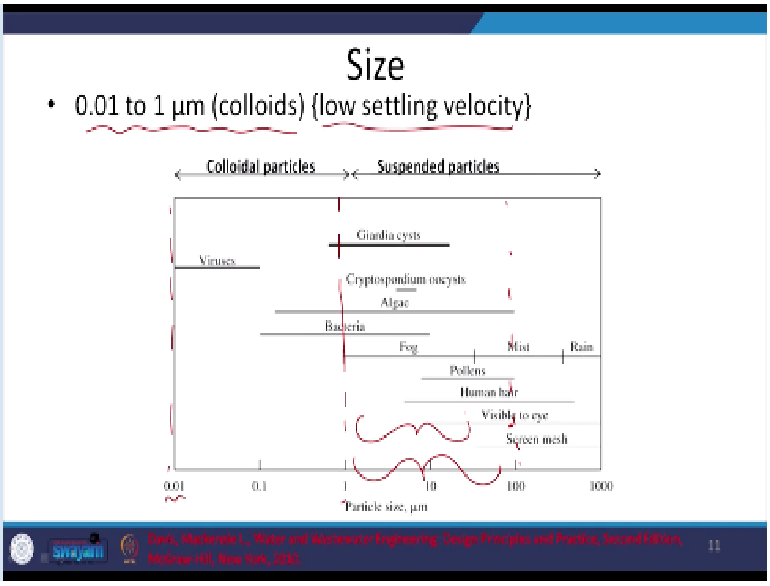

Size

- 0.01 to 1 μm (colloids) {low settling velocity}

Davis, Mackenzie L., Water and Wastewater Engineering: Design Principles and Practice, Second Edition, McGraw-Hill, New York, 2010.

First is why cannot I remove them easily because the size is too small. As you can see, 0.01 to 1, some bacteria and certainly viruses are in this particular zone, they will not set in your lifetime. Even these suspended particles which are relatively heavier, now, you can see from which range they are visible to the eye, as you see all this they are not visible to the eye or most of it here anyway is not very much visible to the eye. There to take their own time so, you want to fast and the rate at which they settle down.

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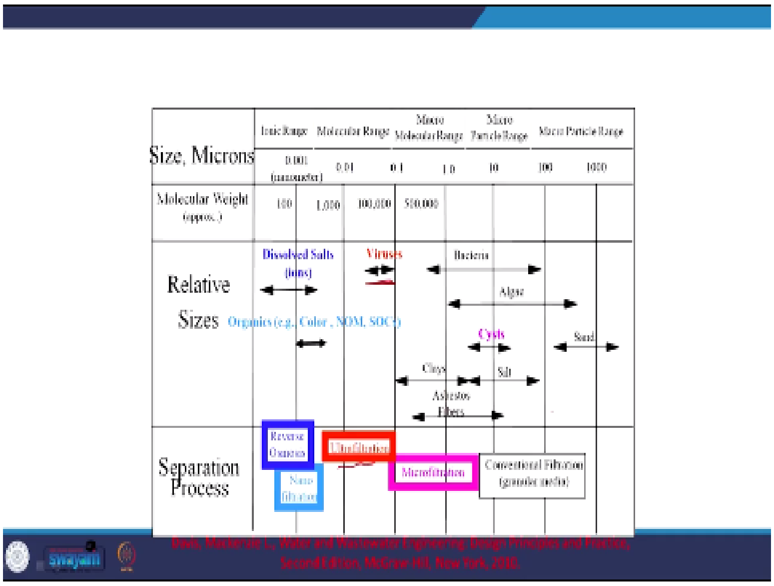

Davis, Mackenzie L., Water and Wastewater Engineering: Design Principles and Practice, Second Edition, McGraw-Hill, New York, 2010.

To do that, there are different ways. One is filtration, conventional filtration by glandular media, you can see that I can capture some bacteria . But viruses are not going to be captured, they are much smaller. So, they will be removed during ultra filtration or nano-filtration. But that is a different aspect. So, here I am concerned about these suspended particles.

And if I want to just use conventional filtration, where the size of the ports is relatively bigger or just sedimentation to remove these particles. What I need to do? I need to see to it that bigger particles are formed from the smaller particles but they will not come together. Why is that? Because they have a net negative charge.

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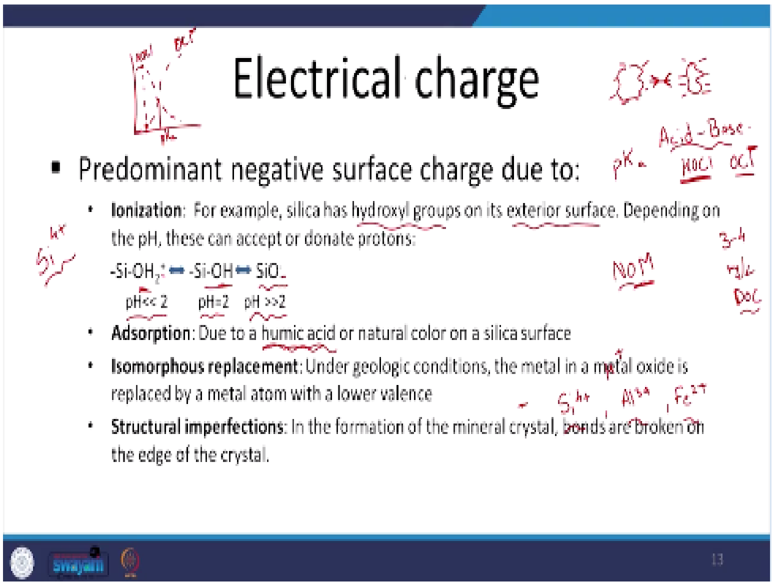

Electrical charge

- Predominant negative surface charge due to:
  - **Ionization**: For example, silica has hydroxyl groups on its exterior surface. Depending on the pH, these can accept or donate protons:

    $-Si\text{-}OH_2^+ \leftrightarrow -Si\text{-}OH \leftrightarrow SiO^-$

    pH<< 2 pH=2 pH >>2
  - **Adsorption**: Due to a humic acid or natural color on a silica surface
  - **Isomorphous replacement**: Under geologic conditions, the metal in a metal oxide is replaced by a metal atom with a lower valence
  - **Structural imperfections**: In the formation of the mineral crystal, bonds are broken on the edge of the crystal.

So, why do they have a net negative charge? that. They have a net you know, , this is my suspended colloid and it has a net negative charge. So, this negative charge will prevent these 2 particles from coming towards each other like, like they repel. There is ultra static repulsion. So, there is a predominant need to surface charge. What is that due to? For example, ionisation.

, it is acid base or based on the pH. So, based on the pH you know, HOCl can predominate or OCl can predominate. OCl^- can predominate. This has no charge, discharge charge. So, you know, it is here these are dissolved compounds, but I am just using that as an example. For example, you have silica, silica has hydroxyl groups on its surface. Here, we are talking about Si^{4+} sand silica and depending on the pH, you know the pH here, we have, we talked about the pKa and pH depending in the acid based context.

So, this is the case and this is pKa. This is the HOCl. This is the OCl^-. If pH is low, most of the acid is present as HOCl and very less is present as OCl^- which has a charge. So, similarly here, we are not talking about acids and basis, but still you have different groups that what do you say, change charge depending on the pH of the water. So, here, we have these silica groups which are pretty common and they have these silica which has hydroxyl groups which are pretty common on its exterior surface.

Depending on the pH, it can have a positive charge, no charge or negative charge. Typically, it will be in this range. Why is that? If you look at it, it is only predominant when pH is far less than 2.0 charges when pH is equal to 2 and when pH is greater than 2 and that is what most of our waters are or that is where most of our waters are. So, it typically has a negative charge. So, that is one reason for it, negative charge.

Adsorption. Due to humic acid or natural colour on the silica surface or be concerned with humic acid, we know that water has a lot of natural organic matter, even 3, 4 milligram per litre of DOC that means there is a considerable amount of organic matter. In NOM mineral waters, so that is 4 or 5 times or 3 - 4 times, so that is pretty high. So, there is NOM, well stay on the surface, not stay, suspended in the water that is one aspect.

But if there are particles the NOM, natural organic matter will be adsorbed onto the particles. So, most of these particles, which we are concerned about will have natural organic matter or organic matter adsorbed onto the surface. And we saw these we know, one general structure for this natural organic matter, I think when we are discussing about disinfection in waste water, we saw that you know there are different functional groups which can release H^+ .

And most of them do release their H^+, so that is why they have a negative charge. And this humic acid or the natural organic matter will lead to a negative charge on the surface. So, that is another thing to keep in mind. Another aspect is isomorphous replacement. For example, metal in a metal oxide metal oxide , is replaced by a metal with a lower valence.

For example, instead of Si^{4+}, if it is replaced by Al^{3+} or Al^{3+} is replaced by Fe^{2+}, you will see that that metal oxide will have a negative charge. So, isomorphous replacement will also need a negative charge and structural imperfections; while this is not as common as the other 3 causes, you know bonds are broken on the edge of the crystal and you typically due to these imperfections, you can have electrical charge or negative charge.

In general, colloid have net negative charge. And so, they cannot come together. So, the solution is stable. So, by correlation, I want to destabilise this.

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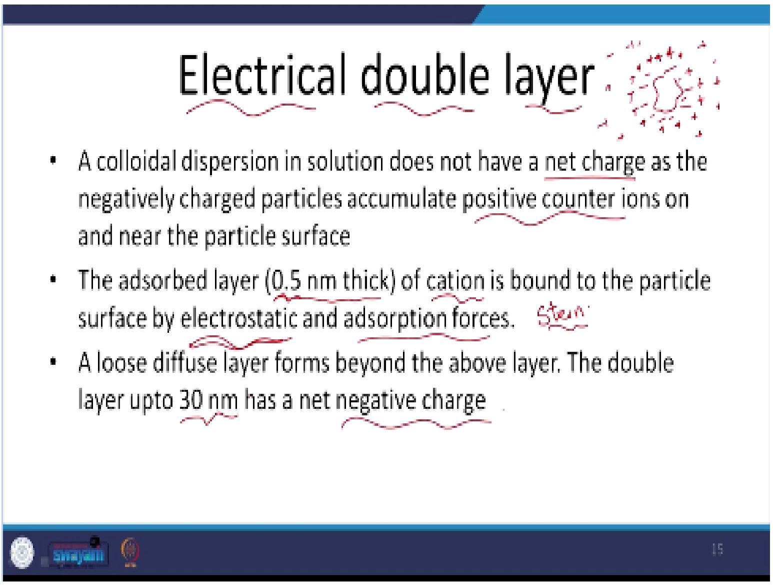

Electrical double layer

- A colloidal dispersion in solution does not have a net charge as the negatively charged particles accumulate positive counter ions on and near the particle surface
- The adsorbed layer (0.5 nm thick) of cation is bound to the particle surface by electrostatic and adsorption forces. Stern
- A loose diffuse layer forms beyond the above layer. The double layer upto 30 nm has a net negative charge

destabilise it, What do I do? I need to see to it that they come together. To be able to come together, what are the forces that are acting there ? Let us look at it. So, we have what is called an electrical double layer, . Unlike, what we just mentioned, a dispersion in solution does not have a net charge. Why is that? Because this colloids which have net charge, negative charge will attract a positive charged layer around it.

So, positive counter ions, counter ions on and near the particle surface. And this layer is pretty what we say, it is only 0.5 nano-meter thick and it is of cations meaning positively charges, they are bound to the particle due to electrostatic and adsorption forces primary electrostatic, . Negative charge on the colloid so, that is why it is surrounded by these cations or positive charge.

And also, even after this, you have a loose layer, relatively loose layer of positive and negative, I think we have a good picture later, we will come to that. That forms beyond this, what we say, stern layer, the above one is called stern layer. And this layer can be up to 30 nano-meters thick and has a net negative charge. And all this is called a double layer. So, this is something we need to keep in mind. So, that is what we have here.

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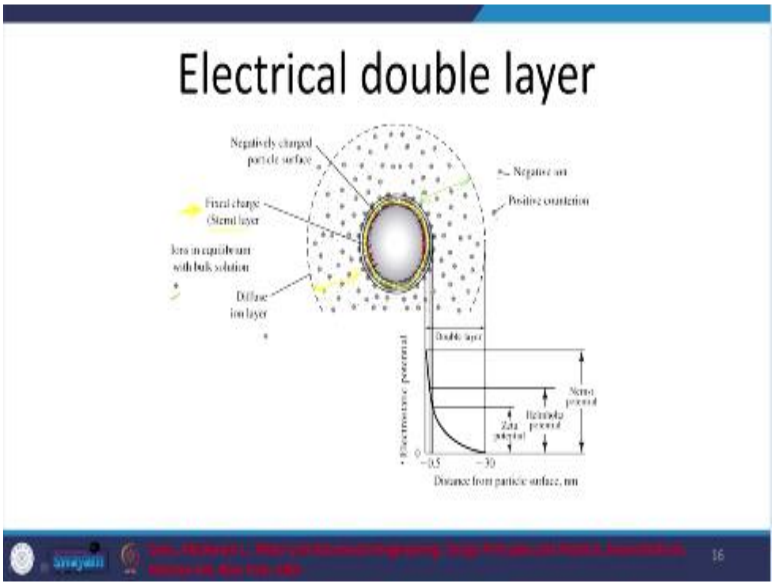

Electrical double layer

So, we see the ultra static potential here. And the first case here, we see the colloid at the innermost region and then you can see the negative charge, negative charge here. And then you can also see the positive charge in this region, the positive charge which is which accumulate around the colloid because of the electrostatic force of attraction and that is called the stern layer. This is the fixed layer or stern layer or fixed layer.

And around this, you will have this diffuse layer. This is what we have diffuse layer. So, negative and positive counter ion and all that is fine. And here, we have the bulk solution, bulk solution meaning in general the water or such, but this is the electrical double layer. From this particular, let me draw it. So, all this is the electrical double layer. So, ultra static potential as we go closer, , it is what do we say, much higher and as we go far away, it decreases.

So, that is one thing to understand or keep in mind. And here, we see something called zeta potential, we will look at that but note that it is the one that is in the that is relevant to the diffuse layer, . So, zeta potential . Let us move on. So, here if a similar particle wants to come nearby, there is a net negative field will not let them come together.

, as you see, you have this ultra static force of repulsion, but we will come back to that. So, how do I, what do we say, see to it that the particles can come together.

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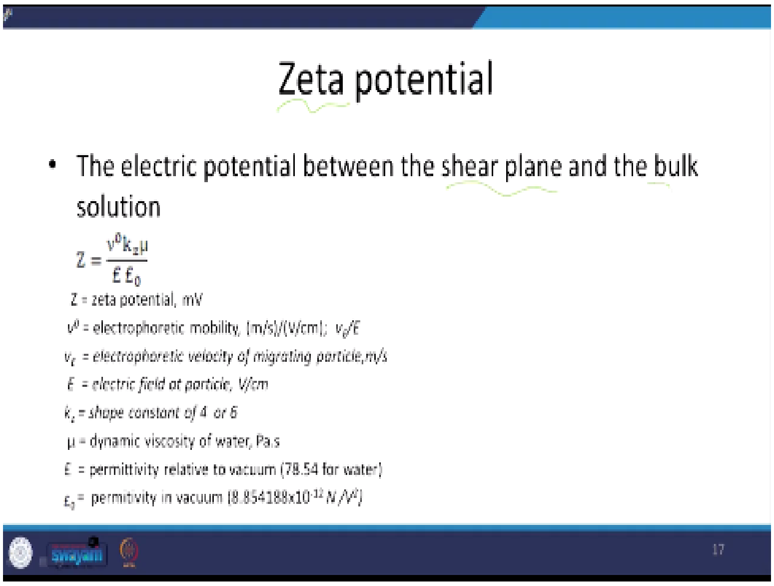

Zeta potential

- The electric potential between the shear plane and the bulk solution

$$Z = \frac{v^0 k_z \mu}{\varepsilon \varepsilon_0}$$

Z = zeta potential, mV
v^0 = electrophoretic mobility, (m/s)/(V/cm); v_E/E
v_E = *electrophoretic velocity of migrating particle,m/s*
E = *electric field at particle, V/cm*
k_z = *shape constant of 4 or 6*
μ = dynamic viscosity of water, Pa.s
ε = permittivity relative to vacuum (78.54 for water)
ε_0 = permitivity in vacuum (8.854188×10^{-12} N/V²)

Before we look at that, we need to understand some other aspects. So, zeta potential just a side aspect, the electrical potential between the shear plane and the bulk solution.

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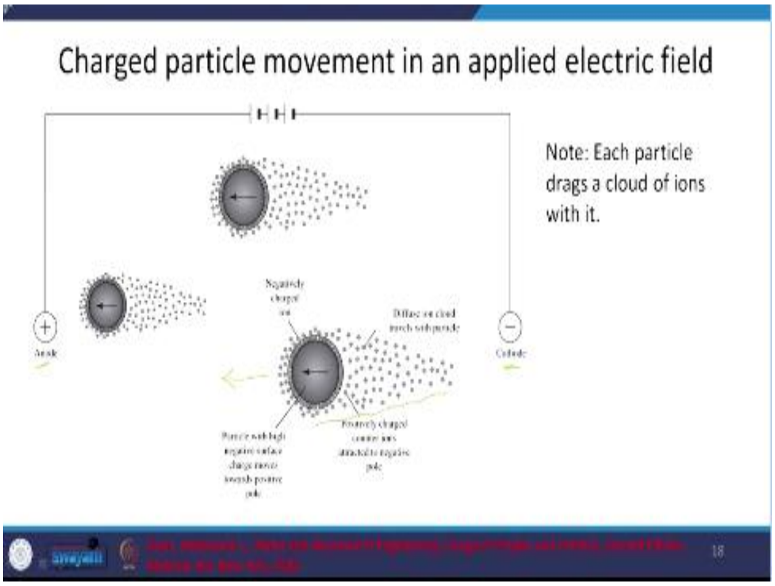

Charged particle movement in an applied electric field

Note: Each particle drags a cloud of ions with it.

So, thus, you can measure from here if I apply a potential negative and positive the colloids which are negatively charged, will move out here and they will drag a cloud of particles, which , typically positive will be towards or aligned towards the negative charge. from this, I can measure the zeta potential which we also looked at here, . So, let me move on.

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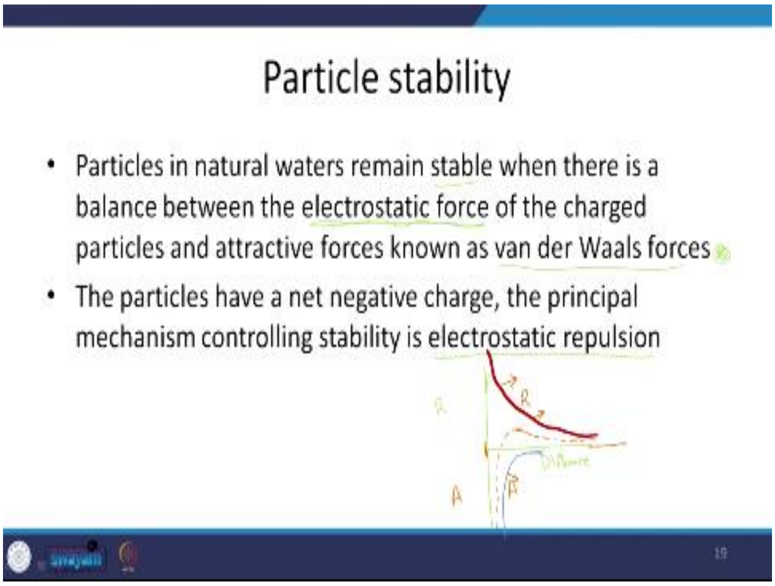

Particle stability

- Particles in natural waters remain stable when there is a balance between the electrostatic force of the charged particles and attractive forces known as van der Waals forces
- The particles have a net negative charge, the principal mechanism controlling stability is electrostatic repulsion

So, particle stability. So, particles in the waters are stable, because there is a balance there. Why is that? We have 2 forces. One is the ultra static force that repels or electrostatic force of repulsion and the attractive force which is the van der Waals force of attraction, . This, we cannot do much about it. And this is something we want in this context, but we can you know, do something about this ultra static force of repulsion.

, the particles with the negative charge the mechanism controlling stability, as I just mentioned, is the electrostatic repulsion and let us just understand this. So, if this is it, repulsion will increase with. This is repulsion, electrostatic force of repulsion. This is it. So, this is the distance. As the distance decreases, you know, this repulsion force will increase .

Let me try to draw it with a better colour. So, as I am coming nearer to my particle of interest, this is increasing. But what about this van der Waals force of attraction that we talked about? How is that going to help me now? So, even that will be depend upon the distance but even more what we say, so, it will come into the picture only when they are close by and more importantly, it will have a remarkable effect something like this.

So, the net will be a repulsion force, when it is near, not near, let me use this colour. So, the net, this is repulsion, this is attraction, this is due to electrostatic force, this is due to van der Waals. What will the net look like? The net will be like that it is in general repulsion here attraction; there repulsion. In general, this and then a steep come down. So, in the area about this green line, it is repulsion. So, when it is relatively far away or just about to come to the surface or near the surface of my particle here, it is repulsion.

And only later when they are very close, will the attraction take over. But because there is repulsion when they are far away or just nearby, they cannot come together. How do I make them come together? I can see to it that this electro static repulsion is decreased. Let me look at that.

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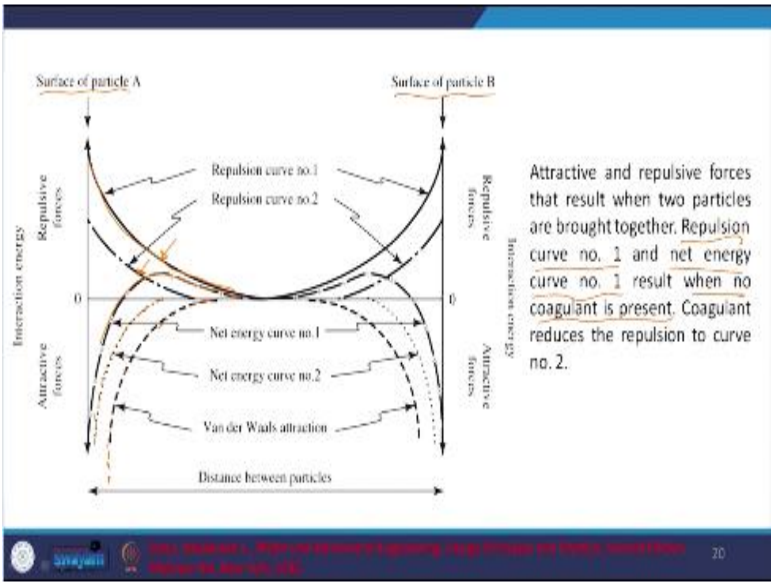

Attractive and repulsive forces that result when two particles are brought together. Repulsion curve no. 1 and net energy curve no. 1 result when no coagulant is present. Coagulant reduces the repulsion to curve no. 2.

We will just look at this curve and end this session for today. So, here is surface of particle A and surface of particle B. So, I have 2 cases; repulsion curve number 1 and net energy curve number 1 when no coagulant is present. So, what do I have here? Particle is zero, here zero. So, as I bring one towards the other, repulsion force is this. And where is my van der Waals force of attraction?

This is my van der Waals force of attraction which increases greatly if I am very near. If I am very near, you see that it is remarkably high. But the net, the net is somewhere here. And as you see, this barrier, my particle cannot cross as it comes nearby. This repulsion will push it away. So, if I want to see to it that this repulsion is decreased from there to here or if I can do that, then I see this net will be like this.

As it comes nearer, you will have a net what do we see, attract to what do we say, curve or such of I say so, (30:15) net attractive force. So, how do I do that? I can neutralise the charge on this particular colloid. So, that was what was causing this electrostatic what do we say, repulsion. So, by adding a charge, which is opposite to the charge on the colloid, I can cut down on this ultra static force of repulsion.

Then as the particles come together, the van der Waals force of attraction takes over and the particles can coalesce. So, this is or this process is called coagulation and trying to destabilise the relevant system or the colloids by adding a coagulant here. And I am trying you know, trigger that initial coalescence of the particles. So, with that, I will end today’s session and we will continue this in the next session.

This sense, we look at coagulation and then flocculation. As usual, thanking you for your patience. I will end today’s session.