Course Name: Industrial Wastewater Treatment

Prof. Alok Sinha

Department of Civil Engineering, IIT(ISM), Dhanbad

Week – 05

Lecture 3: Coagulation, Precipitation and Heavy Metal Removal

So, welcome back we are in module 5, lecture 3 and we are discussing the coagulation, precipitation and heavy metal removals by using the different processes. Here we will be talking about the concepts on the solubility of the metal salts, we will talk about the chemical precipitation in the wastewater treatment, we will talk about the precipitation by using alum, line and iron salts. We will also talk about the independent physical and chemical treatment processes which are used for the wastewater treatment, and we will also look into the calculations for the sludge generation during the precipitation process and then we will talk about the applications of the chemical precipitation process. So, when we talk of the solubility of the metal salts is so it will be very very useful if we consider the solubility of the hydrolyzed metal ions in the sense that the solubility of the hydrolyzed metal ions may decrease and it may be minimum at a certain pH value and based on that we can decide that what can be the optimum pH values at which the precipitation or we can say the sweep coagulation of the colloidal particles may take place. So, here we draw a curve between the log molar concentrations versus the pH values and for the mononuclear species of alum and iron. So, on the left-hand side we are having the curve which is for the alum dosing and on the right-hand side we are having the curve which is for the iron dosing in the wastewater.

So, here we can see that there can be different species which are soluble in the wastewater. For example, when we talk about the alum dosing so here, we are having Al3 plus species, we are having Al (OH)2 plus species, we are having Al(OH)4 minus species. So, these species they constitute the dissolved form of the aluminum salts whereas the AlOH which is the precipitate so it may be formed and because as the solubility of the aluminum decreases as the pH increases. So, if we plot this concentration of these species for example, Al3 plus versus the pH and Al (OH)2 plus versus pH as well as the Al (OH)4 minus species versus the pH value.

So, we can get some straight lines here. So, in this case we can see that this line represents the Al (OH)2 plus species whereas this line denotes the Al3 plus species variation versus the pH and similarly this line represents the Al (OH)4 minus species versus the pH. The dark lines which are showing here so these dark lines they represent the solubility of the aluminum ions at the various pH values. So, we can see that the solubility of the aluminum ions it may decrease with the increase in the pH, and it may go to a minimum value and then again it may increase. So, the solubility decreases because the species like Al3 plus and $Al(OH)_2$ plus so their solubility is decreasing and the aluminum ions are getting precipitated in the form of aluminum hydroxide and it reaches a minimum value and after which the solubility again increases because then the $Al(OH)_4$ minus ions so their solubility increases in the solution and because of which we find that the solubility of the aluminum ions it again increases and the precipitation of AlOH both rise it decreases.

So, we can have an optimum pH value for example, in this case we are having the optimum value of nearly 6. So, at which the aluminum hydroxide will be precipitated and the aluminum salts which we have added it is having the minimum solubility. Similarly, we can see here that the total concentration of the iron is represented by the ferric ions it may be represented by Fe $(OH)_2$ plus ions it may be represented by the Fe $(OH)_4$ minus ions. So, these ions represent here the different soluble species of the iron which are present at different pH, So, we can see here that again here the solid line it represents the solubility of the iron and salts in the wastewater solution and here we can see that the area above these solid line it represents the precipitation of the ferric hydroxide and these lines as for example, here Fe3 plus species and Fe $(OH)_2$ plus species and $Fe(OH)_2$ plus species.

So, these species the solubility decreases as the pH increases whereas the pH increases the Fe $(OH)_4$ minus species their solubility increases because of which the solubility of the iron salts again increases. So, here also we can find that we are having an optimum pH value which is nearly 8 for the iron salts and at which we find that the maximum precipitation as ferric hydroxide takes place. So, from here we can say that the alum precipitation the optimum pH values lie in the range of 5 to 7 and it is having a minimum solubility at pH 6 whereas for the iron precipitation the optimum pH value may range between 7 to 9 and the minimum solubility occurs at pH 8. So, Amritraj and Mills in 1982, so they gave a curve for the pH of the mixed solution versus the log concentration of aluminum species. So, when the alum is being added for the wastewater treatment, so they have found out the concentration of the alum versus the pH values which tells us that what type of mechanism for the coagulation will be followed.

For example, if we are having the low dosages of alum and we are having the low pH values, so in that case the major mechanism of the coagulation process is the adsorption and charge neutralization and then destabilization of the particles and as the dosage of the alum is low and the pH slightly increases it goes nearly 6 or 7. So, then we see that the combination of sweep as well as the adsorption and charge neutralization process happens. Whereas at high pH values that is nearly 7 to 8 and we are having at the higher dosage of the alum we can find that the sweep coagulation process is dominant, and we can say that the optimum particle removal by the sweep lock occurs between the range of 7 to 8 and which occurs as at a dose of nearly 20 to 60 milligrams per liter in this case. So, this type of curve has been made for the water treatment applications, but it can also be applied for the wastewater applications with the minor variations. So, these types of graphs can be used, so that we can find out that what will be the major mechanism at what pH, which type of mechanism will prevail and based on that we can find out that what will be the optimum dose at a certain given pH, so that the colloidal particles can be removed from the wastewater.

So, generally the wastewater effluents they have got high pH values. So, it is nearly between 7.3 to 8.5. So, we see that if we are adding low doses of for example, if we are adding 5 to 10 milli amp per liter of alum doses, then it will not be effective when the pH is high.

So, we have already seen that the sweep coagulation comes into picture, and which requires a higher dosage of the alum to be added in the wastewater treatment. And so, it is possible that if we control the pH, so if we basically lower down the pH and if we are using slow dosage of the alum also, so in that case it is possible that the adsorption and charge neutralization of the particles may happen, and the particle may destabilize and then the removal of these colloidal particles may happen at extremely low dosage also. So, that is why it is very important that the characteristic of the wastewater needs to be determined before we go for the alum dosing or before we go for the fixing doses for the alum or any other coagulant. So, for that we require that the bench scale as well as the pilot scale studies to be done, so that we can establish the optimum dose that is required and at the optimum pH values, so that the maximum removal of the colloidal particles may take place by addition of these coagulants. Similarly, the initial chemical mixing with salts it plays a very important role.

As soon as we add the coagulants into the water, so they hydrolyze, and they begin to polymerize and within a fraction of seconds after being added to the water. So, this means that as soon as the coagulants which we are adding they are polymerizing, so they will contribute more towards the free coagulation as well as they may also contribute towards the inter particle bridging and that will lead to the removal of the colloidal particles, but that may again require a higher dosage of these metal salts. So, we require that the initial rapid mixing must take place, so that the chemicals they go, and they basically adsorbed onto the surface of the colloidal particles, so that the particles can be neutralized and then they can be removed by the adsorption and charge utilization and population process. So, for example, here if we consider that the time required for the formation of mono and poly nuclear species is of the order of 10 to the power minus 3 seconds, whereas it takes around 10 to the power minus 2 seconds for the formation of the polymer species. Whereas the rate limiting step is the step where the particles are brought near to each other, so that can happen by the brand-new motions, or it can also happen by the perikinetic flocculation.

So, the time required for this process to happen is nearly between 1.5 to 3.3 to 10 to the power minus 3 seconds. So, it is necessary that we go for instant and intense mixing of the metal salts, so that they may not form the polymer as well as they may adsorb onto the colloidal particles and they can neutralize the charges on the colloidal particles and or they can lower the surface charge of the colloidal particles and then when these particles they come closer to each other, they can coagulate and they can settle down and they can form the flocs and then they can settle down. So, if we require that we achieve such a low mixing time, so in that case we may use multiple mixers, so that the adsorption onto the surface of the colloidal particles, so that can be brought within few seconds.

So, now coagulation and flocculation are one of the processes by which we can remove the colloidal particles which are found in the wastewater and there can be some dissolved solids or there can be some contaminants which are in dissolved in nature. So, they also can be removed from the wastewater by using a method which is called the chemical precipitation. So, in this case we try to form the precipitates by using a certain precipitance and this process is known as the chemical precipitation. For example, we see here that this reaction shows that if we are having silver and if we want to remove the silver from the wastewater, so if we add potassium chloride to it, so this leads to the formation of silver chloride and this silver chloride may form the precipitate and then it can settle down and it can be removed from the system. Whereas the potassium chloride it basically changes into the potassium nitrate, and it remains in the aqueous forms.

So, in the wastewater treatment earlier this chemical precipitation was used for the removal of the total suspended solids and the BOD removal which may happen when there is a large seasonal variation taking place in the concentration of the wastewater. So, the characteristics of the wastewater if it is changing because of the seasonal variations, so in that case it was required that some TSS and BOD removal may take place by using certain precipitates. Similarly, wherever we require the intermediate degree of treatment for example, if the treatment is not required to that extent to a very higher extent, so in that case the intermediate degree of treatment may be required, and we may use the chemical precipitation method for such treatment. And similarly, it was also used as an aid for the sedimentation process. Now, currently the chemical precipitation methods are being used for improving the primary settling facilities and similarly, we also use the chemical precipitation for the independent physical and chemical treatment of the wastewater, and we are also using the chemical precipitation for the removal of phosphorus and heavy metals which we will be discussing in the coming lectures.

So, there can be a number of inorganic chemicals that we use for the coagulation and precipitation process in the wastewater treatment. For example, we use alum, which is widely used, it may be present in the form of liquid, or it may present in the form of lumps. Similarly, we can also go for using aluminum chloride which is again in the form of liquid. Similarly, we also use calcium hydroxide or lime for the treatment of the water or wastewater. It can be either available in the lumpy powder or it can be slurry form.

Similarly, we used ferric chloride which is again in the liquid and the lumpy form. Ferrous sulphate may also be used which is again in the granular form and we can also use sodium aluminate which is found in the flakes. So, these chemicals are used widely in the chemical precipitation process of the wastewater treatment. So, the precipitation reactions can happen in the real life. For example, we can have the precipitation in the water pipes if we are having a water pipe which is supplying a hard water and it may contain higher amount of calcium and magnesium and this calcium magnesium if the pH changes take place, so it may get precipitated out as calcium carbonate or magnesium hydroxide and this basically can lead to the choking of the pipes.

So, this is one of the examples of the precipitation. We have also seen that the formation of kidney stone can take place in our body where the calcium ions and the oxalic acids which are present in the food, so they may result in the precipitation reaction, and they may form calcium oxalate and these calcium oxalates they can go into the kidney, and they can form a kidney stone. Similarly, the formation of the immune complex also involves the precipitation reactions. For example, when we are having the soluble antigens, so they combine with the soluble antibodies and in presence of electrolyte solution and at a specific temperature and pH values, so they form insoluble visible immune complex in the human body. So, in the chemical precipitation process, we are having two reactants, and we are having two products.

For example, when we talk of the wastewater treatment by using chemical precipitations, so one of the reactants is the wastewater which contains number of dissolved substances that we require to be removed and similarly, we add a certain chemical or precipitate in the wastewater, so that is another reactant that is present in the wastewater. So finally, the product of the reaction it includes the precipitate of the dissolved substances which we want to remove. So, this may be removed out from the wastewater by the precipitation and the wastewater then becomes free from those contaminants or from those dissolved substances which you want to remove from the wastewater and that is how the wastewater is treated. So, such reactions are generally the double replacement reactions as we can see here the different reactions of the precipitation are written here. For example, the copper sulfate when it reacts with the sodium hydroxide, so it may form the sodium sulfate, so sodium and sulfate they basically combine together whereas the copper and hydroxide they combine to form the copper hydroxide precipitate in this case.

Similarly, sodium sulfate and the strong shim chloride it can lead to the precipitation of strong shim sulfate. The reaction of silver nitrate with sodium chloride, so it may lead to the precipitation of silver chloride. Similarly, the cadmium sulfate and the potassium sulfide, so it may lead to the precipitation of cadmium as cadmium sulfide. So, there can be different type of precipitates that can be formed. For example, we can have the crystalline precipitates which are easily settable, and they are also filterable.

So as the name says, so they are crystalline in nature, and they can be easily settled down and they are easily filterable also. Similarly, we can have the precipitates which is difficult to settle but it is filterable. For example, the precipitate of the silver chloride, so it may be curdy white precipitate, and this is difficult to settle down, but it is filterable in nature. Whereas the gelatinous precipitate, so they are formed because of the flocculated solids or the colloids which have been flocculated by addition of a certain coagulant. For example, if we add alum to the water or wastewater, so in that case the colloidal particles may form flocs and this type of precipitate that is formed is known as the gelatinous precipitate.

So, this type of precipitate is having a very small particle size, so this is difficult to settle as well as this is also difficult to filter. So now we will discuss about various type of precipitate that we use for the wastewater and water treatment. In this, the alum is the most widely used precipitate that we use. So, this alum is generally added to water which or the wastewater which contains calcium and magnesium bicarbonate as the alkalinity and it form, it precipitates in the aluminum hydroxide form. The overall reaction for this process is where calcium bicarbonate which represents the alkalinity, it reacts with the alum here that is Al2(SO4)3.18H2O which represents the alum.

So, it forms the precipitate of aluminum hydroxide, and it forms calcium sulfate, carbon dioxide and water. So, if we want to find out what is the losing of the alum that needs to be required stoichiometrically depending upon how much alkalinity is present in the water and what will be the amount of the aluminum hydroxide or the sludge that will form in this case, so we can calculate by using this stoichiometric equation. So here this calcium bicarbonate represents the alkalinity. So, this alkalinity is always expressed in as calcium carbonate. So that's why we have taken here the molecular weight as equal to 100.

Whereas 666.5 represents the molecular weight of the alum and 78 represents the molecular weight of the aluminum hydroxide. So, this aluminum hydroxide precipitate that is formed, it forms a gelatinous block and basically settles down very very slowly. So, it also sweeps the suspended material. So, it not only removes the soluble matter, which is present in the water or wastewater, but it also removes the suspended material by the sweep flocculation process. And similarly, we can also have this reaction in terms of magnesium bicarbonate.

So, we can just replace the calcium bicarbonate by the magnesium carbonate and the reaction remains the same. So, if we want to find out that what is the quantity of alkalinity which is required for a dose of 10 milligram per liter of alum, so we can just multiply this dose by 3 into 100 that is the alkalinity present in the water or wastewater divided by the total amount of alum that we are adding stoichiometrically. So, this may lead to the value of 4.5 milligram per liter as calcium carbonate because alkalinity is always represented in as calcium carbonate. So, if suppose this alkalinity is not sufficient, so in that case we have to add lime additionally so that this treatment or the aluminum hydroxide rocks can form.

But it is seldom required in the treatment of the wastewater as the wastewater may contain high amount of alkalinity. So, the lime can also be added when we are having the low alkalinity values or when we are having some acids present in the water if you want to neutralize those mineral acids or the acid salts, so in that case we add lime to the system. For example, here the first reaction shows here that the carbonic acid is present, and the carbonic acid reacts with the calcium hydroxide that is the lime, and it forms the calcium carbonate. Similarly, when the alkalinity is present in the water or wastewater, so in that case also the lime can react with it, and it can lead to the formation of calcium carbonate. So, this means that we have to add a sufficient quantity of lime so that it can combine with the free carbonic acid as well as the half-bound carbonic acid which is present in form of the alkalinity so that it can produce the calcium carbonate precipitates.

The industrial waste they also introduce a number of mineral acids and acid salts. So, this needs to be neutralized before we go on for the precipitation process. So, it is necessary that the neutralization of such industrial waste which is having low pH values it needs to be done by addition of the lime before we can go for the actual precipitation of other dissolved materials. The ferrous sulphate and lime combination can also be used for the chemical precipitation method. So, when we are using ferrous sulphate alone, so we can see that the ferrous sulphate may combine with the alkalinity which is present in the water or wastewater, and it may form ferrous bicarbonate and calcium sulphate and water whereas this ferrous bicarbonate may again decompose into ferrous hydroxide and the carbon dioxide.

So, this means that if the ferrous sulphate alone is present so it may not lead to the formation of any precipitate like for example ferric hydroxide will not be formed in such a case and we have to add lime to it so that we can form the precipitation of the ferric hydroxide in such a case. For example, if the sufficient alkalinity is also not available in the water or wastewater so in that case also the excess lime is added so that the ferrous sulphate it can basically get converted into the ferric hydroxide. So, we can see this reaction that ferrous bicarbonate when it combines with the lime so it may form ferrous hydroxide and calcium carbonate. So, this ferrous hydroxide may further react with the dissolved oxygen which is present in the water, and this may lead to the formation of ferric hydroxide. So, the ferrous hydroxide can be oxidized to ferric hydroxide if the DO is present in the water.

So, the ferric hydroxide which is formed so it is again bulky as well as the gelatinous flock which is similar to the alum flock. So, if we want to find out that what is the alkalinity which is required for 10 milli amp per liter of the dosage of the ferrous sulphate so in that case we have to multiply the dose into the alkalinity that is present here and divided by the total amount of ferrous sulphate that we are adding. So, this will give you the alkalinity which is required for 10 milli amp per liter of the ferrous sulphate. Similarly, the lime requirement can also be calculated by the dose of the alum into the lime which we are adding so here the lime is always taken as CaO right the molecular weight is 56. So here we are having the two molecules of the lime basically are required so this will basically lead to 2 into 56 here and divide by the total ferrous sulphate that we are adding and similarly the oxygen required can also be calculated based on the equation number 7.

So, this equation gives you the value of the oxygen that is required for conversion of ferrous hydroxide into ferric hydroxide. So here it comes out to be 0.29 milligrams per liter. So, the formation of ferric hydroxide is very much dependent upon the presence of the dissolved oxygen and hence if the wastewater does not contain any DO or the DO is minimal so in that case this reaction will never be completed. In this way this means that there is a lot of limitations for the ferrous sulphate to form the precipitate as ferric hydroxide and it is generally not used in the wastewater.

So, in place of ferrous sulphate, we can also go for ferric chloride so which can counteract the problems which are associated with the ferrous sulphate. So, we can have an advantage that ferric chloride if it is added to the base water, it can directly form ferric hydroxide. For example, here you can see this reaction that ferric chloride when reacts with the alkaline tea present in the water or wastewater, so it directly forms the ferric hydroxide precipitate. We can also use the ferric chloride with the lime where the ferric chloride may react with the lime, and it can form the ferric hydroxide precipitates. The ferric sulphate and lime can also be used where the ferric sulphate can be reacted with the lime and then it can lead to the formation of the ferric hydroxide precipitates.

So, we can have the enhanced removal of the suspended solids in the primary sedimentation so we can add the chemicals for the precipitation so this can remove the soluble as well as insoluble things for example it can remove the suspended solids, it can remove the BOD, it can also remove the bacteria. So, when we are adding the chemical for the precipitation so it is possible that we can remove nearly 80 to 90 percent of the total suspended solids which also includes certain colloidal particles. Similarly, 50 to 80 percent of BOD can also be removed during this process and it may also result in the removal of 80 to 90 percent of the bacteria. So, it is possible that when we are using chemical precipitation process then the efficiency of the primary sedimentation may be enhanced. Similarly, if we compare it with the process where we are not adding any chemicals so it may lead to the removal of nearly 40 to 70 percent of the suspended solids, only removal of 25 to 40 percent of the BOD and only removal of 25 to 75 percent of bacteria.

So, we can also think of independent physical and chemical treatment however the use of the independent physical and chemical treatment for the municipal wastewater is limited or they are very rare because of the lack of the consistency in meeting the discharge requirements. It also basically requires a very high cost for the chemicals and similarly large volume of sludge that is formed so handling and disposal may also lead to some problem because of which it is not used for the municipal wastewater treatment because the huge volume of the municipal wastewater comes for the treatment purposes, and it may lead to the very high amount of sludge generation that may result from the chemical additions. And similarly, there can also be numerous operating problems which restricts the use of the chemicals the independent physical and chemical treatment of the municipal wastewater. However the independent physical and chemical treatment may be used for the industrial wastewater, but here also we have to characterize the industrial wastewater and based on the characteristics and our treatment objectives that we require we have to fix the dose of the chemicals and the application rates so by performing the lab scale and the pilot scale studies so that we can efficiently remove the contaminants which are present in the industrial wastewater and we can meet the discharges. So, we can see here that this figure shows the independent physical and chemical treatment where the untreated wastewater may come to a great removal and combination chamber and after which it goes to the rapid mix and flocculation.

So here we add certain coagulant to it, and we mix it intensely for the few minutes and then later on we mix it at a slow RPM so that the floc basically may form. Initial rapid mixing is required so that the adsorption and charge utilization of the colloidal particles may take place and the coagulant that we are adding so it basically gets adsorbed on to the surface of the colloidal particle and later on for the formation of the flocs we go for the slow mixing or at a very slow RPM mix the wastewater or the water so that the flocs may be formed and once the flocs are formed they are taken to the sedimentation chamber where it is settled down as a sludge and this sludge may be taken to a sludge thickening from where the overflow from the sludge thickening may be again taken back to the influent. So, after the sludge thickener it may go to the sludge dewatering and after the sludge dewatering the sludge may be taken to the sludge drying bed. So, the treatment of the sludge and the handling of the sludge we will discuss in the next module in detail and here whatever the filtrate comes out from the sludge dewatering, so it is also taken back to the influent. So, after the sedimentation process, we may go for recarbonation process where we add carbon dioxide so this may happen in the case when we have added excess lime for the coagulation and flocculation and sedimentation process so in that case, we may require that the pH of the water or the wastewater may be reduced so that very high amount of pH may not go into the effluent.

So, for that we may go for the recarbonation that in addition of carbon dioxide so that the pH values of the water or wastewater may come down. After the neutralization process that is the recarbonation process we take the wastewater to the flow equalization pond and after the flow equalization pond the water may be taken to a filtration where the filtrate or we can say if we are having the backwash waters here also so they may go again back to the influent. After the filtration process, we may take the wastewater to the granular treated carbon chamber where basically the organics may be removed and whatever the wastewater basically comes from here that is from the scrubber underflow as well as the carbon wash water so this wash water can again be taken back to the influent. And lastly, we add chlorine to it so disinfection of the wastewater can happen and then we can dispose it off successfully into any water bodies. So now let us discuss the estimation of the sludge volumes by using the chemical precipitation of the untreated wastewater.

So, we are considering here one problem where we have to estimate the mass and volume of the sludge which is produced from the untreated wastewater with and without addition of the chemicals. For example, here we are using ferric chloride as the precipitant, and which is used for the enhanced removal of the total suspended solids. So, we have to estimate the amount of the lime that is required for a specific ferric chloride dose, and we assume that 60% of the total suspended solids is removed in the primary sedimentation tank without the addition of chemicals and nearly 85% of the total suspended solids is removed by the addition of the chemicals. And these are the various data that is required for the wastewater treatment. For example we are having the flow rate of 1000 cubic meter per day, we are having the wastewater total suspended solids of nearly 220 milligrams per liter, we are having the alkalinity as calcium carbonate 136 milligram per liter and similarly we are adding the ferric chloride in kgs per 1000 cubic meters which is around 40 and similarly the raw sludge properties that is when we are not adding any chemicals so in that case the properties of the sludge is given to us similarly when we are adding the chemicals that properties of the sludge are given to us.

So, first of all we try to compute the mass of the total suspended solids which are removed without and with chemicals. For example when we are having the mass of the total suspended solids without the addition of the chemicals so in that case we can say that the removal by the sedimentation is nearly 60% and the 220 milligram per liter of the suspended solids are present and the flow is 1000 cubic meter per day so this will give us the mass of the solids which are there and 60% removal gives us 132 kgs per day of the suspended solids are removed by the settlement process. Similarly, we also try to calculate the total suspended solids which are removed within the presence of chemicals so in that case 85% removal is reported so we get nearly 187 kgs per day of total suspended solids that is removed so these solids will ultimately form the sludge. Finally, we also need to calculate that how much ferric hydroxide precipitate will be formed when we are adding 40 kgs per 1000 cubic meters of ferric chloride. So here the ferric hydroxide that can be formed so we can find out from the equation 8 that we have already discussed so we can find out that the amount of ferric hydroxide that is formed is nearly 26.4 kgs per 1000 cubic meters. So then we also determine that what is the amount of lime that is required for the dose of the ferric chloride that we are adding so the lime requirement can be had from the equation 9 that we have discussed in the previous slides and from here we can find out that nearly 20.7 kgs per 1000 cubic meter lime is required but here we can see one thing that since the sufficient alkalinity is present so we may not require the addition of the lime in such cases. So now based on this we can calculate the amount of sludge that is generated on dry basis basically which results from the chemical precipitation so the total dry solids comes out to be 187 plus 26.4 that is 213.4 kgs per 1000 cubic meter and we can also calculate the volume of the sludge that is generated from the chemical precipitation method by taking the specific gravity of the sludge as 1.05 and the moisture content to be 92.5. So, we can calculate the volume of the sludge by taking the total weight of the sludge that is generated per day and divided by the specific gravity and the amount of solids which are present in the sludge. So, this gives us the generation of the volume of sludge to be 2.71 cubic meters per day. Finally, we can calculate the volume of the sludge which is generated without the chemical precipitation by considering the specific gravity of the sludge as 1.03 and the moisture content to be 94 percent in that case. So, the total amount of solids which are there so that we have already calculated is nearly 132 kgs per day for without chemicals and we divided by the density of this solids, and we divided by the amount of solids which are present in the sludge. So, we get the volume of the sludge without chemicals to be 2.13 cubic meters per day. So in that case if we are having without chemical precipitation so in that case the mass of the solids which are generated is nearly 132 kgs per day whereas the volume of the sludge that is generated is nearly 2.13 cubic meters per day whereas when we are adding chemical precipitation so we can see that the mass of the solids may increase to nearly 213.4 and the volume of the sludge also increases to nearly 2.71 cubic meters per day. So, in this way we can calculate what is the amount of sludge which is generated by taking into account not only the removal of the suspended solids, but also taking into account the precipitate that is formed because of the precipitation reactions. So now we come to the application of the precipitation reactions where basically we may use such precipitation reactions for the extraction of calcium and magnesium which is present in a highly salty water which is coming from sea, or we are having a brine water. So from there if we add oxalic acid to it so it may form calcium oxalate magnesium oxalate and perform the precipitates of such calcium and magnesium and this may lead to the removal of calcium and magnesium from the highly salty sea water or the brine water. Similarly, we can also use the chemical precipitation reactions for the dissolved solids from the aqueous solutions.

For example, we can remove the hardness by using lime and soda precipitation method where the lime is required for the removal of the temporary hardness whereas lime and soda both are required for the removal of the permanent hardness. And similarly, we can also use the precipitation reactions for the removal of heavy metals which are either in the form of sulfides or in the form of hydroxides. So, these are the references that I have used for this lecture, and we stop here.

Thank you very much.