Water and Waste Water Treatment
Prof. Bhanu Prakash
Department of Civil Engineering
Indian Institute of Technology – Roorkee

Lecture - 36
Coagulation - II

Hello, everyone, welcome back to the latest lecture session on alkalinity and relevant aspects. We were looking at alkalinity in the context of coagulation. And why is it? Because when we add metals, they take up OH^- let us say. And tells, you are going to see a decrease in pH and that is something you do not want. So, we were looking at alkalinity and typically alkalinity is given by the carbonate specious CO_3^{2-} , HCO_3^- .

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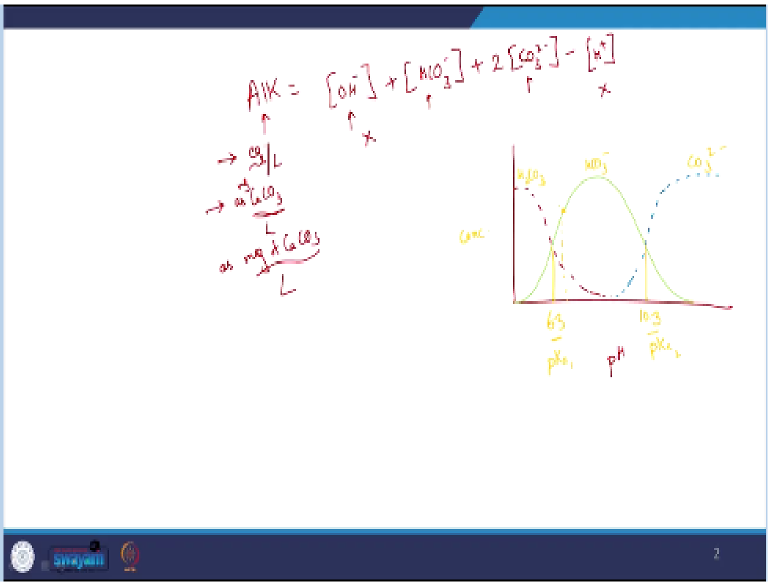

$Alk = [OH^-] + [HCO_3^-] + 2[CO_3^{2-}] - [H^+]$

→ eq/L

→ as $CaCO_3$ / L

as mg of $CaCO_3$ / L

So, alkalinity, theoretical definition assuming that there are no other specious, we list all the basis OH^- and the other basis which are usually present $HCO_3^-$and CO_3^{2-} and because CO_3^{2-} can take up 2 H^+. So, this 2, because this is the equivalence and minus H^+, , . And here, the units are in molar units. Yes, and this units of alkalinity because its relative term will be an equivalence per litre or such.

$Alk = [OH^-] + [HCO_3^-] + 2[CO_3^{2-}] –[H^+]$

Alkalinity can also be expressed as $CaCO_3$ as milligrams of $CaCO_3$ per litre. , this is equivalent, let us say. So, , the units will not be in terms of milligrams of alkalinity, there is no such thing as compound alkalinity milligrams of alkalinity, but it will be expressed in terms of either equals per litre or in terms of $CaCO_3$ how much $CaCO_3$ do I need to add to get this required amount of alkalinity? That is what this aspect as $CaCO_3$ or as milligrams of $CaCO_3$ per litre means. So, that is something to keep in mind.

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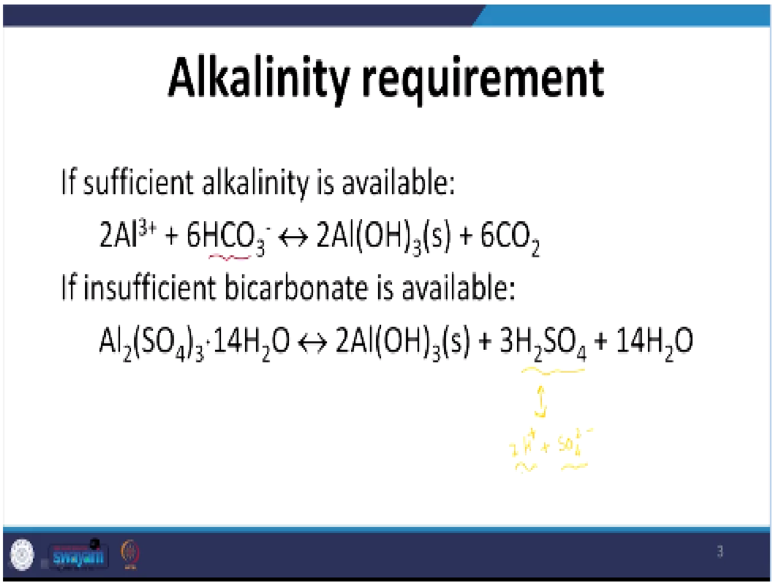

Alkalinity requirement

If sufficient alkalinity is available:

$$2Al^{3+} + 6HCO_3^- \leftrightarrow 2Al(OH)_3(s) + 6CO_2$$

If insufficient bicarbonate is available:

$$Al_2(SO_4)_3 \cdot 14H_2O \leftrightarrow 2Al(OH)_3(s) + 3H_2SO_4 + 14H_2O$$

$$2H^+ + SO_4^{2-}$$

Without it, let us see what can happen and why alkalinity is required? if sufficient alkalinity is available, Al^{3+} and HCO_3^-, well, It is written in a different form. So, net, we are assuming here that there is no decrease in pH. But if there is no alkalinity available here, we are saying that alkalinity primarily HCO_3^-. Why? If the pH is at 7, what will this equation or near about 7, what will this equation transform into? OH^-, H^+ will cancel out, because the pH is 7.

And from this graph, this is the pH; I am just drawing the specious diagram for the relevant carbonate specious. So, let me just label that so, that it is much more clearer. So, this y axis is the relative concentration and this will be the pK. This is 6.3 pK 1 because it is di-protocatechuic H_2CO_3. This will be 10.3. So, below 6.3, H_2CO_3 will predominant between 6.3 and 10.3. HCO_3^- will predominate and about 10.3 CO_3^{2-}will predominate about pH of 10.3.

These are the 2 pKa values; pKa 1 and pKa 2 acid dissociation constants. , as you see near around 7 most of it will be present as HCO_3^-. So, in general you can assume that alkalinity is equal to or approximately equal to HCO_3^- concentration, when the pH is 7. , if alkalinity is present, this is what will happen. If not, you will have this being found but H_2SO_4 will not stay as H_2SO_4it will immediately dissociate into 2 H^+ and SO_4^{2-} let us say.

$H_2SO_4 = 2H^+ + SO_4^{2-}$

H_2SO_4 will dissociate. Why it is a very strong acid? pKa is pretty less. It might not go to 2 H^+. It will go to H^+ and HSO_4^- and then H^+ in SO_4^-. , H^+ will be released and then the pH is going to decrease. So, that is why alkalinity is required.

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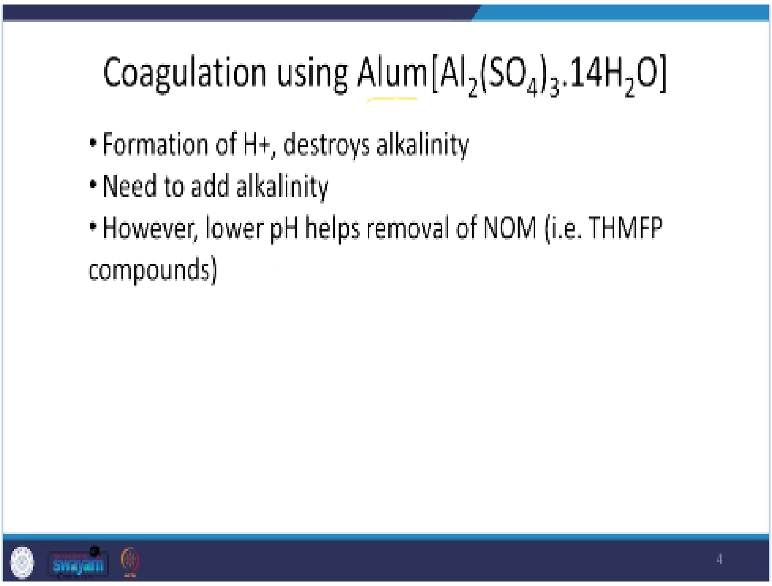

Coagulation using Alum[$Al_2(SO_4)_3.14H_2O$]

- Formation of H+, destroys alkalinity
- Need to add alkalinity
- However, lower pH helps removal of NOM (i.e. THMFP compounds)

So, coagulation using alum. In that context, we were discussing these aspects and we already discussed this aspect need to add alkalinity. Some cases, you will want to not do that because low pH can lead to help remove NOM because of change in charge.

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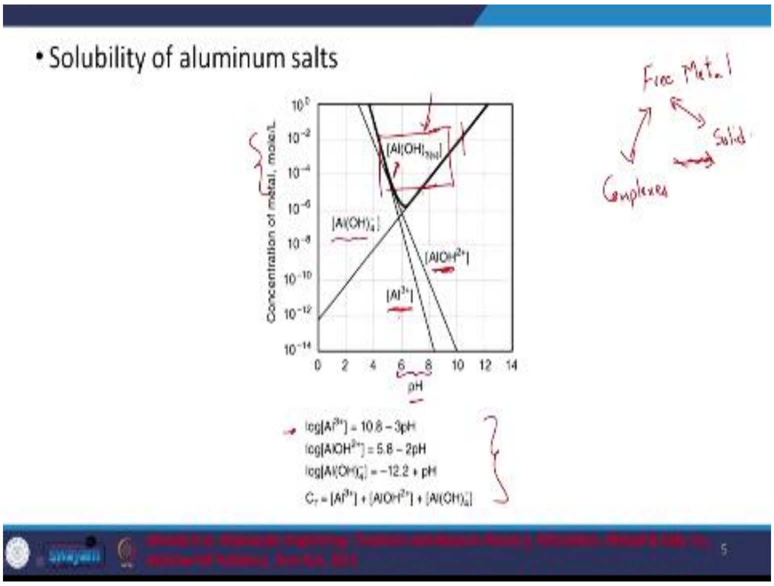
- Solubility of aluminum salts



$\log[Al^{3+}] = 10.8 - 3pH$
$\log[AlOH^{2+}] = 5.8 - 2pH$
$\log[Al(OH)_4^-] = -12.2 + pH$
$C_T = [Al^{3+}] + [AlOH^{2+}] + [Al(OH)_4^-]$

So, solubility of alum salts. Why am I looking at this? Because we mentioned earlier that this particular metal or the some of the metals will not stay as free metal. They will be in equilibrium with complexes, complexes and also what else the solid or the precipitate, let us say. So, they will be in; maybe this, I should not draw here, they will be equilibrium, let us say. It is a fine balance between these 3.

So, let us see in which pH ranges which one will predominate . So, here we have x axis, pH and on the y axis, the concentration of the metal. Please note that the concentration of metal is pretty low. And this seems to be logarithmic scale, let us say. So, you can get the log C-pH relevant lines, let us say for Al^{3+} looks like the if I, , do the relevant analysis, it is going to be depend upon 10.8 minus 3 pH.
$Log[Al^{3+}] = 10.8-3pH$

, I will not go there, but you can see the relevant aspects, but let us just look at the figure. So, at relatively low pH and relatively low concentration or very low concentration, the metal will stay as free metal Al^{3+}. Even at relatively low pH, but higher metal concentration, it will stay $Al(OH)_4^-$. But in general, this will also take place later also, but , let us not go there.

But, in the neutral pH and in the usual concentrations that we add, what is the form that predominates? You can see that this is the form in the neutral pH range and in the metal usual metal concentration that we add, you see that most of it will stay as the or will precipitate out as this solid and if I increase the pH further, then you can have either the solid or the complex (()) (06:59).

So, that depends on the concentration . , this is the predominant form. It does not mean that at pH 7 and the concentration of 10^{-4}, everything will be as solid, but it means that the predominant form of aluminium will be this. This is called a predominance area diagram. It will only give you an idea about in which pH or under which pH range and under what concentrations when you have , well the kind of complex or precipitate or the metal predominant so, predominance area diagram, let us say.

So, that is what you have, you see that at higher pH range , more or OH^- available and you are having complexes and relatively low concentrations and pH mostly the metal but at the usual working range, the predominant one is the metal that is being formed.
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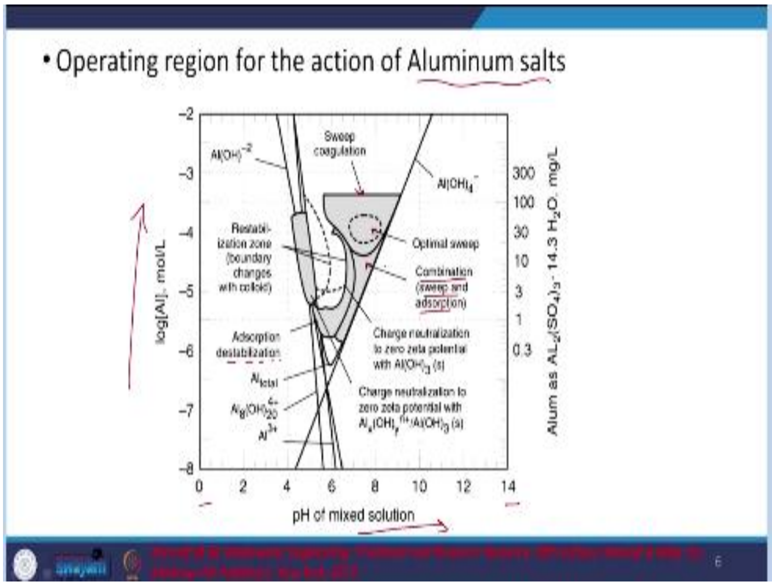

- Operating region for the action of Aluminum salts

And now, you can look at this. Here, we have operating region for the aluminium salts when we are talking about coagulation. So, here is the pH from 0 to 14 and the concentration of the aluminium logarithmic scale. Here, we are increasing the concentration as we go along there and pH is increasing as we go along there. So, as you can see, this figure is relatively similar to the predominance area diagram.

Why? Because depending upon the type of alumium that predominates at that particular conditions of pH and aluminium concentration, you are going to have either charge neutralization or sweep coagulation or such. Let us look at that. So, here where we expect most of the aluminium to precipitate out, let us say 6 to 8 and 4 to 5. So, you see sweep coagulation occurring that is what we see here and optimal sweep, they have a particular location here.

And here, looks like charge neutralization to zero zeta potential with Al thrice solid. So, that also seems to be happening. Different ways and charge neutralisation to zero zeta potential with a different kind of solid, let us say. So, here it is adsorption destabilisation, depending upon where we are, we will have different kinds of destabilisation.

So, only sweep or combination of sweep and adsorption so, that takes place here. So, let me move on. So, here you have the amount of alum that is being added. So, this is though is in milligram per litre. And this free metal concentration is here. So, I am assuming this is total metal, but let us leave that there..

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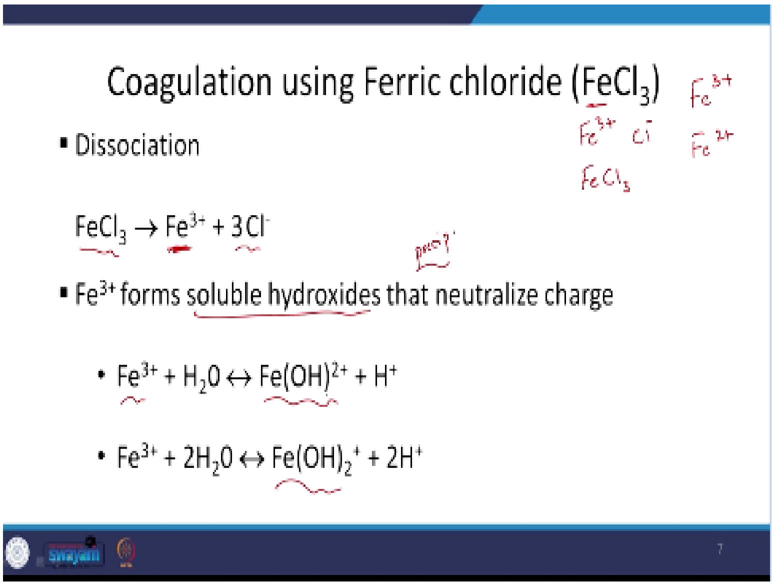

Coagulation using Ferric chloride ($FeCl_3$)

Fe^{3+} Fe^{2+} Fe^{3+} Cl^- $FeCl_3$

- Dissociation

$FeCl_3 \rightarrow Fe^{3+} + 3Cl^-$

precip?

- Fe^{3+} forms soluble hydroxides that neutralize charge
  - $Fe^{3+} + H_2O \leftrightarrow Fe(OH)^{2+} + H^+$
  - $Fe^{3+} + 2H_2O \leftrightarrow Fe(OH)_2^+ + 2H^+$

So, with another common coagulant, which is used it, is ferric chloride ferric is Fe^{3+}; ferrous relatively reduced Fe^{2+} that is something to keep in mind. Here, it is 3 plus let us say, that is Fe^{3+} and Cl^-. So, that is why you need charge neutrality (09:59). For every one ferric iron, you need 3 Cl^- , 3 chloride. , let us not go into that. So, when I added to water, what will happen? Dissociation or dissolution Fe^{3+} and 3 Cl^- but we know that Fe^{3+} will not stay as Fe^{3+} but will form soluble hydroxides or it will precipitate out.

So, same case as aluminium that is what you see, you have the soluble complexes being formed here, OH 1 and 2+ charge, OH 2 and +1 charge. , here also pH will decrease because H plus is being given out. Thus, you need to have some alkalinity in the solution.

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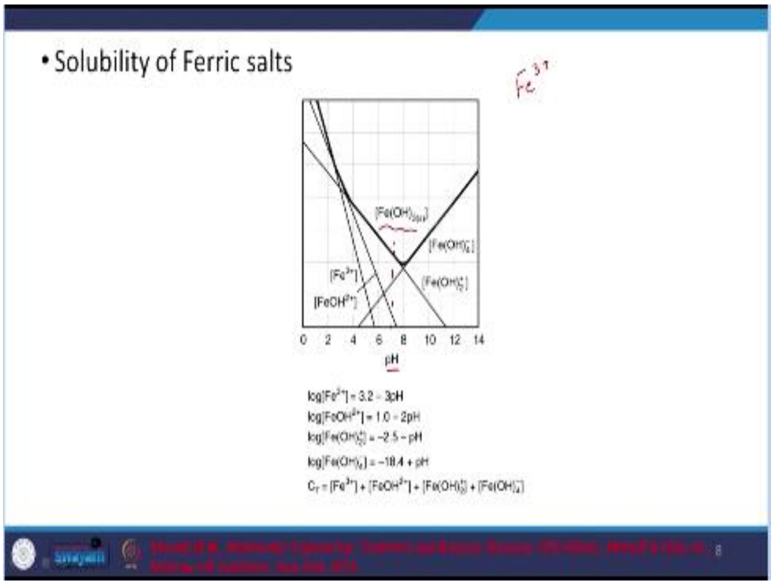

- Solubility of Ferric salts

$\log[Fe^{3+}] = 3.2 - 3pH$

$\log[FeOH^{2+}] = 1.0 - 2pH$

$\log[Fe(OH)_2^+] = -2.5 - pH$

$\log[Fe(OH)_4^-] = -18.4 + pH$

$C_T = [Fe^{3+}] + [FeOH^{2+}] + [Fe(OH)_2^+] + [Fe(OH)_4^-]$

, here another (10:45) the predominance area diagram but this time for Fe^{3+} and you see that what is predominant in the neutral pH range at most working iron concentrations or ferric iron concentration, it is the solid let us say, ferric hydroxide that is precipitating out and at higher pH, you are going to have the complexes predominated. that is something to keep in mind.

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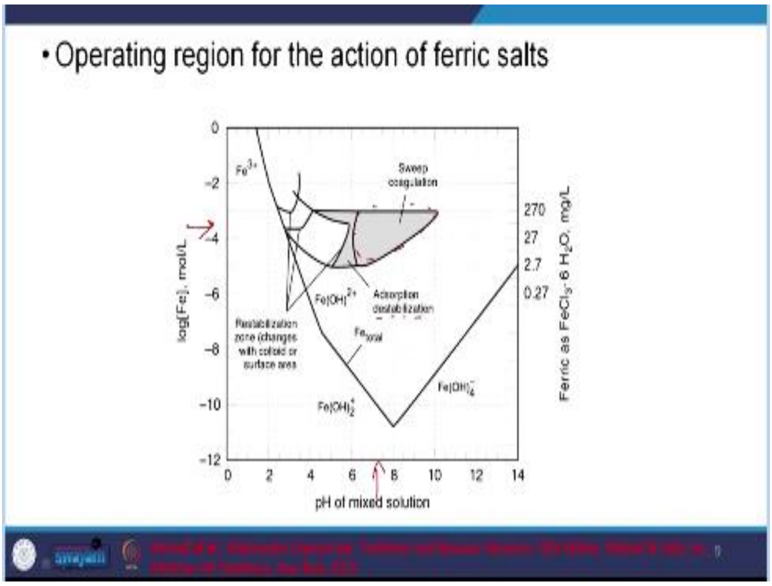

- Operating region for the action of ferric salts

And then here what do we see? So, Fe total but sweep coagulation because this is where precipitation is taking place. So, that is one thing to keep in mind and re-stabilisation zones changes with colloid or surface area, we will not go into that. for most working ranges, , this is the concentration we are looking at and this is the pH. So, we are going to have sweep coagulation, but you can also have adsorption based destabilisation too. That is something to keep in mind.

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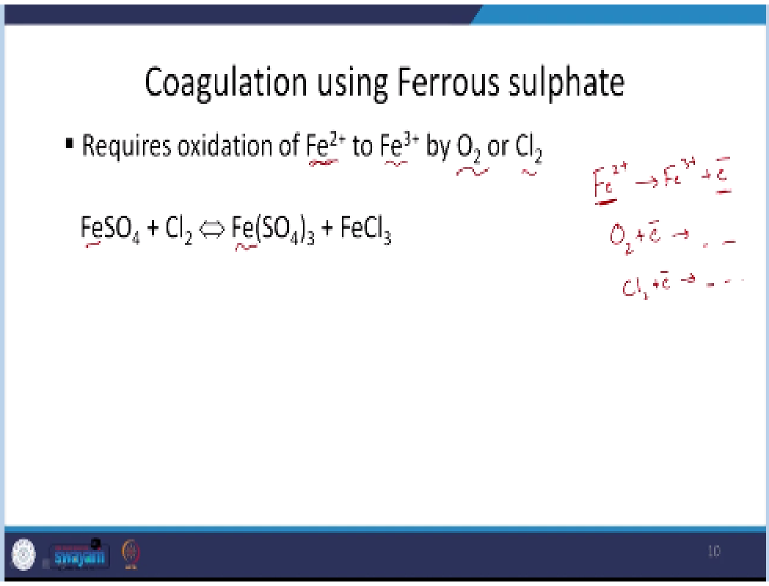

Coagulation using Ferrous sulphate

- Requires oxidation of Fe^{2+} to Fe^{3+} by O_2 or Cl_2

$FeSO_4 + Cl_2 \Leftrightarrow Fe(SO_4)_3 + FeCl_3$

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

$O_2 + \bar{e} \rightarrow . \; -$

$Cl_2 + \bar{e} \rightarrow - \; - \; -$

Let us move on coagulation using ferrous sulphate. So, ferrous, you can add ferrous by without changing it or such so that you can neutralise the charge that is one aspect. Or people sometimes add Fe^{2+} to get 2 Fe^{3+}, but Fe^{2+} to Fe^{3+} , how do you go from there, let us say? This is the half reaction. So, you have to take out this electron and this electron will be accepted by oxygen or by chlorine.

$Fe^{2+} = Fe^{3+} + e^-$

, I am not balancing it. So, you can do that. So, Fe^{2+} can be added as a Fe^{2+} itself so, that it can utilise the charge, it will not precipitate at almost all our usual operating pH and concentration ranges. But if you want to use Fe^{2+} as source of Fe^{3+} , , you can let it be oxidised by the oxygen or add a oxidising agent. But , this is relatively rare. So, this is what you have, , Fe^{2+} and now, it is becoming a Fe^{3+}.

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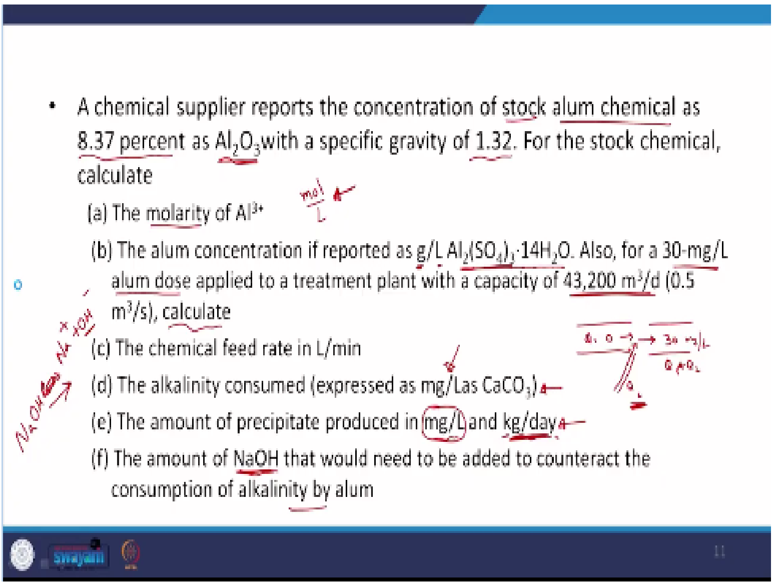

- A chemical supplier reports the concentration of stock alum chemical as 8.37 percent as Al_2O_3 with a specific gravity of 1.32. For the stock chemical, calculate
  - (a) The molarity of Al^{3+}
  - (b) The alum concentration if reported as g/L $Al_2(SO_4)_3 \cdot 14H_2O$. Also, for a 30-mg/L alum dose applied to a treatment plant with a capacity of 43,200 m^3/d (0.5 m^3/s), calculate
  - (c) The chemical feed rate in L/min
  - (d) The alkalinity consumed (expressed as mg/L as $CaCO_3$)
  - (e) The amount of precipitate produced in mg/L and kg/day
  - (f) The amount of NaOH that would need to be added to counteract the consumption of alkalinity by alum

So, here, we seem to have a simple problem, let us try to go through this. , whenever you are solving these problems with stoichiometric, note that there are 3 or 4 major aspects, I will try to maybe touch upon that and you can use that as a basis to solve it either your own way or maybe use these tools to solve in a much easier or in a non-cluttered fashion. Let us see what we have.

A chemical supplier reports that the alum that he has stock alum as is 8.37 as Al_2O_3. Never 100% purity or what I want here, he has some stock alum chemical and in that 8.37% only is present as Al_2O_3 and specific gravity is 1.32. Specific gravity gravity not gravity, density of the particular material to the density of a reference typically water let us say. Specific gravity of that particular chemical is 1.32.

For this stock chemical, we are going to look at coagulation; the concentration of Al^{3+} just the metal, free metal in that particular stock solution. And the alum concentration, if it is reported as grams per litre as this Al_2SO_4; the alum concentration reported as. So, here we see that molar meaning we want to express the units in terms of moles per litre.

In general, chemists will understand this I prefer molarity, let us say. Some people would prefer it to be expressed in terms of alum layman or people who are working with mostly engineering applications, they do not want to look at what is the Al^{3+} free metal concentration. What is the Al^{3+} that is precipitating out? They just want to look at how much alum do I need to add if I want to achieve my level of coagulation and then flocculation?

So, units are sometimes expressed as the amount of or a mass of alum per litre that needs to be added. So, you are going to have such units too. So, it is reported as grams of $Al_2(SO_4)_3.14\ H_2O$. And also for a 30 milligram per litre alum dose with a flow requirement of this let us say, calculate, we will look at that. So, this concentration is required for a particular flow that is coming, calculate the chemical feed rate, what is the concentration of the chemical or such that I need to; not concentration, for water is coming in.

And I want to see to it that the mixing one has a concentration of 30 milligram per litres of alum, let us say. Here, let us say assuming there is nothing and so how much or what is the rate of this pure chemical that I need to add? So, I have Q one and Q 2. Q 2 has alum; Q 1 has zero concentration of alum; Q 2 has this concentration of alum. So, both will mix. And finally, I will end up with the 30 milligram per litre of Q 1 plus Q 2, let us say. So, this is what we have.

So, how much is this feed rate? How much feed rate Do I need and alkalinity consumed? So, if I am adding this alum to the water, how much alkalinity will be consumed? So, we can also look at that. How do we look at this? For this, we will look at the relevant reaction that happens when we add this compound to the solution. From there, you can know how much H plus will be given out equivalents.

Then that will be equivalent to the H alkalinity that will be consumed because in the alkalinity equation, that there is a term minus H plus. So, that is how you will calculate alkalinity let us say and the amount of precipitate produced in milligrams per litre. Usually this is rarely used and kgs per day. This is usually used. Why is milligrams per litre not a good way to look at precipitation?

Because when we say milligram of some compound per litre, it typically means milligram of let us say sugar is dissolved in this solution of 1 litre. But to say that , something has precipitated out and that is per litre does not really work out. So, then you have to clearly specify milligram of this sugar or this particular aluminium hydroxide has precipitated out from 1 litre of solution. So, that is something that we need to be clear.

And , how much mass of the aluminium hydroxide has precipitated out per day? So, different units and how much NaOH; NaOH meaning NaOH will go to Na^+ and OH^-, typically pKa such that this is almost always this way. So, we are adding a base would be needed to be added to counteract the consumption of alkalinity by alum. So, here we are looking at alum consumption.

So, if I do not want the alkalinity to decrease, how much NaOH should I add? So , that is pretty straightforward. OH^- , the alkalinity equation, it has one OH^-, one equivalent of alkalinity will increase per one molar addition of OH minus. So, from that we can calculate it. So, let us get this done or look at it in a bit more detail. So, what is the first aspect molarity of Al^{3+}?

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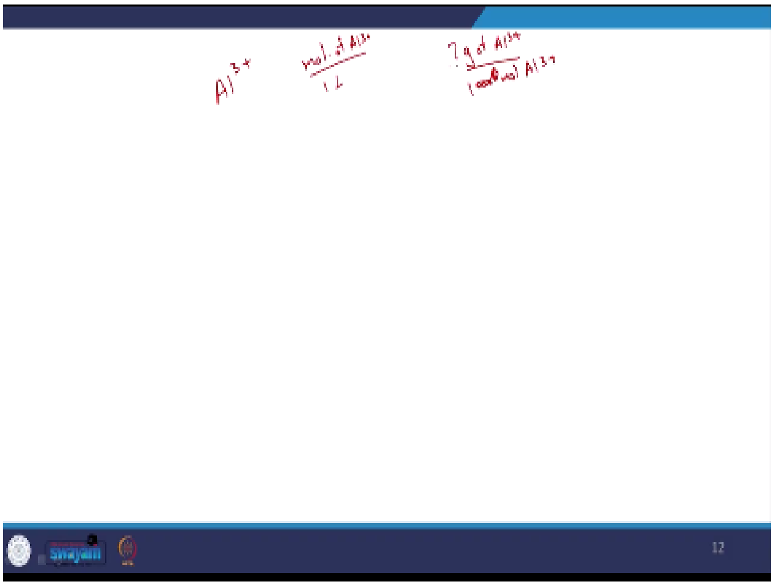

Al^{3+} $\frac{\text{mol. of } Al^{3+}}{1\ L}$ $\frac{?\ \text{g of } Al^{3+}}{1\ \text{mol } Al^{3+}}$

So, I want to be able to calculate Al^{3+}molarity for that I need to know how many moles are there of Al^{3+} per litre of my water, one litre of my solution. For this , I need to know molecular weight. What would molecular weight give me an idea about? It will give me an idea about grams of Al^{3+} per one mole of Al^{3+}. So, how much is this molecular weight(19:06)? So, this will be required.

And , then if I have the mass of that particular solution, I can use this marker way to get the Al^{3+} or such once we look at the stoichiometric. So, let us get that done.

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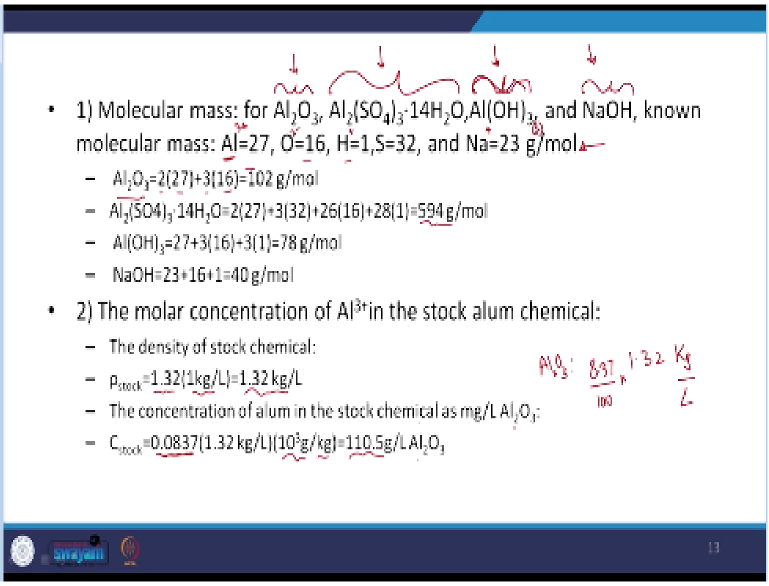

- 1) Molecular mass: for Al_2O_3, $Al_2(SO_4)_3 \cdot 14H_2O$, $Al(OH)_3$, and NaOH, known molecular mass: Al=27, O=16, H=1, S=32, and Na=23 g/mol
  - $Al_2O_3 = 2(27)+3(16) = 102$ g/mol
  - $Al_2(SO4)_3 \cdot 14H_2O = 2(27)+3(32)+26(16)+28(1) = 594$ g/mol
  - $Al(OH)_3 = 27+3(16)+3(1) = 78$ g/mol
  - $NaOH = 23+16+1 = 40$ g/mol
- 2) The molar concentration of Al^{3+} in the stock alum chemical:
  - The density of stock chemical:
  - $\rho_{stock} = 1.32(1 kg/L) = 1.32 kg/L$
  - The concentration of alum in the stock chemical as mg/L Al_2O_3:
  - $C_{stock} = 0.0837(1.32 kg/L)(10^3 g/kg) = 110.5 g/L\ Al_2O_3$

Al_2O_3: $\frac{8.37}{100} \times 1.32 \frac{Kg}{L}$

So, here we are calculating the molecular masses of the different compounds of interest, , Al_2O_3 that was asked in the question. $Al_2(SO_4)_3.14\ H_2O$ because in part B, we were going to look at or we are asked to calculate it in the form of as $Al_2(SO_4)_3.14\ H_2O$ per litre. How much of this will have to be added if I want to get a similar effect? And , this is the solid. So, this is the solid in this context. It is not the complex. So, this is the solid.

, we will calculate the molecular weight and also molecular of NaOH. And for that, molecular masses of the relevant elements Al^{3+} and sulphur, sodium , we have them. So, in general, in the exam, I might give the usual, I mean unique ones, but usual ones, let us see oxygen, aluminium, hydrogen, these you should be able to come up with yourself. So, let us see the approach for Al_2O_3, (2 x 27) + (3 x16).

So you have that simple algebra. And similarly, we are calculating the molecular weight of each of these compounds of interest, which we identified out here, let us say. And AlOH thrice alum, as you see, it adds considerably heavy per one mole. So, that is what you see 594 grams per one mole. Why? , you have a lot of sulphate, let us say. So, that is one thing to keep in mind.

And what is the molar concentration of Al^{3+} in the stock alum chemical? Let us see how to go about it. So, first, what is the density of the stock chemical? I know the specific gravity density of the stock chemical references to the density of water, I know the density of water. From that, we can calculate it. This is the specific gravity density of the relevant water, which we are assuming to be 1 kg per litre.

So, the density of that particular solution, stock chemical solution is 1.32 kg per litre, let us say and the concentration of alum in the stock chemical as milligram per litre of Al_2O_3. And I think, we know that around 8.37% or something was present as Al_2O_3. Yes. 8.37%; 8.37 by 100 is 0.0837, let us say. So, this is present as of this much of your particular solution is present as Al_2O_3.

So, I have 1.32 kgs of that stock solution per litre. But I know that 8.37% is the Al_2O_3, by mass, and then 10.3 grams per kg, so what do I have? I know how the mass of Al_2O_3. So, I have 110 grams of Al_2O_3 per litre of my particular chemical. So, that is what I have. From this, we will be able to calculate the molar concentration of Al^{3+}.

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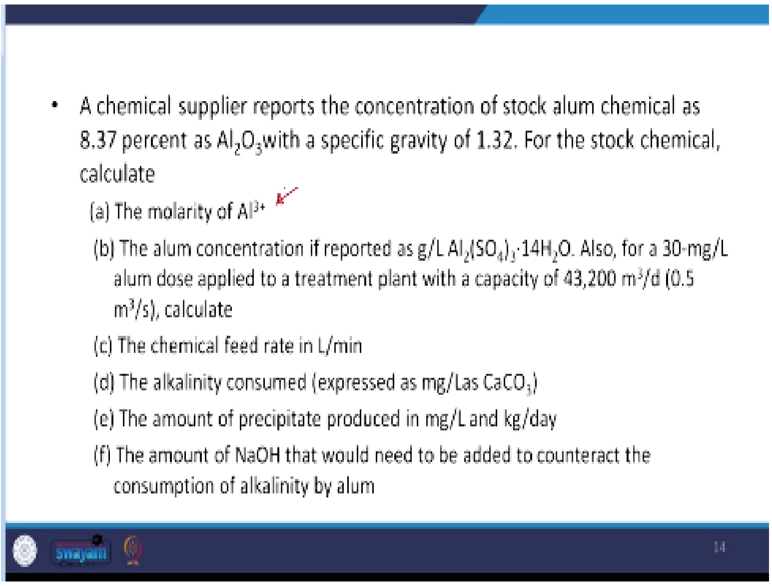

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I just am giving the question , so, that at regular intervals, so, that we can follow what is happening. So, let us move on. It will be useful later, maybe not much now.

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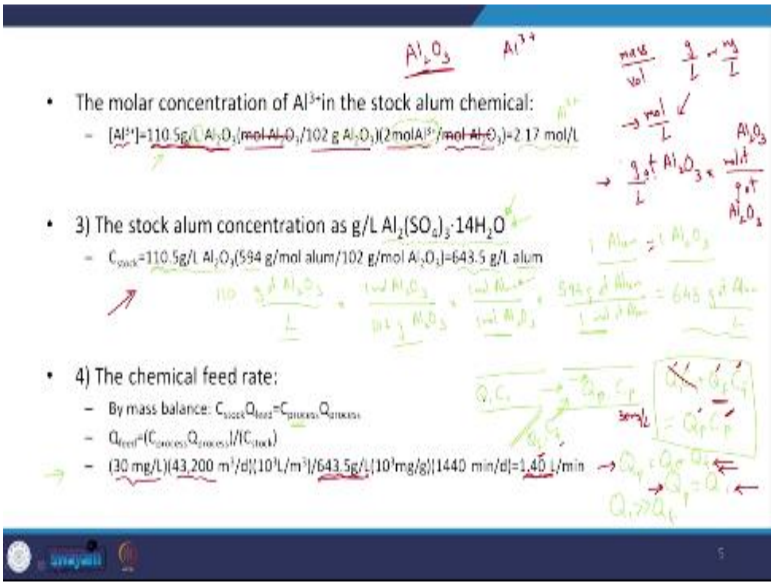

- The molar concentration of Al^{3+} in the stock alum chemical:
  - $[Al^{3+}]$=110.5g/L Al_2O_3(~~mol Al_2O_3~~/102 g Al_2O_3)(2molAl^{3+}/~~mol Al_2O_3~~)=2.17 mol/L
- 3) The stock alum concentration as g/L $Al_2(SO_4)_3 \cdot 14H_2O$
  - C_{stock}=110.5g/L Al_2O_3(594 g/mol alum/102 g/mol Al_2O_3)=643.5 g/L alum
- 4) The chemical feed rate:
  - By mass balance: $C_{stock}Q_{feed}=C_{process}Q_{process}$
  - $Q_{feed}=(C_{process}Q_{process})/(C_{stock})$
  - (30 mg/L)(43,200 m^3/d)(10^3L/m^3)/643.5g/L(10^3mg/g)(1440 min/d)=1.40 L/min

So, let us look at the next aspect. We calculate the relevant molecular weights and got the relevant mass per volume. We have different units or ways of expressing units. One is mass per volume, gram per litre or milligram per litre . Another unit, which we typically want to use based on stoichiometric use, moles per litre. How do I go from here to here though? So, I have grams or mass, grams per litre of let us say, what is this Al_2O_3?

If I want to convert it into units of moles per litre of Al_2O_3, what do I need? I need moles of Al_2O_3 in the numerator. And in the denominator, I need something that will cancel out this term or mass unit, grams of Al_2O_3. And I have a relationship that gives me, the moles per particular mass of the Al_2O_3 that is the inverse of molecular weight. So, that is how you can go from mass units to molar units.

Here, we are first using the mass units of Al_2O_3, which we have, yes and then we are converting that into the molar units that is what we did here. And then I am concerned with the Al^{3+} molar concentration; not the Al^{2+} pardon me Al_2O_3 molar concentration. So, looking at Al_2O_3 and Al^{3+}, I can see that there are 2 moles of aluminium per one mole of Al_2O_3. So, that is why 2 moles of Al^{3+} for one mole of Al_2O_3.

So, there is one mole of Al_2O_3 will cancel out here. Yes and let me use a different coloured pen. And this mass will cancel out here, grams of Al_2O_3. So, what am I left with? I am left with moles of Al^{3+} per litre of water. So, that is what I have. This is moles of Al^{3+} per litre of water. So, it is just using the molecular weight and looking at the stoichiometric ratios. And it is pretty simple.

Maybe in one of the other examples, we will look at equivalence; equivalence typically in terms of charge or electrons or alkalinity, but we will come back to that and look at it. So, that is one aspect to keep in mind. With that we are able to calculate the molar concentration of aluminium. So, next aspect, we want the units now to express same units, the same units, we want them to be expressed $Al_2(SO_4)_3.14\ H_2O$, which is the typical formula for alum.

So, here, we are going to assume that maybe we can look at the equation for one mole of alum. , the equivalent or it will be proportional to one mole of Al_2O_3. So that is what we are going to do. And what do we have here? We have the 110 grams of Al_2O_3 per litre of water. If I divide that by the molecular weight, so, what do we have one mole of Al_2O_3 per 102 grams of Al_2O_3. So, in effect, I am dividing by the molecular weight. So, from here, I will have the molar ratio.

And here, we are saying that it is one mole of alum for one mole of Al_2O_3. So, I then say (26:30) one mole of album per one mole of Al_2O_3. So, here the units are not asking in terms of moles per litre of alum but mass per litre of alum. So, I need to convert moles per litre of album into mass of alum. How do I do that? I will multiply with the molecular weight of alum.

So, molecular weight, what is this looks like it is 594 grams of this. When I say alum, I am referring to this particular formula, molecular formula, grams of alum per one mole of alum. So, what did we do? Mass units to molar units, then the molar ratio, and then molar, , units of alum to mass. So, that is what I have; looks like I will end up with this 643 grams of alum per litre.

So, , in general, what does it tell me? If I want 110 grams of Al_2O_3 per litre, I need to add 643 grams of alum per litre or vice versa. So, that is what it means. So, we are done with this. Next aspect, this is with respect to a feed rate , we have water coming in the flow rate is given. So, let me say that this is Q_1. And the concentration of alum here is C_1.

And I am having to feed a concentrated flow of a concentrated alum to this solution, I am going to call this feed Q feed and concentration of alum in this is C feed. After mixing, it is now going into this which is Q mixture or here, we are referring to that Q process. So, let me use the same subscript Q process and final concentration of alum in the process. So, what is happening?

Two streams are coming in one stream with the most of the water with no alum and one where we are adding the feed let us say, where I am adding the alum as the feed. These 2 are mixing and then you have the process. We know the concentration at which it is supposed to be at; it is supposed to be at 30 milligram per litre. Anyway, we will come back to that. So, how do I get this?

It is just simple mass balance; mass coming in is equal to the mass going out. So, 2 streams joining. So, mass coming in is, this is an alum, Q_1C_1 + Q_fC_f. This is the mass of alum coming in is equal to Q_pxC_p. Here, the way that it was calculated, there assuming that Q_p is almost equal to Q_1 because Q_1 is far greater than Q_f, but in general though as you can see Q_p will be equal to Q_1 plus Q_f. So, what do I have here?

I need to be able to solve this equation now, let me see what we have out here. And we will go through. I have this flow rate which is given; I know that there is no alum coming in along with this flow, so, this C_1 is 0. This is the Q_f, I want to find out. C f, I found out from here C f was found out. Yes, this is what we are using. C_f was found out and C_p was mentioned, I think it was mentioned as 30 milligram per alum.

And Q_p, I know from here either this way or this. In general, I would always suggest that you use this and not make assumptions. Though, we use this here for now in general always assume that or calculate the flow rate based on the relevant aspects there. Do not assume anything. So, we are just left with one unknown which is Q_f and I can calculate or solve for this equation.

So, we just plug it in this term goes to 0, I can substitute the relevant variables and I see that I need to add 1.40 litres per minute or the flow of alum should be at 1.40 litres per minute. And the concentration has to be at 643 grams per litre of alum. If I want a concentration of 30 milligrams, this is 30 milligrams per litre of alum, which has a flow rate of what, 43,200 metre cube per day. So, for 43,200 metre cube per day, so, that is the relevant aspect. It is just mass balance here. Let us move on.

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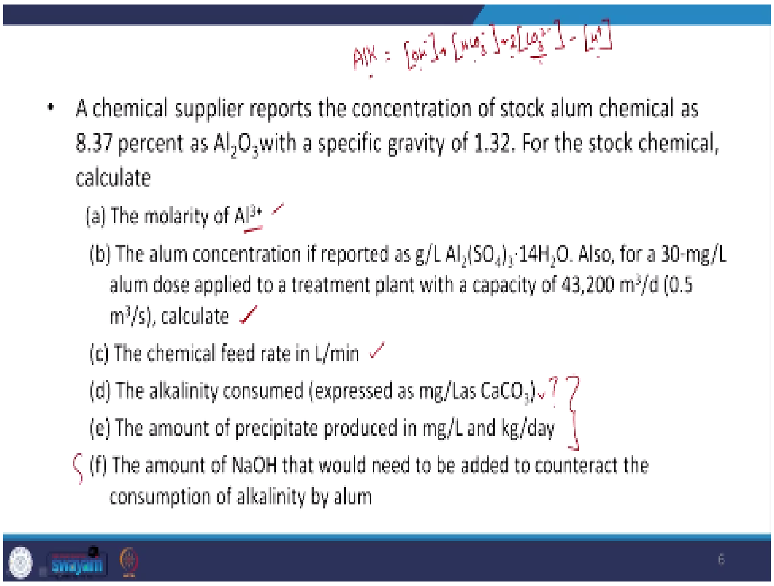

$Alk = [OH^-] + [HCO_3^-] + 2[CO_3^{2-}] - [H^+]$

- A chemical supplier reports the concentration of stock alum chemical as 8.37 percent as Al_2O_3 with a specific gravity of 1.32. For the stock chemical, calculate
  - (a) The molarity of Al^{3+} ✓
  - (b) The alum concentration if reported as g/L $Al_2(SO_4)_3 \cdot 14H_2O$. Also, for a 30-mg/L alum dose applied to a treatment plant with a capacity of 43,200 m³/d (0.5 m³/s), calculate ✓
  - (c) The chemical feed rate in L/min ✓
  - (d) The alkalinity consumed (expressed as mg/L as $CaCO_3$) ✓ ?
  - (e) The amount of precipitate produced in mg/L and kg/day
  - (f) The amount of NaOH that would need to be added to counteract the consumption of alkalinity by alum

So, we are done with this, we are done with this, this is just change in stoichiometric, same case here. And here, it is just simple mass balance and what is the alkalinity consumed? So, what is the approach here? We know the alkalinity equation. Alkalinity is equal to the sum of all the basis typically we are assuming it is only carbonate system that is predominating HCO_3^-; 2 x CO_3^{2-}.

Why? As you can see, CO_3^{2-} can take 2 H^+ - H^+. So, what does this mean? If I add one mole of OH^-, alkalinity will increase by one equivalent per litre. Same case with HCO_3^- but if I add one mole of CO_3^{2-} because of this 2 equivalents, alkalinity will increase by 2 equivalent per litre (32:01). If I add one mole per litre of H^+, it will it meaning alkalinity will decrease by one equivalents per litre. So, that is what it means. That is what we can understand out here.

So, let us take this through and let us look at the relevant equation and what is the amount of precipitate produced. So, for this, you will have to look at the relevant equation or the reaction. We will look at that. And how much NaOH has to be added? If you want to see to it that the alkalinity is not consumed. So, let us look at the equation alkalinity consumed.

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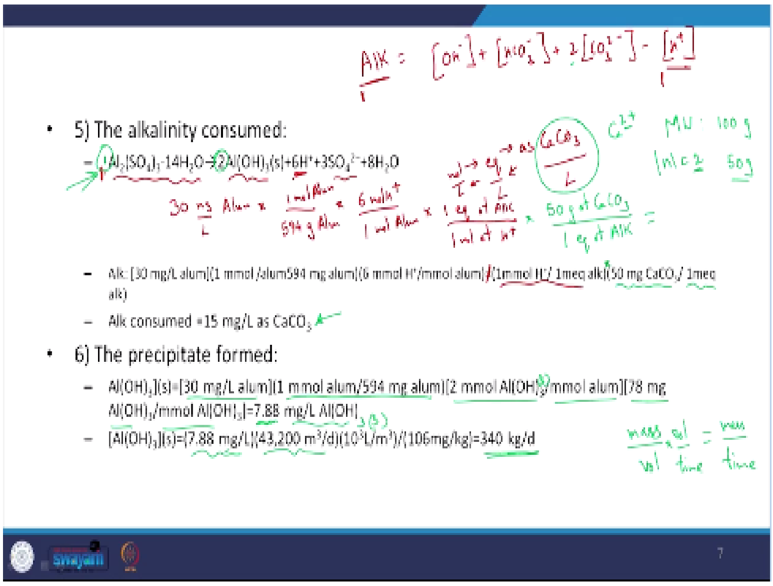


$Alk = [OH^-] + [HCO_3^-] + 2[CO_3^{2-}] - [H^+]$

- 5) The alkalinity consumed:
  - $1Al_2(SO_4)_3 \cdot 14H_2O \rightarrow 2Al(OH)_3(s) + 6H^+ + 3SO_4^{2-} + 8H_2O$

$\frac{30 \text{ mg Alum}}{L} \times \frac{1 \text{ mol Alum}}{594 \text{ g Alum}} \times \frac{6 \text{ mol } H^+}{1 \text{ mol Alum}} \times \frac{1 \text{ eq of Alk}}{1 \text{ mol of } H^+} \times \frac{50 \text{ g of } CaCO_3}{1 \text{ eq of Alk}} =$

$\frac{CaCO_3}{L}$ Ca^{2+} MW : 100 g 1 mol = 2 eq 50 g

  - Alk: [30 mg/L alum](1 mmol /alum594 mg alum](6 mmol H^+/mmol alum]/(1mmol H^+/ 1meq alk](50 mg $CaCO_3$/ 1meq alk)
  - Alk consumed =15 mg/L as $CaCO_3$
- 6) The precipitate formed:
  - $Al(OH)_3](s)$=[30 mg/L alum](1 mmol alum/594 mg alum][2 mmol $Al(OH)_3$/mmol alum][78 mg $Al(OH)_3$/mmol $Al(OH)_3$]=7.88 mg/L $Al(OH)_3$
  - $[Al(OH)_3](s)$=(7.88 mg/L)(43,200 m^3/d)(10^3 L/m^3)/(106mg/kg)=340 kg/d

$\frac{mass}{vol} \times \frac{vol}{time} = \frac{mass}{time}$

This is what we have. So, if I am adding Al to our alum, aluminium hydroxide is precipitating out and sulphate will be released and H^+ is being released. So, pH is going to decrease or H plus is going to be released and we know the equation for alkalinity. Alkalinity is equal to just for the sake of understanding, I am writing this , even though I wrote this out in the earlier slide, minus H^+.

So, if I am adding H^+, alkalinity will decrease. So, we already have it. So, for one mole per litre increase of H^+, one equivalence per litre of alkalinity will decrease. But here we are adding, I mean the ratio is here is 6, but we will look at that. So, let us see what we have. So, alkalinity so, we looks like it says 30 milligram per litre as alum. And I wanted to be converted into equivalents as $CaCO_3$.

The answer was asked in terms of as $CaCO_3$ per litre. Before that, I need to get it in terms of equivalence per litre. Before that, I need to get it in terms of moles per litre. So, only then I can go in this direction and it is my answer. So, first this alum, I have to convert it into modular units. Molar units, what do I do? It is one mole per 594 grams of alum. So, now the units are in moles.

And I know that for one mole of alum, 6 moles of H^+ are being given out. 6 moles of H^+ per litre , here, also I should write as alum. Why do I like the way that I am writing? Because here, I can see now moles of alum, moles of alum cancel out; mass of alum, mass of alum cancels out and I am left with moles of H^+ per litre. So, that is why like to write this moles of alum or moles of H^+ or specify that.

But, I wanted it equivalence per litre of alkalinity. And I know from what I see that it is one equivalences. So, that is what I have here. So, one, I should have written it in the inversely. This should have been divided by here maybe and this should be into anyway, we can always cut it. I know that one equivalent per, equivalent of alkalinity will be consumed per one mole of H plus being produced. So, that is what we have.

Now, the units are in terms of equivalents per litre of alkalinity, but the units are being asked in terms of as $CaCO_3$. What How do I convert that? So, molecular weight of $CaCO_3$, it is 100, 100 grams and is to Ca^{2+} charges CO_3^{2-} charge, n is equal to 2. So, equivalent weight will be 100 by 2, which is 50 grams. So, that is what we have 50 grams of $CaCO_3$ per one equivalent of alkalinity.

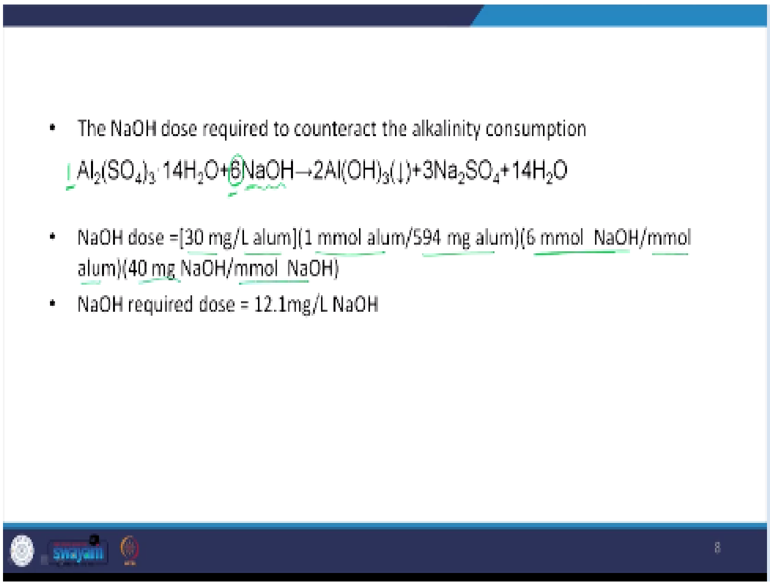
So, I have to multiply that 50 grams of $CaCO_3$ per one equivalent of let us say, alkalinity, let us say, yes, , in terms of alkalinity here. So, here I see that it is not with respect to charge, but $CO3^{2-}$ but even then you can see that its 2 is the relevant factor. So, with that I will get my relevant answer 15 milligram per litre as $CaCO_3$. So, with that, I am done with the alkalinity consume.

Precipitated form, same way I will look at the relevant reaction. So, one mole of alum, one mole of alum, 2 moles of precipitate. So, that is what we have. alum, we are converting it into molar units. And I know that there are 2 moles of this solid, this should be mentioned as solid, precipitating out per one mole of alum that is what we see from this stoichiometric ratio. And I know the mass of AlOH thrice which is 78 molecular weight.

And now, I will get this. But what does this mean? It does not mean that there is 7.88 milligrams of aluminium hydroxide, the solid dissolved in water, no, it means that anyway, the way we calculate it means that this amount of aluminium hydroxide solid is precipitating out per litre of your solution that is what it means. And then I gained it was asked to transform this into units of mass per day.

So, here I have mass per volume units that is what I calculated mass per volume. So, if I wanted in terms of mass per time, I need to do what now, multiply this by volume per time and volume per time is flow rate. So, that is what you multiply it with. And you are going to get your 340 what is this, kgs per day(37:55). So, let me move on.

(Refer Slide Time: 37:37)



- The NaOH dose required to counteract the alkalinity consumption

$Al_2(SO_4)_3 \cdot 14H_2O + 6NaOH \rightarrow 2Al(OH)_3(\downarrow) + 3Na_2SO_4 + 14H_2O$

- NaOH dose =[30 mg/L alum](1 mmol alum/594 mg alum)(6 mmol NaOH/mmol alum)(40 mg NaOH/mmol NaOH)
- NaOH required dose = 12.1mg/L NaOH

And NaOH; how much NaOH is required? There are 2 ways to go about it. Earlier, we looked at the equivalence or concentration of H plus, we can use it until here, this point, and then transform it into NaOH, because I know that 1 H^+ and 1 OH^-; 1 OH^- meaning 1 NaOH. For every H^+,one OH minus has to be added. So, in this way, I can look at it and take it from here. Or another way to go about it is to write the equation such that it directly reacts with NaOH.

So, , you see that for one mole of alum, you have 6 moles of NaOH. Let us take this approach 30 milligrams of alum per litre and molecular weight division to get the molar units and here, I see that for one mole of alum, 6 moles of NaOH are required, so 6 moles of NaOH per mole of alum and then the molecular weight of alum, so, that I get the units in terms of NaOH. So, with that, we are done with this particular session and I thank you for your patience.