

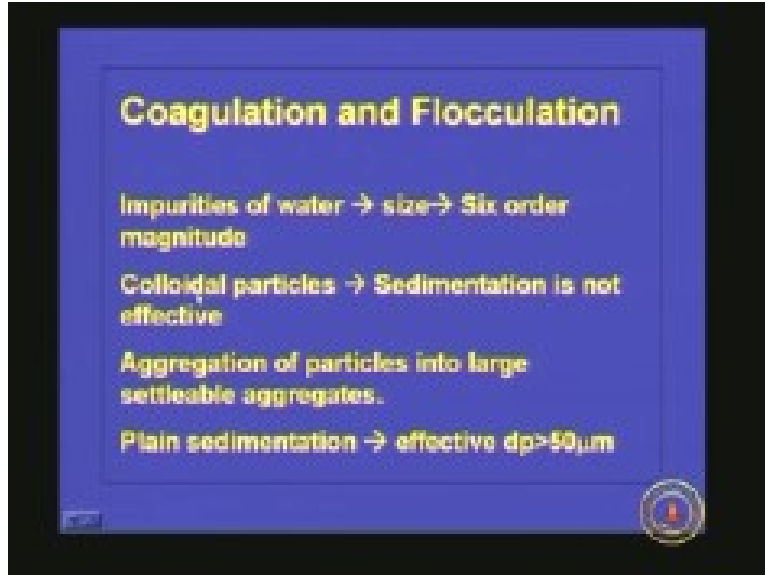
Water and Wastewater Engineering
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Water and Wastewater Engineering
Coagulation and Flocculation
Lecture # 10

Last class we were discussing about sedimentation. We have seen what are the different types of sedimentation and what are the different configurations of sedimentation tanks available and on what the efficiency of a sedimentation tank depends upon and if you want to improve the efficiency what are the alternatives we can provide.

Today we will discuss about the other treatment processes followed by sedimentation that is coagulation. Coagulation is required when the particles are small. In sedimentation we have seen that it's a unit operation that means we are not adding any chemical or any other external force the particles are settled because of the gravity force or because of the settling velocity. So this settling velocity is important or the settling velocity is depending upon the size of the particle. If the size of the particle is large enough then we will have a good settling velocity so that the particle will be settling within a given time. But if the particles are too small then the settling velocity will be so small and the time required for the particle to settle will be almost infinity.

At this condition, or if the particles are very small and the settling velocities are small then how can we remove them from water? For that one we usually adopt this coagulation and flocculation. If you talk about the size of the particle present in water it varies in six order of magnitude. That means starting from pebbles to very very small colloidal particles. So if the particles are of colloidal nature then sedimentation is not effective because colloidal particles as such is very very stable or the suspension of colloidal matter is stable so the settling is impossible. Thus, if you want to remove them by settling then we have to destabilize them or without destabilization if you can agglomerate them then the size of the particle will be increasing and as the size of the particle increases the settling velocity also will be increasing because settling velocity is proportional to the square of the diameter.

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Therefore, if we talk about the plain sedimentation it is effective only if the particle size is above 50 micro meter. This, I am talking about the particles whatever we are finding in water like sand, clay, silt etc which is having a good specific gravity. If the specific gravity of the matter is less then again the settling velocity will be decreasing then we have to have very large particle size to settle them effectively. This table gives as a clear picture about how the settling velocity of the particle varies with respect to time. As I have already mentioned the size of the particles whatever is present in water varies in six order of magnitude.

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Settling velocities of various size particles

Particle dia mm	Size typical of	Settling velocity
10	Pebble	6.73 m/sec
1	coarse sand	0.23 m/sec
0.1	fine sand	1.0×10^{-3} m/s (0.6m/min)
0.01	Silt	1.0×10^{-4} m/s (0.6m/hr)
0.0001	large colloid	1.0×10^{-6} m/s (0.3m/yr)
0.000001	small colloid	1.0×10^{-7} m/s (0.3m/million yr)

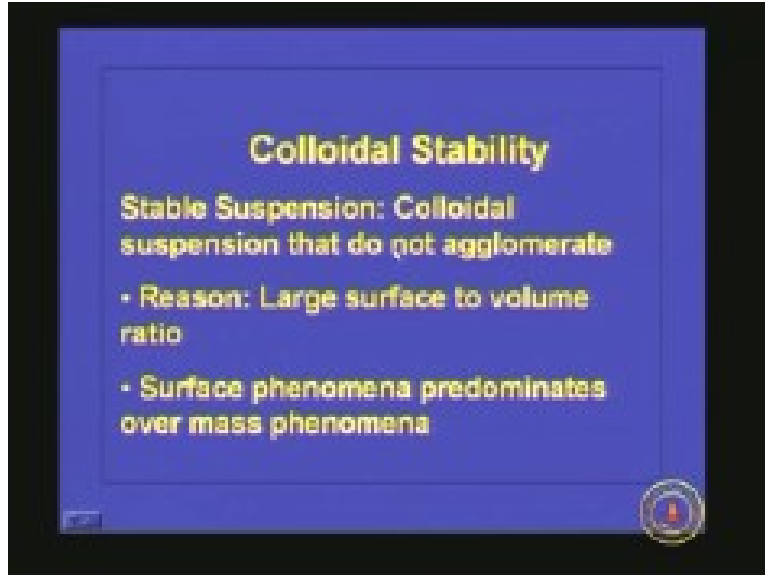
So starting from pebble we can see the average size of a particle will be around 10 millimeter. So if the diameter is ten and we are taking the specific gravity as 2.65 then you will be getting a settling velocity of 0.73 meter per second it's a very very high settling velocity so we can remove the particle very easily or by giving very less detention time the particle will be getting removed from the system.

Now we will come to the next size of particle that means coarse sand. The average size of this particle can be taken as 1 millimeter so the settling velocity will be around 0.23 meters per second. Here also the settling or removal by sedimentation is very very easy because in sedimentation time we usually give the detention time in the order of three to four hours so this requires very less time so hundred percentage removal of these things can take place in sedimentation time.

Now we will talk about fine sand. The particle diameter is 0.1 millimeter and the settling velocity is coming down to 0.6 meter per minute and if you talk about silt the settling velocity is 5.6 meters per day and if you talk about large colloidal particle the settling velocity is 0.3 meters per year. Hence, if you go for colloidal particle and we are going to use only plain sedimentation it takes years to clear the water and once we come to small colloids that means the particle size is in the order of 0.000001 that means 10 raised to minus 6 the settling velocity is 3 meters per million years. For example, if you take the milk, milk is an example of a colloidal solution, for whatever time we keep it; it is not going to clarify by itself unless there is some bacterial action and some other byproducts coming into picture.

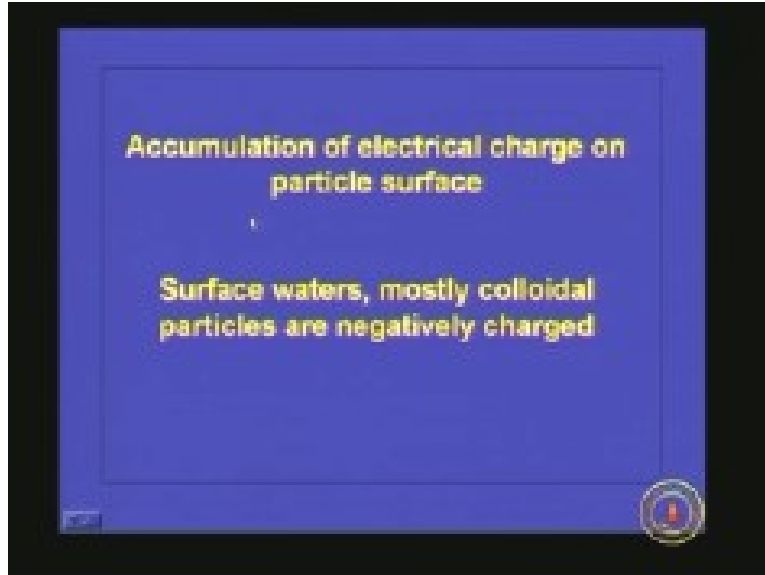
So if you want to clear such type of water we have to make the particle unstable and make them agglomerate together so that the settling velocity will be increasing considerably of this order then only we can go for sedimentation. How can we do this one? Before that one we will talk about the colloidal stability. Why the colloids are so stable compare to other suspension. The colloids are stable because of its large surface area to volume ratio. So, because of that one what will happen they will be undergoing the Brownian Motion and all the colloids will be in motion and surface phenomena predominates our mass phenomena.

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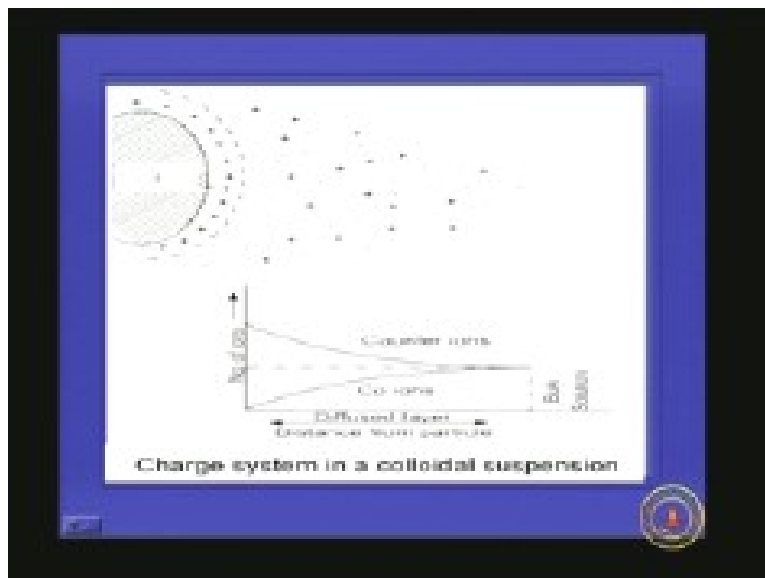
Therefore, because of that one what will happen is because of the force the weight of the particle will become negligible and moreover the colloidal particles accumulate some electrical charge on the surface of the particle. So if the particles are charged what will happen....., so many colloidal particles are there in the suspension and each one is having the same charge so when two particles of same charge come together or try to come together what will happen is because of the charge they will be getting repelled and in surface water most of the time the colloidal particles are basically because of clay and silt. These particles have a negative charge most of the time. How is it getting this charge? It is because of the reorganization of the crystal structure as well as the losing of atoms because of abrasion which is happening in the suspension or in the solution.

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So most of the time whatever colloidal particles we see in water will be having a negative charge so all these particles are negatively charged and when they come in contact it is not possible them to agglomerate because of the negative charge.

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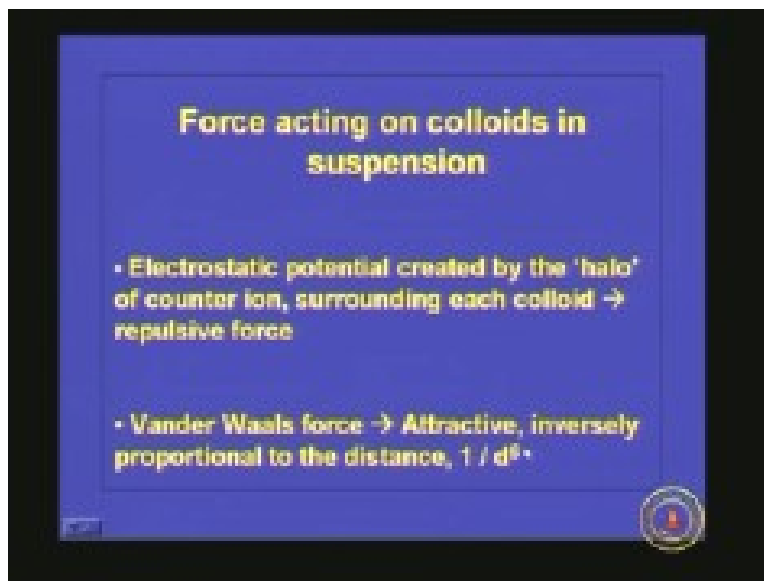
For example, this is a colloidal particle a clayey particle, we have already seen that most of the colloidal particles whatever is present in water are having negative charges so this is having a negative charge and because of the negative charge, in the solution there will be so many other ions present, in water for example we have calcium, magnesium, sodium, sulphate, chloride etc and both cations and anions will be present in water so

when you take this colloidal particle and water as a whole it will be electrically neutral so this particle cannot stay as such. So what will happen is since it is having a negative charge most of the positive charged ions whatever is present in the water will be coming very close to this one and as I have already mentioned water is electrically neutral so these positive ions cannot stay like that so the counter ions that means negative ions also will come into the picture.

So as the distance from the particle increases the concentration of the positive ions and negative ions will be decreasing but we will be having a diffused ion layer like this. Hence each colloidal particle will be having a diffused ion layer like this so because of that one what will happen is that the colloidal particles will not be able to come closer and unless they come closer they will not be able to agglomerate.

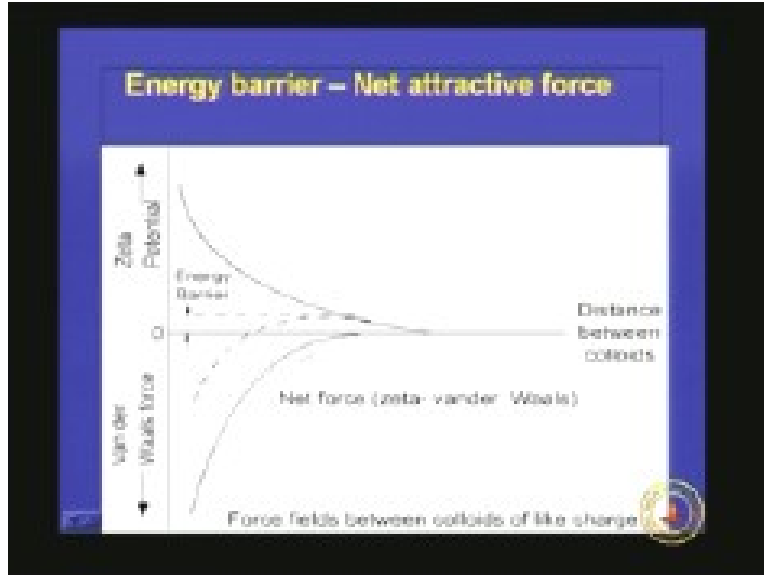
When we talk about colloidal particles this is the repulsive force (Refer Slide Time: 10:13) or the **zeta** potential. There is an attractive force, wherever there are two particles there is a weak attractive force acting between them that is known as the Van der Waals force. The Van der Waals force is proportional to the distance that means it is inversely proportional to the distance not as one power; it is proportional to 1 by d raised to 6 that means as the distance decreases the Van der Waals force will be increasing in the order of six magnitude.

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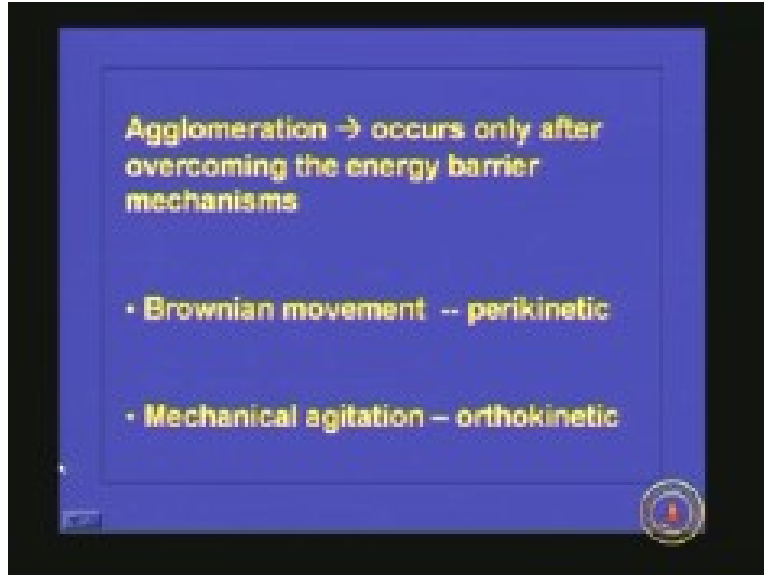
So if you want to bring the colloidal particles together what we have to do is first we have to overcome this energy barrier, energy barrier means the repulsive force whatever is there so the attractive force should overcome the repulsive force. How can it be possible? We have seen this zeta potential, which is the repulsive force and this is the Van der Waals force and that is the attractive force.

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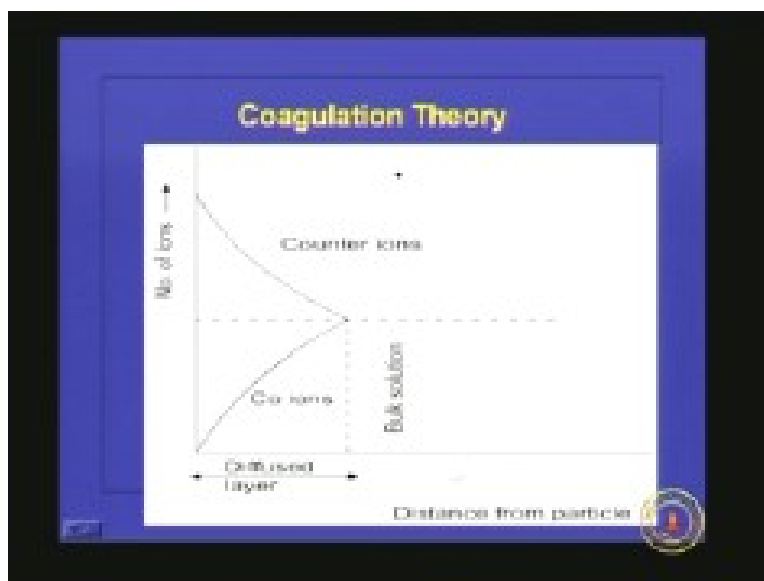
So the particle will be able to come together only when this zeta potential or the repulsive force minus Van der Waals force become positive. Or if you draw the net force, here we can see (Refer Slide Time: 11:45) this is the net force so here we can see that the Van der Waals force is higher than the zeta potential so at that time only the particle will be able to come together. So up to this point it is not able to agglomerate them so how can we bring them together? I was already mentioning that agglomeration occurs only after overcoming the energy barrier mechanisms. So how can we bring them? If you give some disturbance in the system the ions whatever is getting attached to the colloidal particle or the ionic layer, the diffused ionic layer will be shearing off from the particle so the particle will be able to come more and more closer so the Van der Waals force will be predominating and the particle will be agglomerating.

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How can we achieve this one? We can achieve this either by Brownian movement or by mechanical agitation. Brownian movement: the transport due to the Brownian movement is known as perikinetic flocculation and by mechanical agitation it is known as orthokinetic flocculation. Now we will see what is the coagulation theory. This we have seen. This is your colloidal particle and this represents the number of ions with respect to distance.

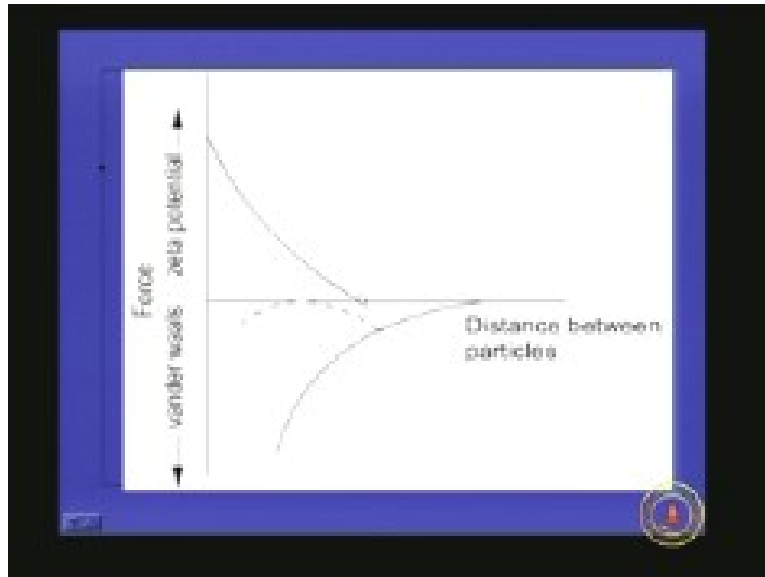
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This we are calling as diffused layer. It will be having equal number of counter ions and co ions. That means it is having same number of positive ions and negative ions. And as

we move towards the bulk solution away from the colloidal particle the concentration will be decreasing and finally there will not be any arrangement of this counter ions and co ions along with the colloidal particle. This is the figure (Refer Slide Time: 13:50) which represent both the zeta potential and Van der Waals force.

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This is the Van der Waals force. Van der Waals is very very negligible when the distance from the colloidal particle is large and this is the diffused layer. If other colloidal particle comes up here to this point then this diffused layer and other particle's diffused layer will be interacting so they will be repelling each other. This shows the net force. Here the net force is somewhere here when you take the difference between the zeta potential and Van der Waals force. Unless this Van der Waals force or the net potential becomes positive the colloids cannot come together.

How can we do this one? How can we reduce the repulsive force and make the colloidal particles come together? For that we usually add chemicals in water treatment process. What are the most commonly used chemicals as coagulants used in water treatment are alum which is nothing but aluminum sulphide $Al_2(SO_4)_3$. And we have trivalent metal ions and we also use ferric chloride, ferrous sulphide etc and even some natural coagulants we use to achieve this agglomeration.

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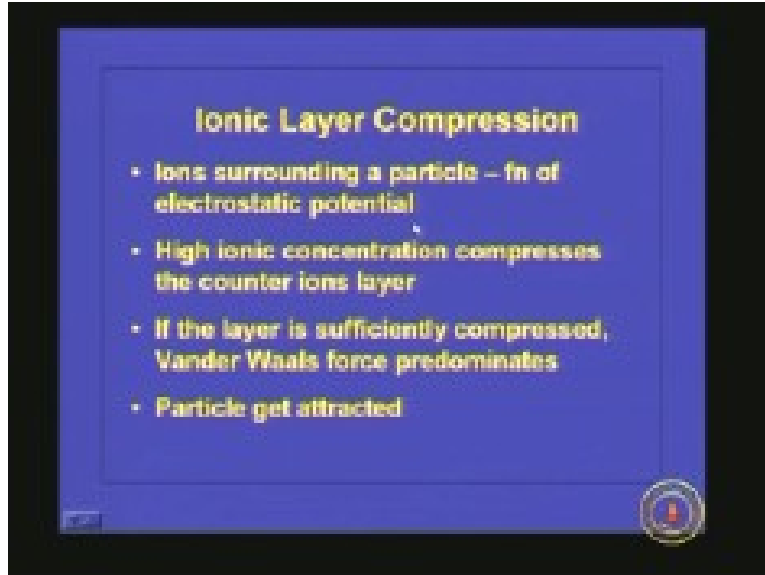
What are the mechanisms involved or how these chemicals are acting on the colloidal particles that make them destabilize and agglomerate?

The coagulation mechanism can be divided into four categories. First one is ionic layer compression; second one is adsorption and charge neutralization; third one is entrapment in a flocculent mass and adsorption and inter-particle bridging. We will discuss one by one in detail.

What is this ionic layer compression?

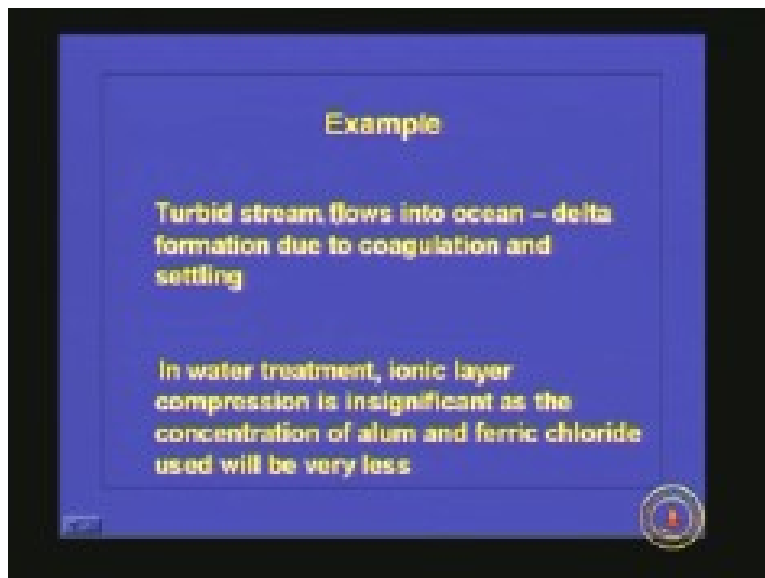
We have already seen how the diffused layer of ions is associated with a colloidal particle. If two colloidal particles are coming together because of the diffused layer they will not be able to come closer so if you can decrease that diffused layer distance the particle can come more and closer. In this ionic layer compression what the chemical does is it will be compressing the ionic layer. So how can you compress the ionic layer? The ion surrounding a particle is a function of electrostatic potential so if you give high ionic strength, ionic concentration in the liquid and since the ions concentrations are very very high more and more ions will be going closer to the colloids and the charge effect will be decreasing drastically so the diffused layer length will be reducing.

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If the layer is sufficiently compressed then what will happen is Van der Waals force predominates and particle gets attracted. That is what is happening in ionic layer compression.

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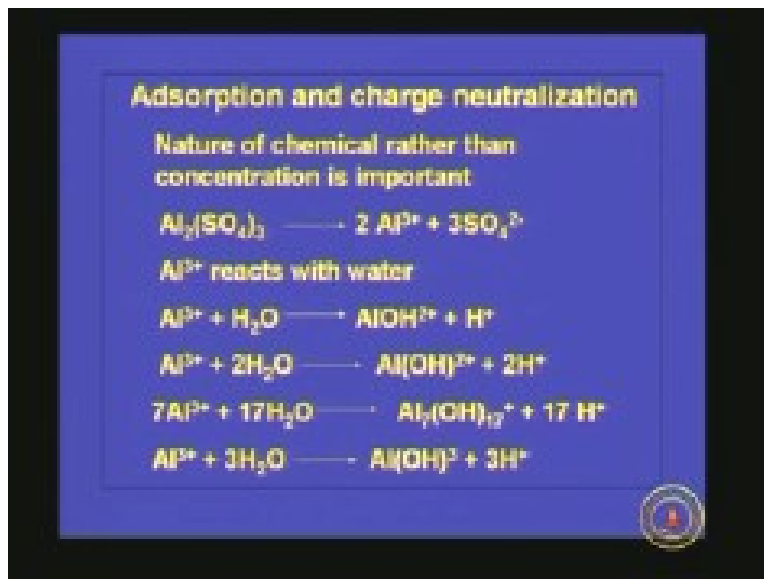


This is an example for ionic layer compression. The turbid stream flows into the ocean so the river is passing and flowing through the plane and it is going to the ocean so in estuary what is happening is there is so much of colloidal particles or sand and clay particles present in the incoming river and when it enters in the estuary the salinity of the water will be increasing because in the estuary the river water and sea water will be

getting mixed together so the ionic strength of that water is very very high compared to the river water. So at this time what happens is because of the high ionic strength the ionic layer or the diffused layer of the colloidal particles will be getting compressed. So when two colloidal particles come together this diffused layer is so thin compared to the earlier thing whatever was occurring in the stream. Therefore, what will happen is the Van der Waals force will predominate and the colloidal particles will be coming in contact and they will be agglomerating. This is the reason why deltas are formed in estuaries, so till then the colloidal particles are very very stable in the stream water and once it comes to the estuary because of the ionic strength increase or when ionic layer compression is taking place the solution becomes unstable and the particles will be settling down.

But if you talk about ionic layer compression it is not having a predominate role in water treatment because the chemical whatever we are adding as coagulants in water treatment the concentration is very very less so it will not be creating a high ionic strength in the water so the ionic layer compression due to the chemical whatever we are adding in the water treatment for the removal of colloidal particle is not very significant. That is what I have given here. In water treatment ionic layer compression is insignificant as the concentration of alum and ferric chloride used will be very less so the concentration range we usually use in water treatment is in the range of 5 to 40 milligram per liter for alum and all these depend upon the colloidal concentration, the alkalinity of the water etc. **These things will be discussed later.**

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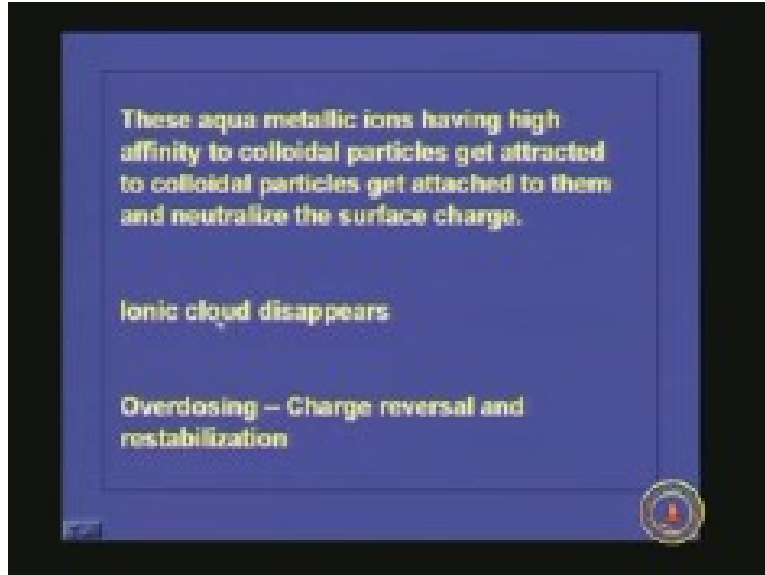
Now the second mechanism is adsorption and charged neutralization. So what is happening here? We have already seen that the chemicals whatever we are using as coagulants in water treatment are alum and ferric chloride and sometimes ferric sulphide. So when we put this chemical in water we get this reaction; alum $\text{Al}_2(\text{SO}_4)_3$ will be dissociating into aluminum and sulphide. Aluminum will be reacting with water because

this metal ions will be forming complexes with water and this water will be acting as a weak cationic acid and it will be dissociating and we will be getting different compounds like $\text{Al}(\text{OH})_2^+$ plus $\text{Al}_7(\text{OH})_{17}^+$ $\text{Al}(\text{OH})_3$ etc. These aqua metallic ions are having high affinity to the colloidal particle so what will happen is these aqua metallic ions will go and get attached to the colloidal particles and already the colloidal particle is having a negative charge, the charge of these aqua metallic ions is having a positive charge so when they go and get attached to the colloidal particle the charge will get neutralized.

Once the charge gets neutralized there will not be any diffused layer of ions surrounding the colloidal particle and because of this the diffused layer will not be there so the colloidal particles can come together and they can agglomerate and they can settle down, or we can remove them easily. But one problem with this adsorption and charge neutralization is that the colloidal particles are having a fixed charge or a fixed quantity of charge and these aqua metallic ions are having opposite charge so a certain amount of aqua metallic ions can go and sit on the colloidal particle so the charge will be getting neutralized. But, if more and more aqua metallic ions, goes and gets adsorbed to the colloidal particle, then the charge of the colloidal particle will be changing from negative to positive.

If all the colloidal particles are changing from negative to positive, then again the same problem will be there, because similar charged particles will be repelling each other. Here if the mechanism is adsorption and charge neutralization then we have to be very very careful about the dose. Dose should be sufficient just to neutralize or just to destabilize the colloidal particles. If you add little excess of the required then again restabilization of the particle will be taking place. This is what I was explaining. As we add the aqua metallic ions the aqua metallic ions get attracted to the colloidal particles and get attached to them and neutralize the surface charge. Once the surface charge is neutralized the ionic cloud disappears so the particles can come together.

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But when overdosing, charge reversal and restabilization will be taking place. Initially the solution was stable then by adding the chemical we are destabilizing them, now if we add in excess or if the dose is over then there will be restabilization or the colloidal suspension will become stable again. So we have to be very very careful about this one.

One more thing I want to tell is that, in ionic layer compression the valency of the ions are also important. We have seen how counter ions and co ions are coming so, if the ions present in the solution are monovalent then naturally the diffused layer will be longer compared to divalent or trivalent ions so the valency of the ions whatever is present in the solution that is also important when we talk about ionic layer compression. The third mechanism is sweep coagulation. First one is ionic layer compression which is not applicable in water treatment because the concentration of chemical whatever we are adding is not sufficient to change the ionic strength considerably.

Second one is adsorption and charge neutralization. This is a common phenomena whatever is taking place in water treatment when we add alum or ferric chloride. But the most important point to be remembered here is the dose whatever we are adding is very very important because if you overdose the colloidal particles will be again restabilizing from negative charge to positive charge, again we have to go for some other mechanism by which we can agglomerate them and remove them from the system.

The third mechanism is nothing but sweep coagulation. Here what is happening? After the charge neutralization and colloidal particle agglomeration, all these depend upon how many particles are present in the system if the suspension is dilute and the number of colloids present in the suspension is less then the agglomeration chances are very very less.

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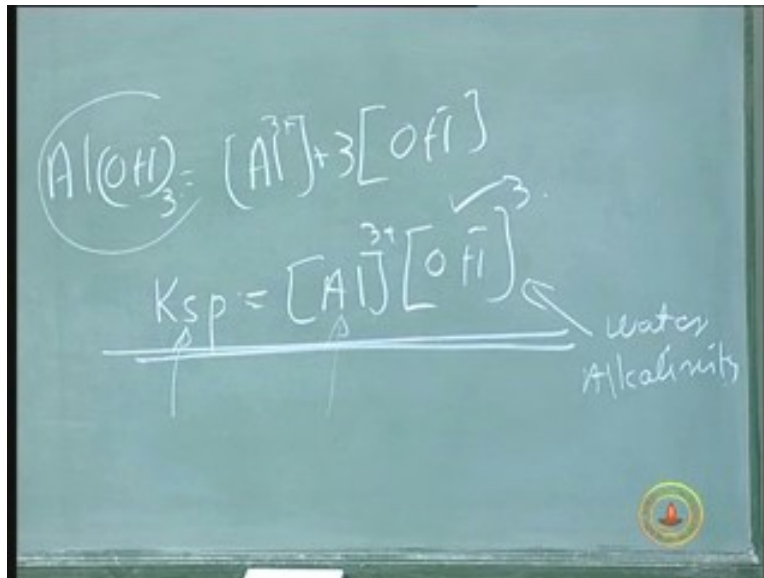
In such cases how can we remove the colloidal particle from the system? In such conditions we are going for sweep coagulation. Here what will happen, addition of metal salts like aluminum sulphate, ferric chloride, calcium oxide or calcium hydroxide at high concentrations causes the precipitation of metal hydroxide because if aluminum sulphate is added to water then aluminum sulphate will be dissociating into aluminum as well as sulphate. This aluminum will be reacting with water and it will be forming $\text{Al}_2(\text{OH})_3$ and it will be consuming some alkalinity also during this process.

So if the concentration of the chemical whatever we have added is sufficient enough for the precipitation then naturally the aluminum hydroxide precipitation will be taking place and **disprecipitate** it will be a dense floc that will be settling down because of its weight. So, when it settles down it will be entrapping the colloidal particle whatever is present in water that means aluminum hydroxide will be acting as a mass, the floc will be settling down so along with that one it will be entrapping the colloidal particles and removing it from the system. Same thing is true with ferric chloride also. Ferric will be forming ferric hydroxide and it will be removing the particle.

But when we talk about water treatment most of the time we go for aluminum sulphate or alum. The reason is, ferric ions as we know, will be giving some color to the treated water because when it forms the precipitate, when some compound has to be precipitated **it has to how the concentration more than** the K_{sp} value. That means solubility product constant so up to that level it will not be precipitating. So whatever be the condition we want be able to remove ferric or aluminum completely from the system. So some concentration will be always remaining in the system which is lower than the solubility product constant. Because of that one the ion is having some color in it so the treated water also will be having the color therefore for water treatment most of the time we go for alum.

Now we will see what are the factors affecting the precipitation? Precipitation is affected by concentration of salt because precipitation takes place something like this so we have to aluminum and hydroxide so this will be forming aluminum hydroxide, aluminum plus 3 hydroxide will be forming aluminum hydroxide so what will happen is the solubility product constant it is nothing but Al power 3 plus into OH raised to 3. This is very very important.

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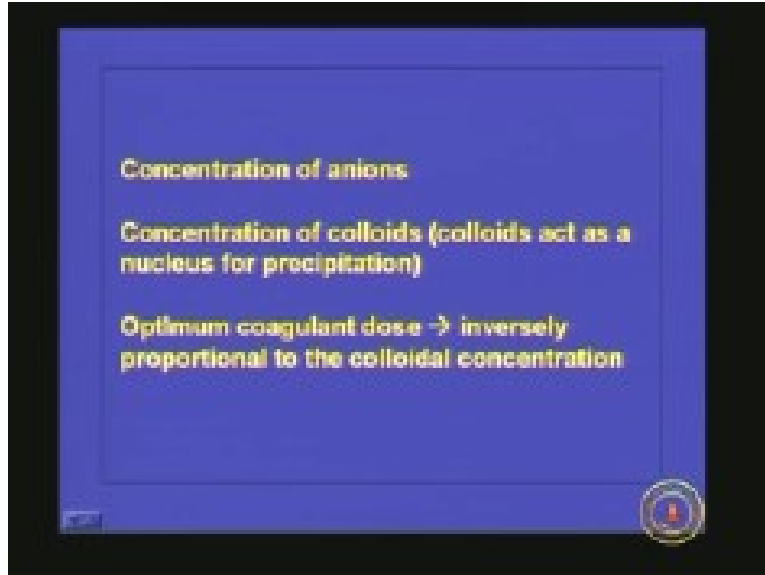


The compound will be remaining in the solution as long as this aluminum and hydroxide concentration product is less than the ksp value. This ksp value is a constant for the metals so if we are adding very low concentration of the salt the value will not be higher than the ksp value so we will not be getting any precipitation. But if you add more chemical the aluminum concentration will be very very high so we can get a value higher than the ksp value so naturally the precipitation will be occurring.

Another one is hydroxyl ions, from where the hydroxyl ions are coming? Mostly it is coming from water and it's all depending upon the alkalinity of the water. Thus, one of the important things for increasing the precipitation efficiencies is to add more chemicals.

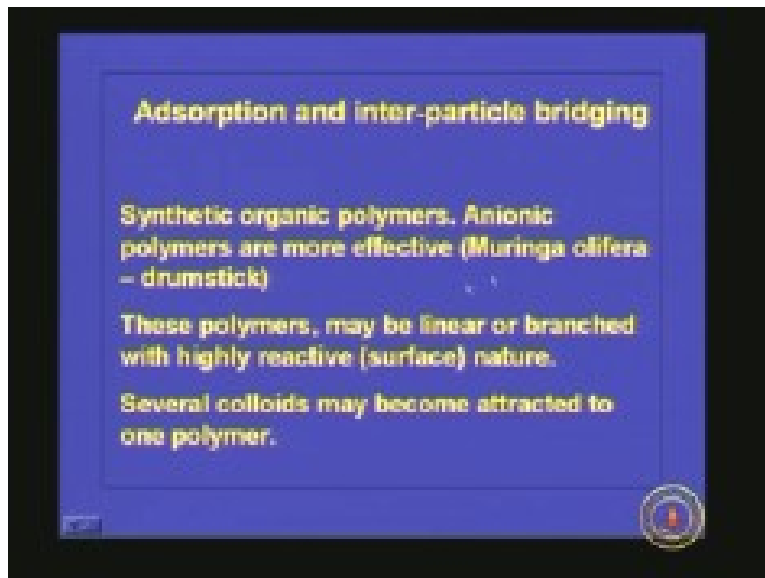
Second one is concentration of anions. We have seen that for aluminum hydroxide hydroxyl ions are required. Then if other ions are also present that can also increase the precipitation potential. Another important factor is concentration of colloids. Why it is important? It is because aluminum and hydroxide is combining together to form aluminum hydroxide. Initially it will be very very fine flocs and unless we get a large floc it will not be settling down so how can we make it a large one? This one is held by the colloidal particles. So what the colloidal particles do is, the colloids act as a nucleus so the particles will be getting or the compound whatever is formed, aluminum hydroxide will be getting attached to the colloidal particle and it will be growing in size so naturally the precipitation will be much much faster.

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Therefore, because of this reason if the mechanism of coagulation is sweep coagulation then optimum coagulant dose is inversely proportional to the colloidal concentration, because colloidal particles will be acting as a nucleus so the precipitation will be much much faster. So if you have very little colloidal particles there will not be any nucleus available so more and more alum is required to form this aluminum hydroxide precipitate or more and more ferric chloride is required to form ferric hydroxide precipitate which will be coming down as a sweep flow and removing the colloidal particle.

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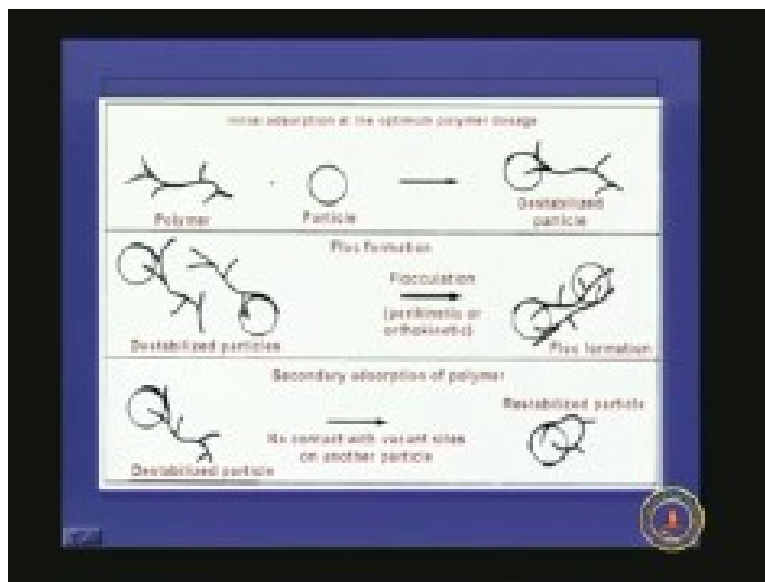


The last mechanism among the four is adsorption and inter-particle bridging.

Till now we were discussing about alum and ferric chloride which are the most commonly used coagulants in water treatment. But we can even use synthetic organic poly polymers whether anionic or cationic or neutral polymers for the removal of colloidal particles from water. Compared to non ionic or cationic polymers, anionic polymers are more effective. It is also found that even natural coagulants are very very effective; one of such is muringa olifera seeds which is nothing but the drumstick what are usually use for cooking. If you make a paste of this drumstick seeds and put it in water we can see that the colloidal particles are getting settled so that's an example of natural polymer. Moreover, this muringa olifera is having one more property which is helpful for water treatment, it is having disinfection characteristics.

So if you use muringa olifera seeds for coagulation what will happen is, it will be removing colloidal particles as well as it will be disinfecting the water. Another natural coagulant we use is nirmally seeds. Apart from this alum and ferric chloride we can use synthetic organic polymers. When we consider these polymers how they will be looking like? These polymers may be linear or branched with highly reactive surfaces. it is a branch with several functional groups attached to that one so what will happen is the colloids will be coming and getting attached to different branches and as a result what will happen is the polymer chain is there and many colloidal particles are getting attached to this one so the weight of that polymer will be increasing and it will be settling down faster.

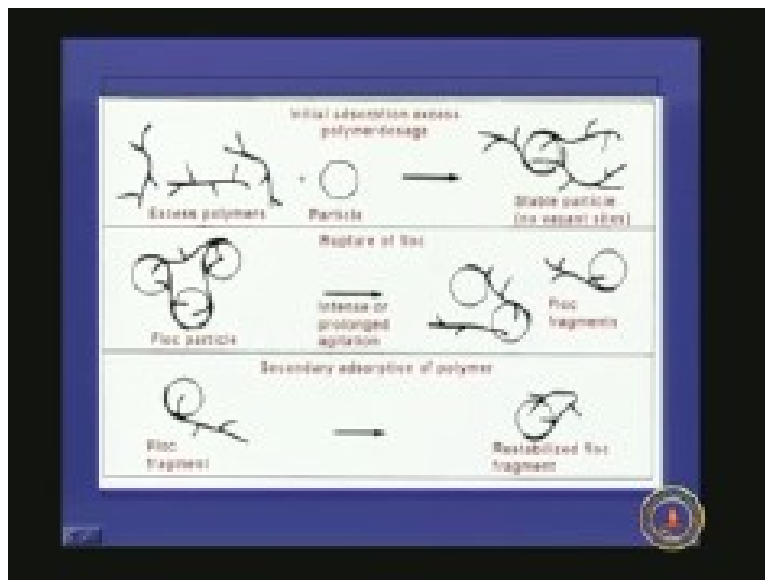
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This is a polymer. We can see it is a long one with many branches and this is the colloidal particle (Refer Slide Time: 33:43). Now, the particle is having one charge and the polymer is having another charge and it will be getting destabilized. Hence, when two such particles come in contact which is already destabilized by the polymers they can combine together and they can form a floc like this. This flocculation can occur because of perikinetic motion or orthokinetic flocculation.

Sometimes what will happen is the branch chains are there and this is the destabilized particle and if the polymer is not coming in contact with other colloids then this one will be again getting attached to the same colloid. That means here one charge site is there and this colloid is having another charge or the opposite charge and here it is getting destabilized, but see, this chain is having so many other locations with specific charges so it is searching for other colloidal particles but your suspension is not having enough concentration of colloidal particles then what will happen is this will not be getting other colloidal particles and if you are stirring or there is perikinetic flocculation or orthokinetic flocculation happening in the system then sometimes the polymer chain will be getting attached to the colloidal particle again. That means, more than one functional group or more than one surface charge is getting attached to the colloidal particle so the colloidal particle will be restabilizing again. As such the polymer is not very heavy so the particle is again restabilized so it will not be getting removed from the system.

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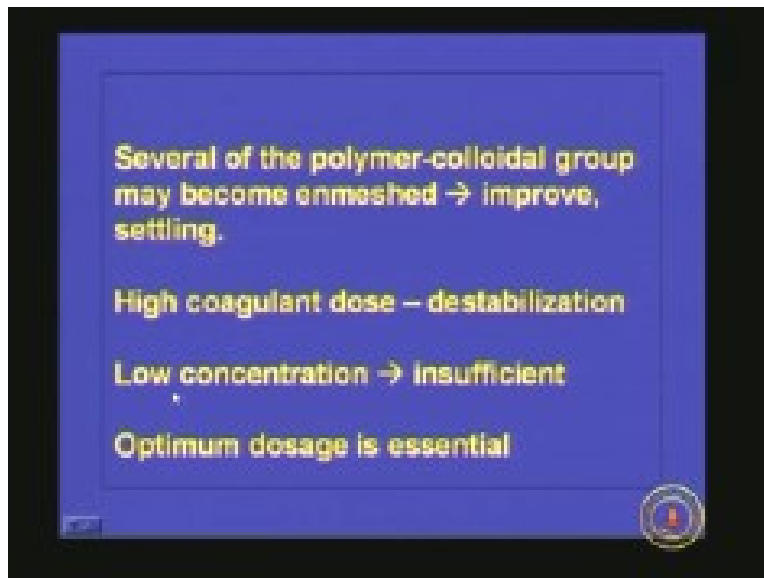
This is another thing. If you add excess polymers, so two or three polymer molecules are there and particle is there so initially itself all the three polymers are getting attached to the same colloidal particle so no vacant sites are available for the polymers so no more attachment can take place. And if you consider the colloidal particle what is happening is more than one side is getting attached so the charge is reversed and the colloidal particle will be becoming stable again. This is an example of a floc.

Here we have seen, one colloidal particle is getting attached to a polymer and another one is getting attached to another polymer, so if you give gentle mixing or proper flocculation the floc will be formed. This is a floc and if you give more and more flocculation or more and more mixing the floc will get ruptured like this and again it will be affecting the efficiency of this colloidal particle removal. This is another example. What is happening is already the floc is formed and it is searching for another colloidal particle but some other polymer branch is coming and getting attached to that one. This process is known

as secondary adsorption of polymer so again the particle will be getting restabilized. Therefore, we should be very very careful when we go for this adsorption and entrapment of particles.

This is more preferable so those should be sufficient enough for the destabilization of the colloids and the velocity gradient or flocculation whatever we are providing should be sufficient enough to form the flocs and it should not be having high intensity so that the flocs will be shearing of or rupturing. **I will once again read whatever I have explained;** synthetic organic polymers for example anionic, cationic or non ionic polymers can be used for coagulation. But anionic polymers are more effective compared to others and these polymers may be linear or branched with high reactive surfaces; several colloids may become attracted to one polymer; then several of the polymer colloidal group may become enmeshed and that will improve the settling. But if the coagulant dose is high then restabilization will be taking place. Low concentration is insufficient for the destabilization. If you are using polymers also it is essential to find out the optimum dosage of the coagulant.

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How can we find out the optimum dosage? **Once again I will repeat.** The four mechanisms of coagulation are; ionic layer compression, adsorption and charge neutralization, sweep coagulation and adsorption and inter-particle bridging.

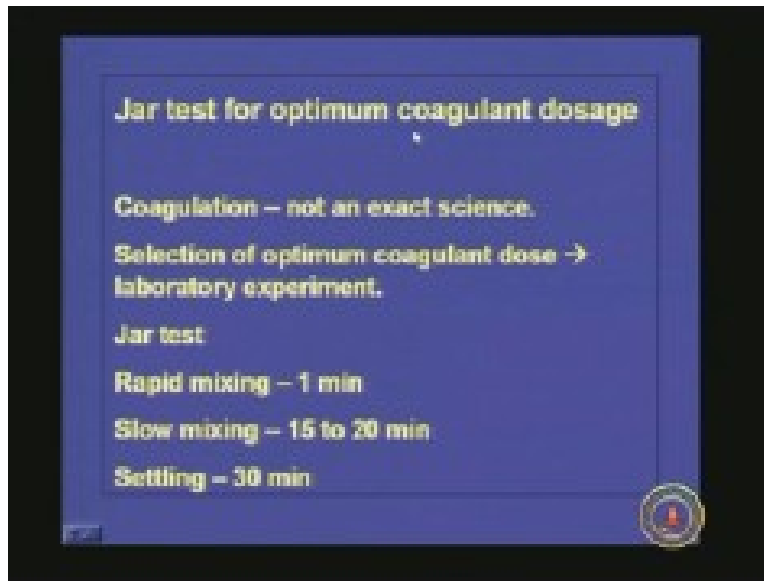
The first one is not coming under water treatment so for all these things optimum coagulant dose is essential otherwise the colloidal particles will be restabilizing and we will not be getting sufficient removal.

How to find out the optimum coagulant dose?

Though we know the reasons for coagulation, the coagulation theory is not yet fully developed. By theoretical means we are not able to find out what is the coagulant dose required. One more thing is that the coagulant dose will be varying with respect to the

water because it's depending upon the alkalinity of the water, colloidal concentration of the water etc. So it is essential before designing any coagulation flocculation system to carry out the experiment in the lab using the same type of water and same coagulation flocculation system or same design criteria and conduct the jar test to find out the coagulant dose.

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What is this jar test? It is nothing but, we are taking the water samples in a series of six beakers and we are adding different doses of the coagulant either alum or ferric chloride and one beaker we will be keeping as blank or it will be acting as a control. Add the coagulant dose simultaneously to all the six beakers then mix the content rapidly for one minute, this ensures the chemical is getting mixed properly and is uniformly available throughout the volume of water then carry on with slow mixing. Slow mixing is for fifteen to twenty minutes, after slow mixing we are giving a settling time of thirty minutes.

What is happening here? First we are adding the chemical then we are providing rapid mixing so the chemicals are getting mixed well and the ions will be going and either get attached to the particle that means adsorption and charge neutralization or sweep coagulation or adsorption and inter-particle bridging. Whatever be the mechanism the chemical reaction will be taking place here in the rapid mixing.

In slow mixing the particles whatever is restablized initially will be coming closer or we are trying to agglomerate the particle by giving a slow velocity gradient or small velocity gradient thus, slow mixing will be ensuring the transport step of coagulation and flocculation and chemical addition and rapid mix is ensuring the destabilization step of coagulation and flocculation.

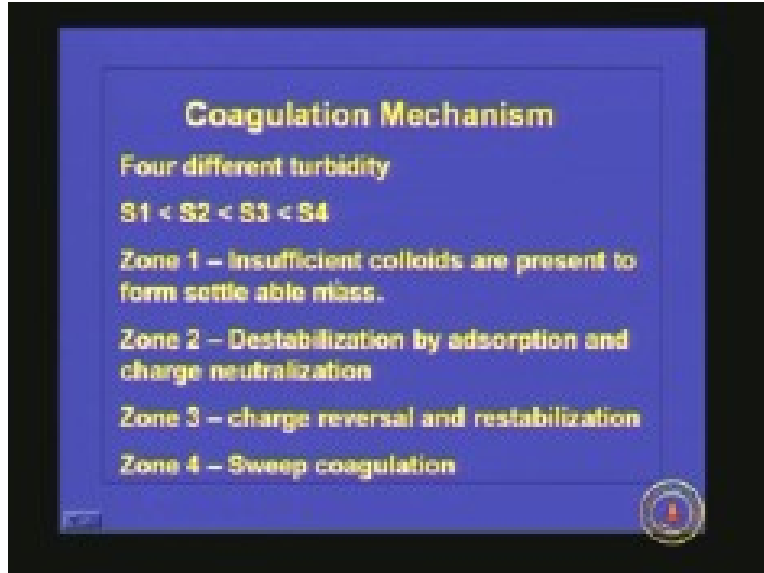
In other words coagulation and flocculation basically involves two steps; one is particle destabilization and second one is transport of the particle. Destabilization is essential to bring the colloidal particles close by and transport is required to agglomerate them. This is what is happening in jar test. This is exactly what we do in coagulation flocculation system.

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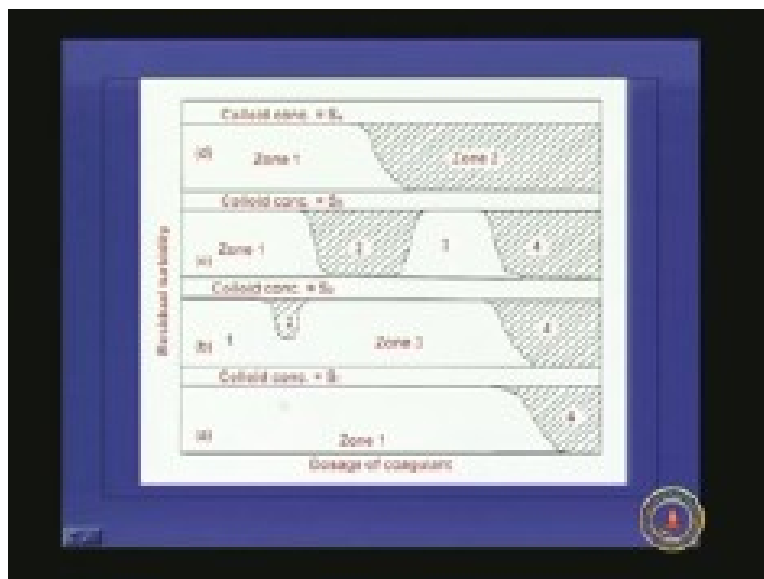
This shows a jar test apparatus. This is a mixing device and these are the different jars which are having same quantity of water and different doses of alum and this is a speed controller. Hence, all the paddles are moving at the same speed so we can control the speed. For rapid mixing we will be giving a high speed and for slow mixing we will be giving a very low RPM. And coagulation mechanism is varying depending upon the turbidity of the water. Turbidity can be classified into four categories; S1 S2 S3 S4. So, by considering these four different turbid concentrations we can explain the coagulation mechanism very very clearly.

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Here the S1 is very low compared to S2 and S4 is very very high concentration. We can see four different zones when we go for the coagulation. In zone one what is happening insufficient colloids are present to form settleable mass. In zone two what happens is destabilization by adsorption and charge neutralization is taking place and in zone three charge reversal and restabilization takes place and zone four sweep coagulation. So zone one will be predominant in S1.

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These are the different colloidal concentrations. This is for colloidal concentration S1. In the first zone what is happening is, in zone one the colloidal concentrations are so less or

the particle concentration is less so inter-particle contact and agglomeration is not possible. If the colloidal concentration of the water sample is less then what is the mechanism of colloidal particle removal? It is nothing but sweep coagulation. That means the coagulant whatever is added it will be forming a precipitate and that precipitate will be coming down as a blanket and it will be enmeshing all the colloidal particles present in the water so the mechanism is nothing but sweep coagulation.

Now, coming to the colloidal concentration S2, S2 is slightly higher than S1, here the colloidal concentrations are sufficiently large and we are adding coagulant to the system. Therefore, what will happen is, the coagulant or these aqua metallic ions will be going and getting attached to the colloidal particle and they are destabilizing. Now, this destabilized particle will be coming into contact and they will be agglomerating and getting precipitated or getting settled down. But if you increase the dose of the coagulant what as in zone three, this is nothing but, here something is getting precipitated, but in zone three that means the coagulant dose is more so whatever is getting attached, more and more aqua metallic ions are getting attached to the colloidal particle so their charge is reversing so the suspension is again becoming stable. Therefore, this zone represents the restabilization zone. Therefore, we will not be able to remove any colloidal particle here.

Coming to the last stage here the removal is taking place by sweep coagulation. This is what is happening. If we can adjust the coagulant dose we can remove a certain extent of the colloidal particle if the suspension is coming under S2 that means moderately high concentration. Now we talk about the colloidal particle or colloidal concentration of S3 that means it is higher than S2 and lower than S4 where we have moderately high concentration.

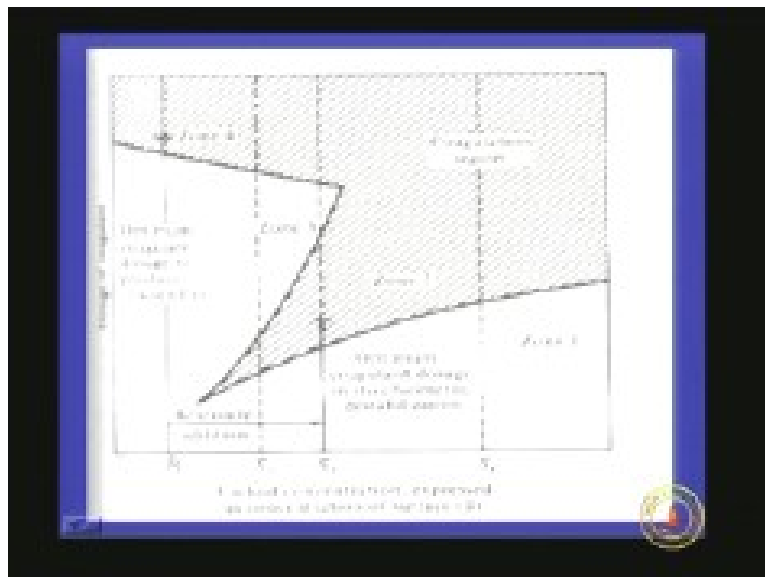
In zone one, we are not getting anything because initially the dosage is not sufficient to destabilize all the particles so the destabilized particle concentration is lower here. Here, there will not be enough agglomeration so we are not getting any removal of turbidity, this axis (Refer Slide Time: 47:13) represents the residual turbidity and that turbidity of the system will be remaining as such. But if you increase the coagulant dose slightly more then all the particles will get destabilized by adsorption and charge neutralization. This zone represents the adsorption and charge neutralization.

Now, what happens is, there is considerable amount of colloidal particles present in the system and the particles are destabilized by the coagulant addition. So this destabilized particle will be agglomerating or because of perikinetic motion or orthokinetic flocculation these particles will be coming into contact and they will be agglomerating and settling down so you will be getting a residual turbidity as almost zero here. But if you further increase the dosage then the entire destabilized particle will be adsorbing more and more metal ions and they are again getting restabilized that means the charge is getting reversed and the solution will be restabilized so again the colloidal particle concentration in the solution will be very very high. If you want to remove the colloids further then we have to go for sweep coagulation

Now we will talk about the last category. Here the colloidal concentration is very very high so the amount of alum dose required for charge neutralization or destabilization is very very high. So here we can say that initially everything is not getting destabilized but as the coagulant dose increases the destabilization will be taking place and all the colloidal particles will be getting removed because here the concentration of colloidal particles are so high so we do not have to bother about the dosage of coagulant and worry about whether charge reversal will be taking place or not because the dose whatever we have commonly used in the treatment system will not be sufficient to reverse the charge. These are the mechanisms of coagulation and it depends upon the colloidal concentration in the solution.

That means if the concentration of the colloids or the turbidity of the water is not very very high the mechanism which prevails is sweep coagulation. If the colloidal concentration is moderately high then we can get some removal because of adsorption and charge neutralization but major mechanism is sweep coagulation. But if the colloidal concentration is considerably high then we can remove everything by adsorption and charge neutralization but we have to be very very careful about the dosage of coagulant. If the coagulant dosage is slightly higher all the particles whatever is destabilized and is about to be removed from the system will be again restabilized or charge reversal will be taking place and it will become a stable solution and it will not be getting removed and we can remove them only by sweep coagulation. This is the last one; that means the concentration of the colloids are so high so here the mechanism is adsorption and charge neutralization and we don't have to bother about the concentration of the coagulant whatever we are adding or dosage of the coagulant because the concentration of the colloidal particles are so high so the reversal may not be taking place unless we add very very high concentration of coagulant to the system.

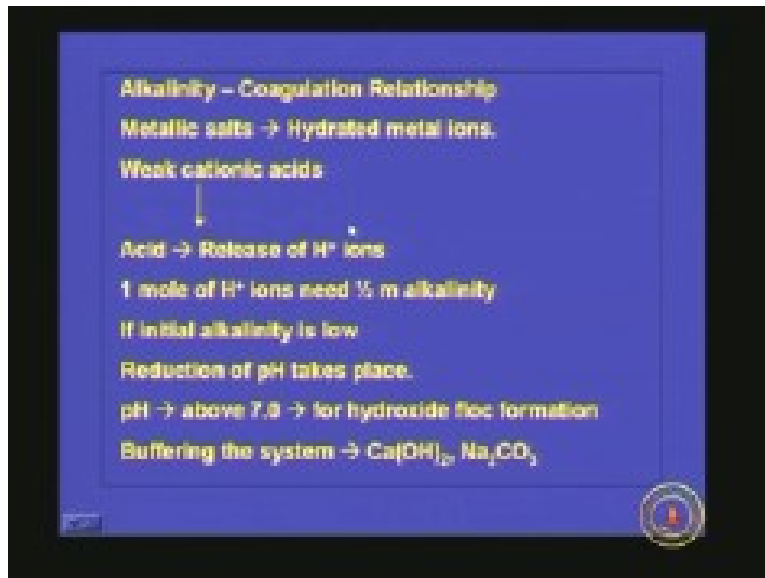
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This is the same concept represented in another way. This is S1 S2 S3 and S4 and this is the dosage of coagulant. If the concentration of colloid particle present in the system is very low then we have to add very high concentration of coagulant because the mechanism is sweep coagulation. And if it is moderately high, if we add some extra turbidity to water then adsorption and charge neutralization will be taking place but that will be happening only for a short range of this dosage because initially it is not sufficient to destabilize everything, here everything is getting destabilized then it is removing. But if we slightly increase the dosage again restabilization will be taking place and the removal mechanism is sweep coagulation, this is S3 (Refer Slide Time: 52:12), here also initially there will not be any removal. Here adsorption and charge neutralization is taking place and if the dose is high reversal can occur and again we have the sweep coagulation, the concentration is very very high here so initially the dose is not sufficient for destabilization, once it is destabilized agglomeration will take place and it will be getting removed from the system.

Another important point when we talk about coagulation and flocculation is the nature of the water. Alkalinity plays a very very significant role.

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We will see about this alkalinity and how it is affecting the coagulation process in detail in the next lecture. Now we will try to recollect whatever we have discussed today. Sedimentation is basically a unit operation, we are not adding any chemicals or external substances, it is because of the physical force of gravity the particles are getting removed from the system. But we know that water will be having various sizes of particles. It is not easy to remove everything by mere gravity force because the size of the particles vary in the order of six magnitudes starting from pebble to small colloidal particles. The settling time if you consider it varies from few seconds to millions of years.

We are not able to provide so much of time in a sedimentation time because if you want to provide say one day or two day, imagine what is the volume of tank required, because if you consider a city we have to supply so much quantity of water and if you want to store them in a tank for a day or two or for half year then imagine the volume of the tank that is required so the treatment is not economical so how can we improve this process, for that one we are going for coagulation and flocculation.

Here what we do is we are making the finer particles to come closer and agglomerate so that the particle size will be increasing and the settling velocity will be increasing considerably so that the time required for removal will be reduced drastically. That is the basic principle of coagulation and flocculation. It involves two steps; one is the transport step and another one is the destabilization step.

In transport step what we are doing is we are trying to bring the colloidal particles together either by perikinetic flocculation or orthokinetic that means mechanical mixing or the thermal mixing whatever is taking place in the liquid. The second one is destabilization, how can we destabilize the particle by adding some chemical which can change the nature of the colloidal particles. Why the colloids are stable? This is because of the surface properties of the colloids. Because of that one it is having a repulsive force because most of the colloids will be having a charge. Because of the charge it will be having a repulsive force and there will be an attractive force. Unless the attractive force overcomes the repulsive force we will not be able to make them come closer.

How we are doing this in coagulation and flocculation?

Basically coagulation involves four mechanisms; they are ionic layer compression. Here what we try to do is narrow down the diffused ion layer whatever is surrounded in the colloids so two colloidal particles can come together and agglomeration can take place and second one is adsorption and charge neutralization here what happens the coagulant dose whatever coagulant whatever we are adding to the water they will be forming aqua metallic ions which is having high affinity to the colloidal particles so it is getting attached and neutralizing the thing.

And third one is forming a precipitate and along with the precipitate removes the thing and the last one is adsorption and inter-particle bridging. So in all the cases the coagulant dose is very very important and the optimum coagulant dose is a function of the nature of water as well as the concentration of turbid matter present in the water. It is always easy to remove water which is having very high turbidity compared to a water sample which is having low turbidity because for high turbidity the major mechanism is adsorption and charge neutralization whereas in low turbidity water the mechanism is sweep coagulation. To form that sweep coagulation we have to add more and more chemicals because the precipitation is basically depending upon the concentration of the chemical we add.

We will continue in the next class.