Course Name: Industrial Wastewater Treatment

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Week – 02

Lecture 02: Ion Exchange Process

This is module 2, lecture 2 and the topic that we will discuss today is on ion exchange chemistry. So, the concept covered in this lecture will be on ion exchange chemistry. We will talk about that how the ion exchange chemistry works and how the ion exchange process happens, what are the chemical reactions that happen behind it and what are the different type of parameters that we need to consider so that we can find out that how much percentage of the ions will remain on the resins, how much percentage of the ions will go into the solution. And this also depends upon the selectivity coefficient. So, we will talk about the selectivity coefficient then, we will talk about the ion exchange regeneration technologies, and we will talk about the co-current regeneration system and counter-current regeneration systems in the coming slides. So, when we talk of the ion exchange chemistry, let us consider a simple equation here that is R^-A^+ that is here this R^-A^+ represents the A^+ ions which are present on the resin whereas B^{+n} are the ions which are present in the solution.

$$\mathbf{nR^-A^+ + B^{+n} \leftrightarrow R_n^-B^{+n} + nA^+}$$

So, when this B^{+n} ions are there, so they will try to replace the A^+ ions which are present on the resin and the reaction will happen in such a way that the B^{+n} ions will go on to the resin whereas A^+ ions will come into the solution. That is how the ion exchange takes place. So, we are talking about the constituents which are present on the resin that is R^-A^+ represents the percentage or basically we can say the ions which are present A^+ ions which are present on the resin whereas the ions only they represent the ions present in the solution. So, here we can see this R^- is the anionic group which is attached to the ion exchange resin, and it represents the resin form.

So, if we write down the equilibrium expression or equilibrium constant for such an equation which is again reversible equation as we have discussed earlier also. So, we can see that the value of the k that is the equilibrium constant where B^{+n} is replacing A^+ ions. So, this can be represented by A^+ which is in the solution, similarly into the B^{+n} which is present on the resin whereas divided by R^-A^+which is there on the resin and divided by the B^{+n} which is again in the solution. This value of the equilibrium constant represents the selectivity coefficient, and these are the concentration of A in the solution and R^-A^+ represents the concentration on the exchange resin.

$$\frac{[A^+]_S^n[R_n^-B^{+n}]_R}{[R^-A^+]_R^n[B^{+n}]_S} = K_{A^+\to B^{+n}}$$

So, as we go further, we can write down the removal of sodium and calcium from the water by using a strong acid synthetic cation exchange resin and the regeneration of the exhausted resins with HCl and NaCl.

So, we can write down the equation or the reaction which happens when we are having R^-H^+ as the resin. So, the resin is having H^+ ions as the exchange ions and Na^+ is present in the solution. So, after the reaction the R^-Na^+ becomes that is the Na^+ is replaces the H^+ ions and H^+ ions move into the solution. So, this is the reaction that happens for resin which is basically a cation exchange resin having H^+ as the exchange ions and the sodium is there in the solution. Similarly, we can write down another equation.

$$R^-H^+ + Na^+ \leftrightarrow R^-Na^+ + H^+$$

So, now if this resin which now becomes R^-Na^+plus now comes in contact with the calcium. So, then the equation basically becomes like this that calcium ions will replace the sodium ions and sodium ions will go into the solution.

$$2R^-Na^+ + Ca^{2+} \leftrightarrow R_2^-Ca^{2+} + 2Na^+$$

So, if we want to regenerate this resin. So, we can say that R^-Na^+ we put it in contact with HCl where basically we are having the HCl maybe having a strong solution of HCl that we prepare. So, H^+ ions will replace Na^+ ions here and now our resin becomes R^-H^+ and similarly the NaCl goes into the solution.

$$R^-Na^+ + HCl \leftrightarrow R^-H^+ + NaCl$$

And similarly, when we are having the resin which is laden with calcium, we take it into the contact with the brine solution a concentrated brine solution. So, here also the sodium ions will replace the calcium ions, and our resin will now be replaced with sodium ions, place of the calcium ions and calcium goes into the solution. That is how the regeneration process takes place. So, regeneration process you can see that instead of the calcium replacing the H^+ ions the reverse is happening, or we can say the sodium ions replacing the H^+ ions the reverse reaction is happening that is now H^+ ions they are replacing the sodium ions. So, that means, when we are having a very high ionic strength which is basically put onto the resin.

So, if we are having a very high ionic strength water or solution for example, we are having concentrated solution of HCl solution or we are having concentrated solution of brine. So, they replaces generally they replaces the ions which otherwise basically may not be replaced in the dilute solution. So, that is why we provide a concentrated solution of brine or concentrated solution of HCl so that the resins can be regenerated.

$$R_2^- Ca^{+2} + 2NaCl \leftrightarrow 2R^- Na^+ + CaCl_2$$

So, the equilibrium expressions for these reactions that is the reactions-1 here and reaction-2. So, this can be represented by equation that is Na^+ is replacing H^+ ions.

So, here we can see that H^+ and Na present on the resin and similarly R^-H^+ that is present on the resin here and this Na^+ which is present on the solution.

$$\frac{[H^+][R^- Na^+]}{[R^- H^+][Na^+]} = K_{H \rightarrow Na}$$

Similarly, calcium is replacing the sodium ions. So, we can write down the equilibrium expression for this that is $[Na^+]^2$ because you can see that when you balance the equation. So, 2 times of Na^+ comes into the solution. So, $[R^- Ca^{2+}]$ present in the resin and similarly this $[Na^+]^2$ is present in the solution. Similarly, the $[R^- Na^+]^2$ present on the resin so this will again come as square here that is on the resin and the Ca^{2+} which goes into the solution.

$$\frac{[Na^+]^2[R^- Ca^{2+}]}{[R^- Na^+]^2[Ca^{2+}]} = K_{Na \rightarrow Ca}$$

So, these expressions which are there so they are also known as the collectivity coefficient. So, we can see here that there are typical series where basically we can talk about that whether the cations or the anions, they will replace another cations or anions or not. So, these series basically you can see that for example here you can see that in the monovalent cations, the silver can replace rubidium, rubidium can replace potassium, potassium can replace ammonium ions, ammonium ions can replace sodium ions, sodium ions can replace hydrogen ions and hydrogen ions can replace Lithium ions. Similarly, when we talk of divalent ions so the barium can replace strontium, strontium can replace calcium, calcium can replace copper and cobalt and then zinc and magnesium.

$$\mathbf{Li^+ < H^+ < Na^+ < NH_4^+ < K^+ < Rb^+ < Ag^+}$$
$$\mathbf{Mg^{2+} < Zn^{2+} < Co^{2+} < Cu^{2+} < Ca^{2+} < Sr^{2+} < Ba^{2+}}$$
$$\mathbf{OH^- < F^- < HCO^- < Cl^- < Br^- < NO_3^- < ClO_4^-}$$

So, in this way we can by seeing these series, the typical series so we can decide that which ions present in the solution will replace which ions present on the ion exchange resin. So, these series, typical series are generally applicable for dilute solutions when we are talking of the dilute solutions. In that case these series they hold good whereas in the concentrated solution as we have seen or the solutions having highest ion extent generally this may not be the same case because we have seen earlier that in case of regeneration this is often reversed. Similarly, we can see for the anions for example chlorate will replace nitrate, nitrate will replace bromide, bromide will replace chloride and bicarbonates and then Fluoride and OH^-ions. So, in this way we can decide that what type of ions will replace which type of ions which are present, and when we talk of the selectivity coefficients, so these selectivity coefficients they are generally measured in the laboratory and they are valid for the conditions in which they are measured that is why we can say that the select whatever the selectivity coefficient values we get so they are specific to a certain set of conditions.

We can see here that the table-1 which shows that what are the selectivity coefficients for various type of cations here in this case for example we can say that lithium is having 1, Hydrogen ions 1.3, sodium is having 2. So, these values basically tell us about the k values which we get basically when we are having different type of reactions that are happening in the ion exchange residence. So, these k values will represent what are the selectivity of various ions over the H^+ ions.

Table: 1
Approximate selectivity scale for cations on 8 percent cross linked strong acid ion exchange resins

Cation	Selectivity	Cation	Selectivity
Li^+	1.0	Co^{2+}	3.7
H^+	1.3	Cu^{2+}	3.8
Na^+	2.0	Cd^{2+}	3.9
NH_4^+	2.6	Be^{2+}	4.0
K^+	2.9	Mn^{2+}	4.1
Rb^+	3.2	Ni^{2+}	3.9
Cs^+	3.3	Ca^{2+}	5.2
Ag^+	8.5	Sr^{2+}	6.5
Mg^{2+}	3.3	Pb^{2+}	9.9
Zn^{2+}	3.5	Ba^{2+}	11.5

Similarly, we can see the selectivity values or selectivity coefficient values for the anions in the table-2 and we can see that there is different type of values which are given here, and these values may also be used for finding out the k values or for finding out the concentrations of various cations and anions which are present on the resins and what fraction is present in the pollution.

Table: 2 Approximate selectivity scale for anions on strong acid ion exchange resins.			
Anion	Selectivity	Anion	Selectivity
HPO_4^{2-}	0.01	BrO_3^-	1.0
CO_3^{2-}	0.03	Cl^-	1.0
OH^-(Type I)	0.06	CN^-	1.3
F^-	0.1	NO_2^-	1.3
SO_4^{2-}	0.15	HSO_4^-	1.6
CH_3COO^-	0.2	Br^-	3.0
HCO_3^-	0.4	NO_3^-	3.0-4.0
OH^-(Type II)	0.5-0.65	I^-	18.0

Affinity of ions can be generalized. For example, we can say that in general the high valency ions are always preferred over the low valency ions. This performance increases with the decrease in the ionic strength. So, as I have already discussed that if we are having a very high ionic strength so in that case this preference may not hold good.

For example, the high valence is preferred over the low valence. So, this condition is always applicable when we are having a solution which is having a low ionic strength. In that case this is applicable. Similarly, if we are having the same valency of ions so the extent of the exchange will depend upon the hydrated radius that is if the lower the hydrated radius the higher the affinity and similarly the increasing atomic number increases the affinity. For example, here the larger hydrated radius so it increases the swelling of the resin and that is why it decreases the affinity of the resins for such ions because the pore sizes decrease as the swelling of the resin increases.

So, that is why the decreasing hydrated radius will always have a higher affinity towards the ionic exchange resin. Similarly, when we are having the high ionic strength so in that case our exchange reaction follows no general rule, and it is often reverse as I talked in the first point also. So, when we talk of the regeneration of the cation exchange resin or anion exchange resins, so we are having a very high ionic strength with water and that is basically put on to the resin. So, in that case the ions which are less preferred in the dilute solutions so they may also replace the ions which are more preferred. For example, the monovalent ions can also replace the high valent ions in that case.

So, that is why this rule may be reversed in the case of high ionic strength pollution which is applied to the resins. In the lead the degree of cross linking and size of the hydrated ions may also affect the exchange reactions. For example, if we are having a high degree of cross linking so then the ions basically may be too large so they may not penetrate the matrix of the resin and that is why the ion exchange process may be hampered because or the efficiency of the ion exchange may decrease because of the lesser amount of space that is available for the ion to penetrate into the resin and to go inside the resin and there may be other sites also which may not be accessible in that case. And similarly, the size of the hydrated ions may also impact that is it may increase the swelling and because of which the size also reduces. If we are having a very high affinity resin for example, when we talk of the strong resins, strong acid resins or strong base resins so in that case we can find certain properties for example, we can have a sharp beak root curve.

What does this mean? For example, let's say we are having a resin which is having a very high affinity of certain ions so what will happen that initially the water which contains a certain targeted ions so it will slowly and slowly fill or replace the ions which are there on the resins and until and unless all the entire the total exchange capacity of the resin is utilized then suddenly you will find that cations or anions of interest they start coming out of the solution. So, you will find the breakthrough curve just like this that is suddenly a sharp rise of calcium or magnesium or whatever the ions of interest, so which are basically being removed by the resin, so they start eluting out suddenly sharply right. So, the breakthrough curve may not be slowly and slowly rising that as happens and the affinity of the resin may be low right. So, when we talk of the weak exchange resin so in that case you will find such type of break through curve but in case of the strong basic or strong acid resins so we find that the breakthrough curve may be they become like this that suddenly the concentration start increasing in the effluent. And the second point is that we may require the shorter ion exchange column because the affinity is higher so the exchange capacity is also higher so we find that we can use a smaller amount of ion exchange resins in comparison to the weak resins which are there may require a shorter depth of the exchange column.

And similarly, we can also apply a higher flow rate because we are having a very high affinity towards the ions which are being replaced so that's why we may find that the higher flow rates may be applied to the column. And similarly, but the one of the drawback that we are having is that we may require a very high regenerate concentration because the affinity to the ions so it is very high so the resins they are holding very tightly to the ions which basically have been replaced by the resins. So, when we try to remove these ions so we may require a very high amount of regenerate in that case so that we can replace the entire cations or anions which have been exchanged by the resins by ions of interest. For example, if we want to replace it by H plus ions or Na plus ions then we have to apply a very high concentration of regenerate in comparison to resins which are having lower affinity ok. So, this means that when we are having a strong acid resin or a strong base resin so then it may require a high value of regeneration or high value of regenerate in comparison to the weak acid or base resins.

So, now we consider a very simple equation that is R^-A^+ and which is the A^+ ions are being replaced by B^+ ions that is we are talking here of the ion exchange process which are involving two monovalent ions.

$$R^-A^+ + B^+ \leftrightarrow R^-B^+ + A^+$$

So, Anderson 1975 so they discussed this process of ion exchange using the strong ionic resins. So, this equation can be applicable to the strong ionic resins and here we can see that the B^+ ions are replacing the A^+ ions so the B^+ ions are going on to the resin and A^+ ions are going into the solution ok. So, if we say that at the equilibrium conditions so the fraction of the A^+ ions which are present in the solution will be the concentration of A^+ ions in the solution divided by the total ionic concentration in the solution. For example, here we are talking about the cations so the total cationic concentration in the solution and similarly the fraction of B which is present in the solution will be determined as B^+ ions the concentration of B^+ ions present in the solution divided by the total cationic concentration.

$$X_{A^+} = \frac{[A^+]_S}{C} \quad \text{and} \quad X_{B^+} = \frac{[B^+]_S}{C}$$

So, if we take the fraction of A and fraction of B which are present in the solution if we add these two things and if these two ions are only present so then we can say that the fraction of A and fraction of B we add these two things then it is equal to 1. So, here C is the total cationic or anionic concentration in the solution whichever is really we are doing it is. For example, in this case we are talking about the cations.

Now, similarly when we are having a resin, so resins are having A^+ ions so A^+ ions and B^+ ions are there in the solution. So, now this B^+ ions are replacing A^+ ions and A^+ions are going into the solution.

So, then what happens that at a certain point this equilibrium happens that is the rate of the replacement is equal to the rate at which it is going out of the resin right. So, in that case the equilibrium condition happens, and we find that the fraction of the A^+ on the resin will be given by R^-A^+ that is the concentration of the A^+ ions on the resin divided by $\overline{C}$. The $\overline{C}$. is the total ionic concentration present on the resin. For example, here we are having only two ions here that is A^+ ions and B^+ ions. So, it may also represent total resin capacity in equivalents per liter.

$$\overline{X}_{A^+} = \frac{[R^-A^+]_R}{\overline{C}} \quad \text{and} \quad \overline{X}_{B^+} = \frac{[R^-B^+]_R}{\overline{C}}$$

That is why we are talking about only two ions here A^+ ions and B^+ ions because A^+ ions will also be present on the resin and similarly some amount of B^+ ions may also remain on to the resin at the equilibrium condition. So, we can say that the fraction of B plus ions present on the resin will be R^-B^+ that is the concentration of B^+ ions on the resin divided by the total concentration of the ions on the resin.

So, now we can write down this equation that is the selectivity coefficient here for example, we can write down the selectivity coefficient for this equation as B^+ ions here this is not B^+only. So, we can say that the B^+ being replacing the A^+ ions. So, selectivity coefficient for this can be written as A^+ ions present in the solution into the B^+ ions present on the resin divided by A^+ ions present on the resin into the B^+ ions present in the solution.

$$\frac{[A^+]_s [R^- B^+]_R}{[R^- A^+]_R [B^+]_S} = K_{A^+ \to B^{+n}}$$

So, this equation we can write down as the selectivity coefficient or we can say the equilibrium expression for the above reaction. So, this reaction or we can say this selectivity coefficient can be replaced as the fractions of the ions. For example, we can write down $\overline{X}B$ that is representing our B^+ ions present on the resin similarly XA^+ that is the representing the fraction present on the in the solution of A^+ ions similarly $\overline{X}A$ that is the fraction of the A^+present on the resin and B^+ions present in the solution.

$$\frac{\overline{X}_{B^+} X_{A^+}}{\overline{X}_{A^+} X_{B^+}} = K_{A^+ \to B^+}$$

So, now if we can write down for example XA^+ will be equal to 1-XB^+similarly we can write down that $\overline{X}A^+$will be equal to 1-$\overline{X}B^+$because these two fractions when we add they come equal to 1 ok. So, we can write down in this way and if we replace the previous equation that is the selectivity coefficient equation.

So, we get the equation.

$$\frac{\overline{X}_{B^+}}{1 - \overline{X}_{B^+}} = [K_{A^+ \to B^+}] \left[\frac{X_{B^+}}{1 - X_{B^+}}\right] \ldots..(1)$$

So, this equation gives us or tells us that what fraction of the B^+will be there in the solution and what fraction of B^+will be there on the resin. So, if we know these values for example, we have already talked about these values in the previous slides right. So, these values can be taken for a specific set of conditions. So, we will discuss this in a coming numerical.

This equation is specifically applied for exchange between the monovalent ions. So, now we can see that if we draw a curve of the monovalent ion that is the concentration of a monovalent ion let us say A^+ here which is present in the solution and the concentration of monovalent ions present on the resin that is $\overline{X}A^+$and XA^+. So, this distribution will depend upon the selectivity coefficient value. For example, you can see here that if the selectivity coefficient values are low. So, in that case the higher concentration of this A plus or higher fraction of A^+ will remain in the solution.

As you can see that the 0.1 selectivity coefficient find that mostly it is present in the solution. Similarly, if the selectivity coefficient increases the value increases, we find that a higher fraction of the A^+ goes on to the resin. So, these distribution curves can be used to assess the effectiveness of the resin for removal of a given ion based on the selectivity coefficient. So, here so $\overline{X}B$ represents the extent to which the resin can be converted to the B^+ form right and similarly $\overline{X}B$ also corresponds to the maximum extent of regeneration that can be achieved with a regenerant which is having a composition of XB. So, suppose when we are talking of the regeneration process it is possible that all the sites may not be replaced by the ions of the interest that we want to replace.

So, this $\overline{X}B$ will give you or the fraction of B will give you the amount of regeneration that can happen when we are putting a regenerant which is having a composition of B^+ions. So, this will also tell you that what is the maximum extent or what is the maximum percentage of the regeneration that can take place it will also tell you about the regeneration efficiency of that particular resin in respect to the particular type of ion. So, now we have seen that the equation it was applicable for only monovalent ions. So, we can now write an equation between the monovalent ions and divalent ions on a fully ionized exchange resin. For example, we can write down the equation for example, B^{2+} placing the A^+ ions which are present on the resin. So, this equation represents the exchange of B^{2+} placing A^+ ions.

$$2R^-A^+ + B^{+2} \leftrightarrow R_2^-B^{+2} + 2A^+$$

So, this equation can be represented and again we basically solve the electivity coefficient for this equation. So, we can get this type of equation here. For example, here $\overline{X}B^{2+}$ which is there divided by 1- $\overline{X}B^{2+}$ that is the fraction of the resins which are present the B^+ which is present on the resin. So, this is the square term comes here because we are having a square term here this case right and similarly the selectivity coefficient for the reaction into $\overline{C}$ divided by C will come here right and similarly the fraction which is remaining in the solution divided by the fraction which is there which is not there in the solution that is $XB^{2+}/[1 - XB^{2+}]^2$.

$$\frac{\overline{X}_{B^{2+}}}{(1-\overline{X}_{B^{2+}})^2} = [K_{A^+\rightarrow B^{2+}}]\left[\frac{\overline{C}}{C}\right]\frac{X_{B^{2+}}}{(1-X_{B^{2+}})^2} \quad \dots (2)$$

So, in that case, we are replacing we are having the equations where the divalent ions are replacing the monovalent ions. So, in that case this equation may be applicable for finding out the fraction of the ions in the solution and fraction of ions on the resin ok. So, if we write a generalized equation that is B^{n+} replacing A^{+} ions or the monovalent ions or n^{+} valency ions replacing the monovalent ions. So, this equation can be written where basically we can see the resin fraction, the solution fraction, the resin fraction and the solution fraction. This is at the equilibrium what is happening, and this equation can be again solved by solving the selectivity coefficient values and we can get a generalized equation where the n^{+} ions n^{+} valency ions they are replacing the monovalent ions.

So, here you can see that the n^{+} ions present on the resin. So, it comes here and here also this is the 1 minus the fraction of the ions which are present on the resin and raised to power n. So, you can see here that raised to power n basically comes here and similarly this is the selectivity coefficient or n^{+} ions replacing monovalent ions and $\left[\frac{\bar{C}}{C}\right]^{n-1}$.

So, it will become 1. So, that is why basically we can see here in the previous equation that is equation 2 and see that is $\bar{C}$ by C whereas in this case this $\bar{C}$ by C raised to power n-1. So, this is the values that is the fraction present in the solution and fraction which is not present in the solution raised to power n. So, this may be your assignment also that you can solve the monovalent ions equation in the similar way that we have solved in the monovalent ion's cases. So, you can solve, and you can get this derivation can be your one of the assignments.

$$nR^{-}A^{+} + B^{+n} \leftrightarrow R_n^{-}B^{+n} + nA^{+}$$

$$\frac{\bar{X}_{B^{n+}}}{(1-\bar{X}_{B^{n+}})^{n}} = [K_{A^{+}\rightarrow B^{n+}}]\left\{\left[\frac{\bar{C}}{C}\right]^{\wedge}(n-1)\right\}\frac{X_{B^{n+}}}{(1-X_{B^{n+}})^{n}} \quad \ldots.(3)$$

So, now we go on to the regeneration of the resins. So, when all the exchangeable H^{+} ions or OH^{-} ions in the cation exchange or anion exchange resins, so they get exchanged with the cations and anions of the interest right which are present in the raw water and the ion exchange resins are said to be exhausted. So, suppose we are having a resin which is laden with H^{+} ions and we are passing calcium through it. So, once the initial concentration that is the inlet concentration becomes equal to the effluent concentration of the calcium, so then we say that cation exchange resins have been exhausted. So, at that point of time we try to regenerate it by using HCl or by using NaCl the pyrene solution or by using NaOH in case of the anion exchange resins HCl and NaCl in case of the cation exchange resins. So, these are the simple reactions that can happen right. So, here this reaction basically tells us how the regeneration is happening that is now the H^{+} ions they are replacing the sodium ions right whereas, in dilute solution the opposite is the case whereas, in the regeneration the case is reversed and similarly the OH^{-} ions basically they are replacing the chloride ions in case of the anion exchange resin.

$$RNa^{+} + H^{+} \rightarrow RH^{+} + Na^{+}$$

$$RCl^- + OH^- \rightarrow ROH^- + Cl^-$$

So, that is how the regeneration happens, and we take strong solutions for example, 8 to 10 percent of solution may be taken or HCl or NaCl or NaOH solution, so that we can regenerate the cation exchange resins or the anion exchange resins. So, it also depends upon the type of the resin that we are talking about if it is a very strong resin then in that case, we may increase the concentration of HCl NaCl and NaOH and if we are having the weak acid resins or weak base resins that case we can reduce the concentration of the our regeneration. So, they are also known as the regenerate. So, now regeneration of resins means that we return the resin to its initial exchange capacity.

It is possible that we may take it back to the initial exchange capacity or we may not be able to take it to the initial exchange capacity. So, it depends upon it tells us about regeneration efficiency. So, if the complete regeneration has occurred, so this means that the number of equivalent of ions removed from the resin during the service period is equal to the number of ions which are exchanged during the service cycle. So, this means that the complete regeneration has happened in that case whereas the regeneration efficiency can be defined as the total equivalent of ions which are removed from the resin during the service period and total equivalent of ions present in the volume of the regenerate used. When we are doing the regeneration process, how many equivalents of ions are removed from the resins and how many total equivalents of ions which were basically subjected to the resin.

So, that tells us about the regeneration efficiency. So, if the efficiency is low, so this means that we will require a high regeneration will be used and it may also increase enhance the cost for the regeneration. And if we want to increase the level up to which regeneration happens is also known as the regeneration efficiency. So, regeneration efficiency will be higher for the weak ionic resins because they have a high affinity for H^+ or OH^- ions whereas when we are having strong acid resin or strong ionic resin, so in that case we can have the low affinity for H^+ and OH^- ions and that is why the regeneration efficiency is generally smaller. The value of k that is the value of the rate for the regeneration is inversely proportional to the value for the initial reaction. For example, when we talk of the strong acid or base ion exchange resin, so in that case the initial reaction the value the rate of the initial reaction is quite high.

So, the rate of the regeneration will be smaller. So, ion exchange regeneration technologies can have two type of applications that is we can have the co-current regeneration systems, we can have a counter current regeneration system. For example, when we are providing the service in one direction and we are providing the regeneration also in the same direction, so we say it is a co-current regeneration. Whereas the counter current regeneration system means that we apply the service in one direction whereas we go for the regeneration in the opposite direction. That is called the counter current regeneration system and the counter current regeneration system has a definite advantage that it provides a better quality of water because it is having a low ionic leakage and it is having a higher chemical efficiency and it is also basically it results in lesser amount of regenerate basically that is used and it basically reduces the base water that is being generated from the ion exchange process. So, let us talk about that what is the co-current regeneration system and what is the counter current regeneration system.

So, you can see here that the top figure that you see is the co-current regeneration system in which the feed basically water is being put on to the resin and this resin is a H^+ resin right. So, here let us say the sodium ions basically are being removed by this resin. So, we see that the initial phases will be covered by the sodium ions and the lower phases here we can see that it will be the H^+ ions because the H^+ ions will be replaced in the top layers by the Na plus ions, but it is possible that in the lower layers some of the H^+ ions they remain here right. So, after the service cycle that is the treated water is coming here and when we stop the operation that is the service cycle is stopped.

So, then we go for the backwashing. So, backwashing is done so that we can expand the bed of the resin so that if there are certain suspended particles suspended in quickly so they will go out with the washing. So, we go in the backward direction for the backwash and after that we apply the regenerate and rinsing and regenerate in the same direction as we applied for the feed that is why it is called co-current method and we see that the top layers again will be placed by the H^+ ions and it is possible that the sodium ions may not be replaced in the bottom layer. So, as soon as we now start the service, we will see that the sodium ions in the bottom layer which were remaining right which should remain during the regeneration process. So, they may start coming into the product water initially and that is called the leakage of the ions. So, you will find that in the co-current system we may have a higher leakage coming into the effluent water in the initial stages whereas in the counter current system we go for feeding in one direction for example, let us say we are feeding it here the sodium ions are replacing the H^+ ions and we are getting the treated water here.

So, that H^+ ions basically remain here right sodium ions on the top. So, now when we go for the regeneration in the opposite direction so we find that now here everything is replaced by the H^+ ions right and sodium may remain in the top layers because if the regeneration efficiency is not higher so you may find that the sodium may remain at in the top layers. But again, when we start servicing so we find that a product water may not have any leakage. So, no leakage basically is found in such type of system and that is why we prefer more of the counter current regeneration. So, here we have already discussed about the ion leakage which happens for the co-current method and the counter current methods right and we see that the sodium ions they may exit the column as leakage as it is shown in the figure-4a whereas there is no leakage which is happening in the counter current system which is represented by figure-4b and we see that the resin bed is predominantly in the regenerated form at the bottom of the vessel and because of which a lesser leakage takes place in that system.

So, now when we use the counter current systems, we can reduce the chemical costs right we can improve the water quality, and we can have less waste volumes in comparison to the co-current system ok. So, this means that it is thus counter current system is more productive it utilizes small vessels, and it may have faster regenerations to a mechanical. So, we stop here only, and these are the references that I have used for this lecture and in the coming lecture we will talk about applications of the ion exchange process in different type of wastewater systems or water systems right and we will also talk about a certain numerical example so that can clear whatever we discuss.

Thank you.