Physico-Chemical Processes for Wastewater Treatment
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Lecture 40
Ion-Exchange – IV

Good day everyone and welcome to these lectures which are there for Physico-Chemical Processes for Wastewater Treatment. And in the previous few lectures, we have been studying the Ion-exchange process. And we have already studied the different details of the Ion-exchange resins how to select Ion-Exchange resins, then we understood regarding the mode of operations of different columns, which already contain the ion-exchange resin for water treatment or ion-exchange.

So, all these factors we have already studied in the previous lectures. Now, what we will continue to understand the design aspect of the Ion-exchange column and also we will try to perform some calculations, as to better understand that how Ion-exchange bed works and how we can perform some calculations out of that.

So, going further as early as ion-exchange column may have certain range of values for different parameters, which are used as design criteria for sizing the ion-exchange columns and vessels.

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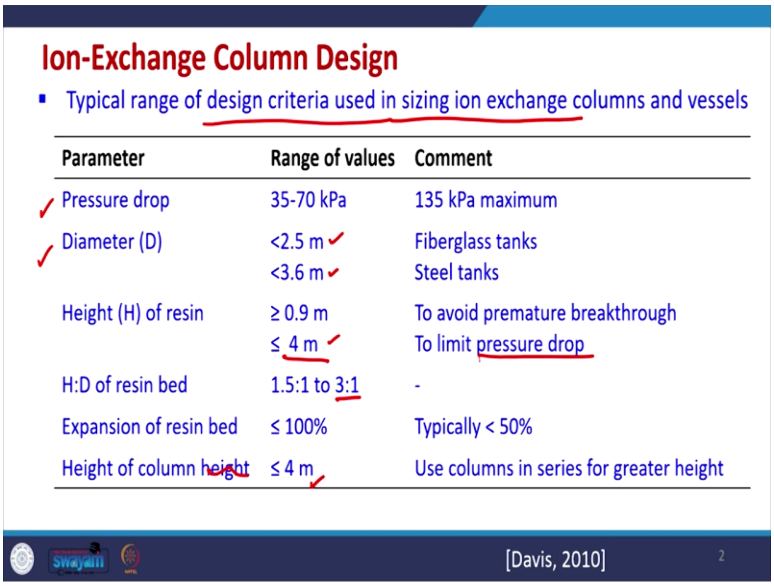

So, these are different design criteria which is used in the sizing of the ion-exchange columns. Now, these parameters already we have discussed. So, these parameters for ion-exchange column may include the pressure drop, because what is the maximum pressure drop and pressure drop will affect the resin and its stability, the loading stability also then the diameter of the column, the height of the column, the height to diameter ratio and then the what is the maximum expansion which is possible and the height of the column itself beyond the range in which the bed is there.

So, this is there, so, pressure drop is generally kept in the range of 35 to 70 kilo Pascal, it may be at maximum to 135 kilo Pascal maximum, then the diameter is also depends upon the type of column which is being used. So, we may have less than 2.5 meter or less than 3.6 meter depending upon whether we are using fiberglass tanks or steel tanks. So, it is possible.

Height of resin maybe, generally it is kept more than 0.9 meter or like 1 meter to avoid the premature breakthrough, it may go up to 4 meter also depending upon the pressure drop. So, this is there, it may vary from 1 to 4 meter. Now, height to diameter ratio is for the resin bed maybe from 1.5 is to 1 or 3 is to 1. So, this is the ratio generally it is kept.

Now, it is possible that the resin bed may expand a little bit. So, typically 50 percent or otherwise and height of the column is generally kept within 4 meter it may go beyond also a little bit when we are using the upmost limit 4 meter for the resin height itself, this is possible so, these are the typical design criteria, they may change also depending upon our requirements and extreme conditions or otherwise. So, these are the typical range of design criteria which is there.

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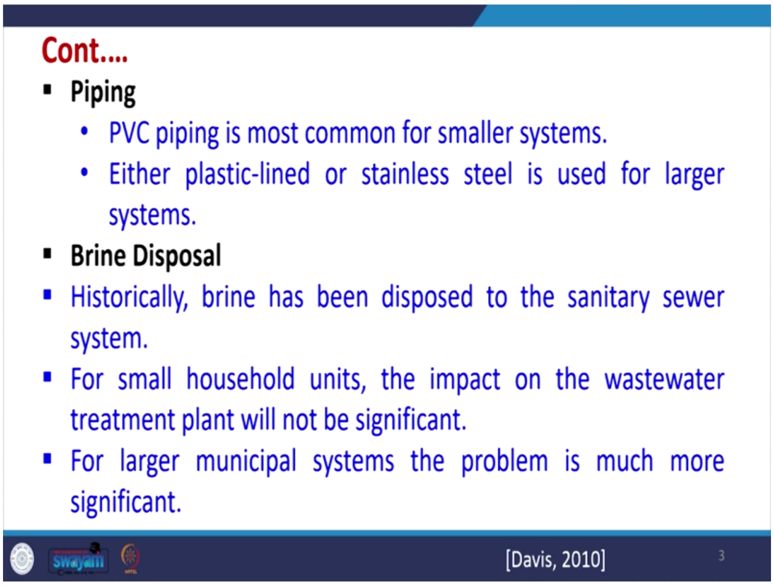

Now, in addition for piping, the pvc piping is most common for smaller system, we can use the plastic lined or stainless steel one for larger system, then the brine solution which is used for regeneration. So, this has to be disposed to the sanitary sewer systems, etc. For small household units which are there the impact on the wastewater treatment plant will not be significant. So, we can do this.

But for large municipal system the problem is much more significant. So, we have to check the, how to treat this the water which is coming out after the regeneration. So, that aspect is very important.

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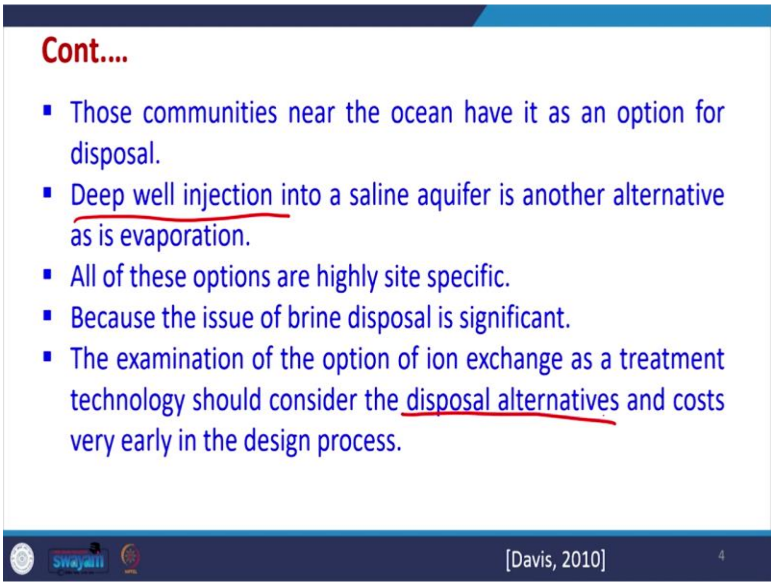

Those communities which are near to ocean, they have the option for direct disposal to the ocean. There is another option of deep well injection into the saline aquifer is another alternative.

So, all these options are highly site specific, it may be available, it may not be available and because the issue of the disposal is highly significant, the examination of option of ion-exchange as a treatment technology should be considered, considering that how we will dispose of that brine. So, that is very very important if you are going to select any ion-exchange resin for treatment and cost also will depend upon that. So, all these parameters are very important.

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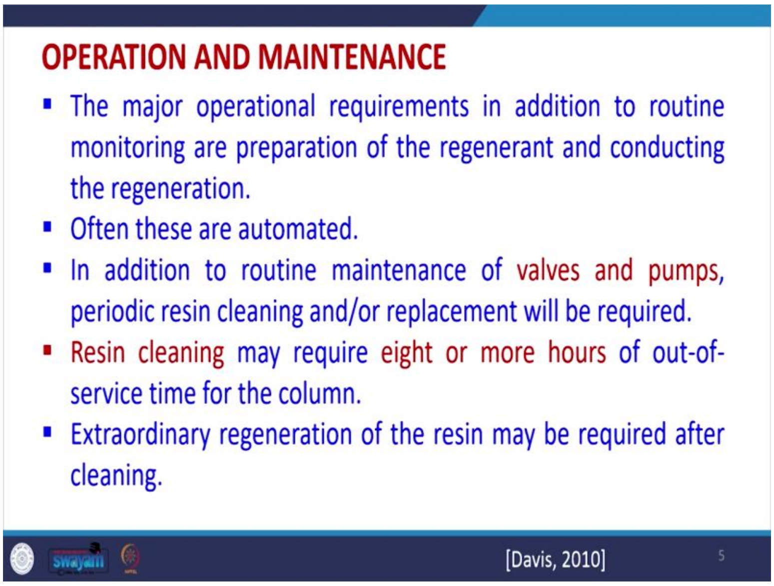

Then during operation and maintenance, the major operational requirements in addition to routine monitoring are like preparation of the regenerate or performing the regeneration itself. So, all these processes may be automated in addition to routine maintenance of valves and pumps, because they have to be checked thoroughly periodic resin cleaning or replacement may also be required when the efficiency of the resin goes off drastically.

So, it is possible that after a large number of cycles, the resin may not work that well. So, under that condition, the resin itself has to be replaced. Now, resin cleaning may require 8 or more hours of out of service time of operation of the column as compared to tentative 2 hours which is required for out of service time. So, it is possible, so, extra ordinary regeneration of the resin may also be required after cleaning. So, this is possible.

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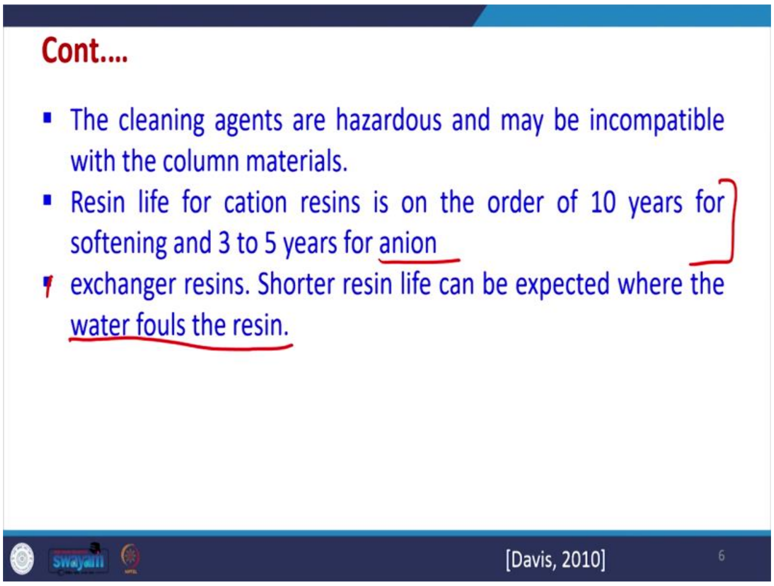

Now, the cleaning agents are hazardous and may be incompatible with the column material. So, this is possible also the resin life for cation resins is of the order of 10 years for softening and 3 to 5 years for anion-exchange etc. So, we may have to replace these resins after this duration and shorter resin life can be expected for where the water fouls the resin itself. So, if water contains significant amount of other materials, it may fall the resin itself and it will cause problem. So, this is possible.

Now, what we will do is that these were the basic thing that we have understood regarding the design, operation, how the ion-exchange beds, etc., work. Now, what we are going to do is that we will solve some numericals related to ion-exchange or some problems and we will try to understand that how we can perform these calculations if the treatment is being done via a ion-exchange bed or ion-exchange column.

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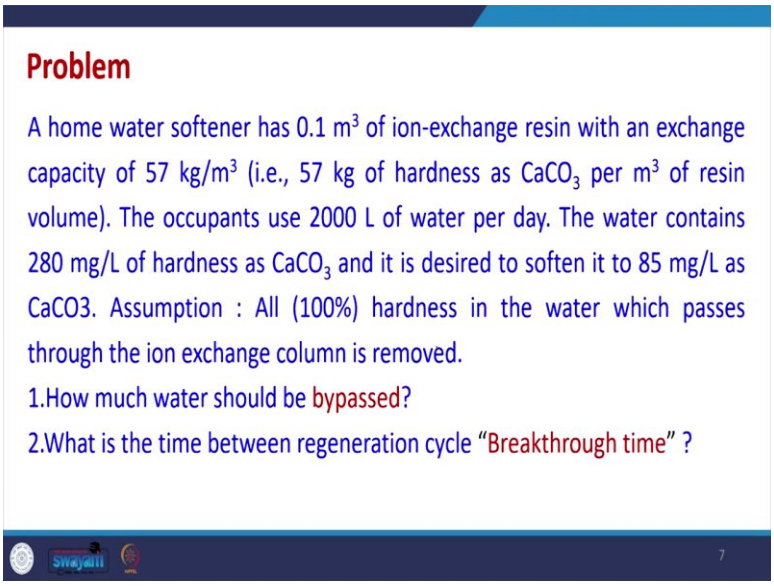

So, let us start with some first problem itself. So, a home water softener has 0.1 meter cube of ion-exchange resin with an exchange capacity of 57 kg per meter cube or that may be called as 57 kg of hardness as CaCO3 per meter cube of resin volume, it is the maximum capacity that resin has. Now, the occupants require around 2000 liter of water per day, the water itself contains 280 milligram of hardness, as CaCO3 and we desire it to be removed to be 85 milligram per liter as CaCO3.

So, this is there and all, another assumption that has been there that all hardness in the water which passes through the ion-exchange column gets removed. So, what we have to do is that we have to perform a calculation with respect to how much bypassing should be done, so, that we can reach the 85 milligram per liter target, which is desired and what is the time between regeneration cycle the breakthrough time that is there.

So, this also we have to perform the calculation based upon the data which is available and so, if we can perform these calculations, we can learn that if the capacity is known, how much how to select any ion exchanged resin or how much time it will operate or how much water it will be able to treat, we can use this problem differently. So, let us start with the problem.

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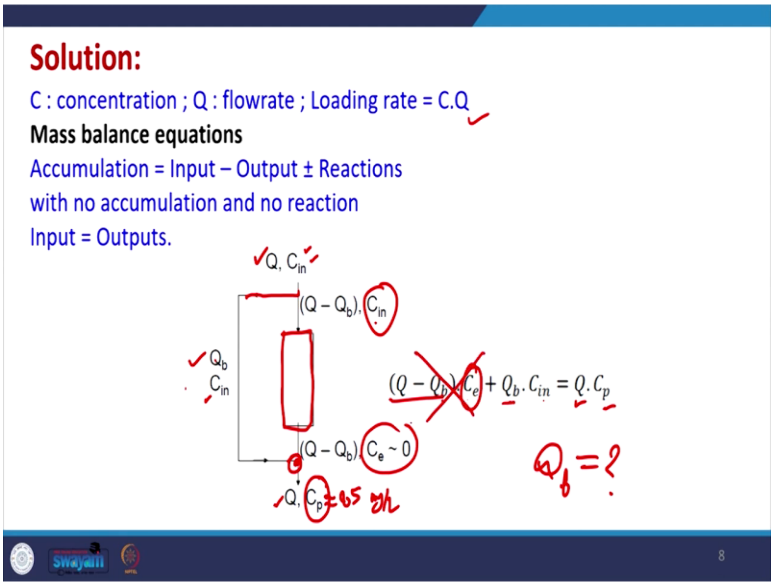

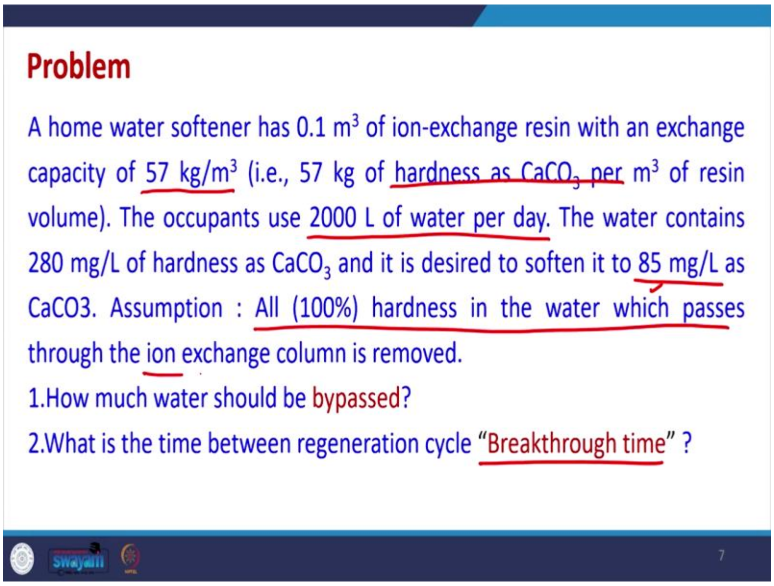

So, If suppose C is the concentration, Q is the flow rate. So, the loading rate will be a concentration into flow rate. So, this CQ. Now, if this is the column which is being used for this removing the hardness, now, the flow rate which is coming is Q and the Cin is the concentration in the initial condition.

Now, what we do is that we bypass some amount of material, some amount of water and the flow rate is Qb and rest water is sent to the ion-exchange basin, where the treatment happens and after the treatment, the whatever is the concentration here that concentration will go into the exchange basin and that will concentration will go into the bypass itself.

Now, this concentration which is there, it will totally get removed when the water passes through the ion-exchange bed, because it has already been told that 100 percent of the hardness in the water gets removed when it passes through the column.

So, this is already given. Now, after that, this bypass stream and this treated stream they mix, merge together and then this flow rate will again become Q and we have a concentration which is Cp and this Cp is desired to be 85 milligram per liter. So, this is desired to be 85 milligram per liter as per the question.

So, this is there. So, we have to find out how much water should be bypassed. So, that means, in this case we tried we have to find out what is the flow rate of the bypass that has to be done.

Now, there are 2, 3 positions where we can perform the calculation, one of the calculations where everything is done is this mixing point. So, at this mixing point, the flow rate which is coming is Q minus Qb into Ce and from bypass stream Qb into Cin and then we have the flow rate, which is and this flow rate will be because Q, if we add Q minus Qb into Qb it will become Q. So, this is Q and Cp is the concentration which is always ready 85 milligrams per liter.

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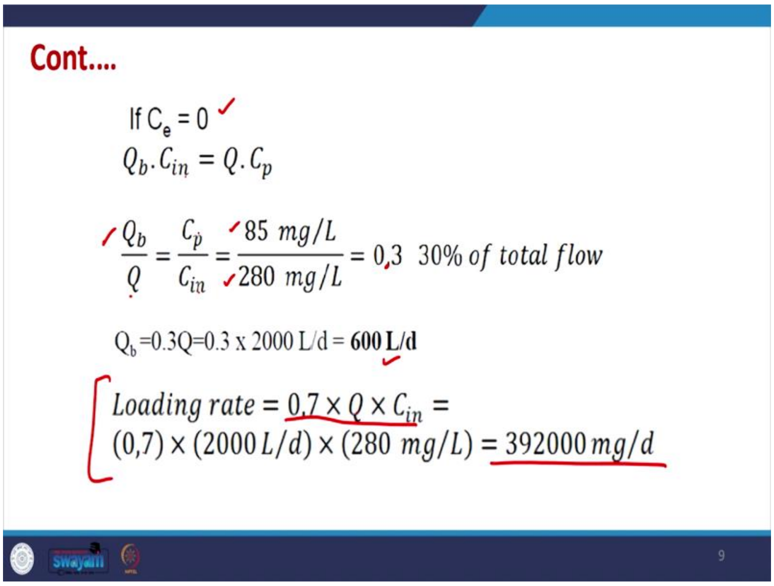

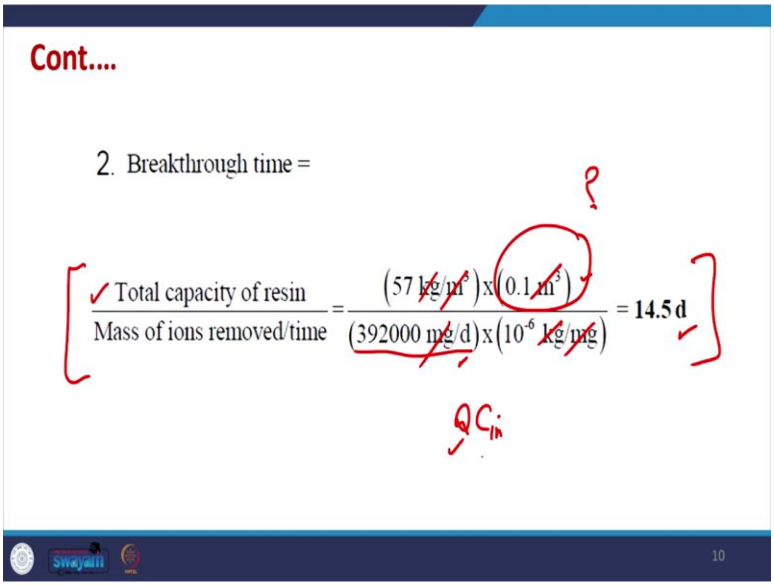

So, if we put all the values together, so, Ce is already 0 in this case, so, this value is already 0, this whole term goes off. So, we have only two term which is remaining and we out of this term, two term we have to find out the Qb value. So, Qb, Cin is equal to Q Cp. So, that means in this Qb upon Q is equal to Cp upon Cin so CP is 85, which is desirable, Cin is the concentration and the influent is 280 milligram per liter.

So, we have, we can perform the calculations it will be 0.3. So, that means, that Qb value should be 0.3 of the total full rate. So, that means, around 600 liter per day that should be the bypass stream and in the loading rate if you perform the calculation on the column will be given by this equation.

So, because only 70 percent is going through the column, so, 70 percent of the flow rate into Cin, so, this is the loading on the bed. So, now, as soon as we can find out the loading rate on the bed itself, we can find out the breakthrough time also, because the total capacity of the resin is only 57 kg per meter cube, which is already given and the 57 kg per meter cube and we are only using 0.1 meter cube of the resin.

So, 57 into 1 is the total capacity of the resin, now mass of ions removed per unit time is this total capacity and but this capacity the unit is milligram per day, and we have to convert into kg so, that the unit goes off this meter cube meter cube already or can be they cut each other.

So, we have milligram so, we convert this unit now milligram, milligram can go off and kg kg can go off so, we have the only unit which is left is day. So, if you perform the calculation that means, we can use this particular resin for 14.5 day without regeneration and this is the after that the breakthrough will be achieved and we will have to regenerate the bed.

So, this calculation can be performed very easily for this bed itself and using this equation we can always perform the calculation that, okay how much mass of how much resin we should use sometimes we may have to find out this parameter. So, this is one of the parameters we can find out and this will depend upon the loading which is there.

So, that will also be calculated using Q into Cin because we always know that how much water has to be treated and what is the concentration of anything in the water itself. So, this loading rate we can always calculate here only 70 percent of the initial flow rate is going through the bed, but in some many cases it will be 100 percent.

So, we can always find out the loading rate and once the loading rate is known, we know the capacity we can find out that what is the volume that will be required. So, and this is possible. Now, going further, we will take another question and this is, this question is with respect to some material balances and other things. So, let us understand this question and then try to solve this question.

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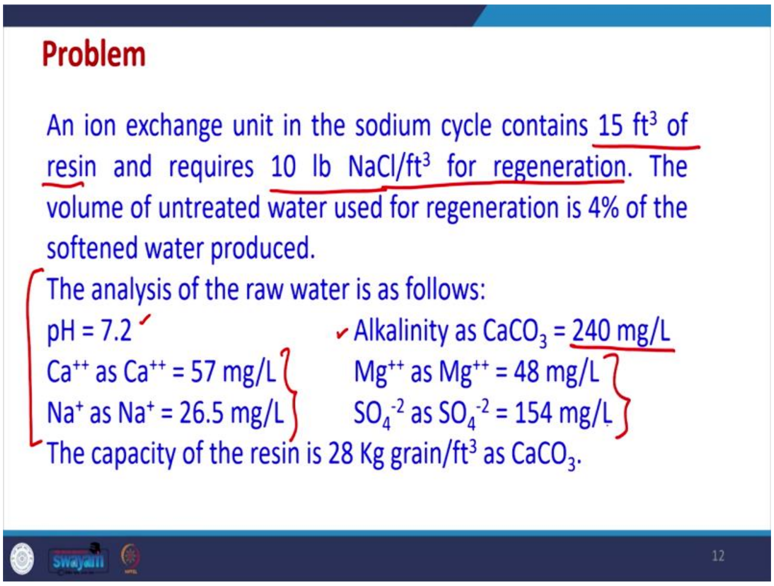

Now, an ion-exchange unit in the sodium cycle contains 15 feet cube of resin. This is there, and requires 10 pound of NaCl per feet cube for regeneration. This is another parameter which is given. Now, the volume of untreated water used for regeneration is 4 percent of the soften water produced. So, the volume of untreated water which is used for regeneration is only 4 percent of the water which is actually getting produced. So, this is there.

Now, the analysis of raw water which is used which is being treated is given here it has a pH of 7.2, alkalinity as CaCO3 of 240 milligram per liter and rest different types of ions are present in the water itself. So, we have calcium, sodium, magnesium sulfate, so, these are already present in the water. Now, the capacity of the resin is 28 kilo gram grain per feet cube of CaCO3. So, this is the capacity which is given.

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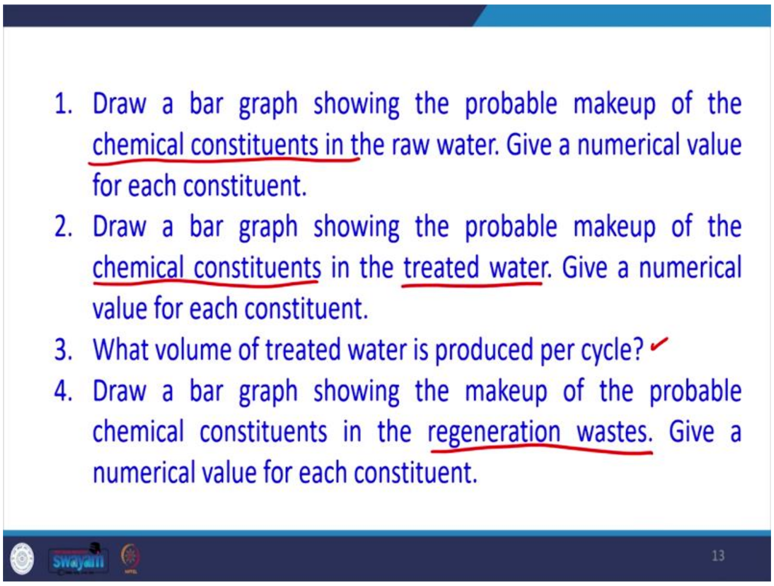

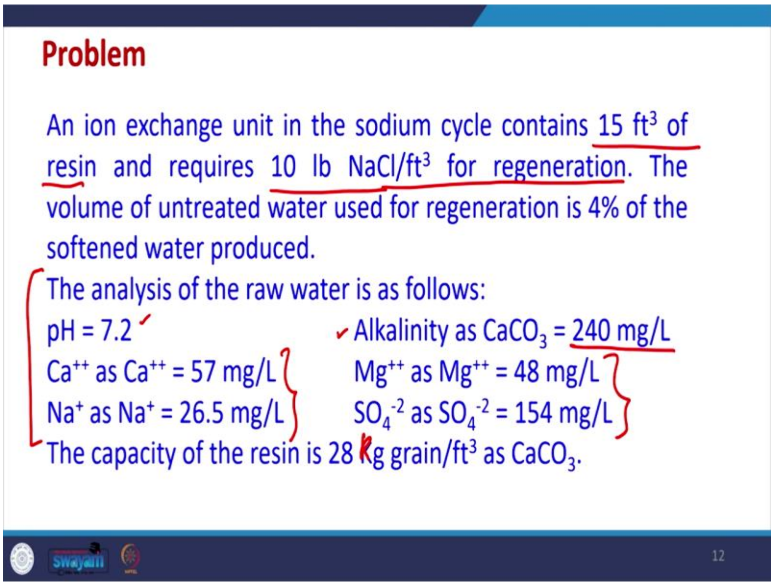

Solution

To calculate all ions as $CaCo_3$

$Ca^{++} = 57$ mg/L

$$\frac{C_{Ca^{++}}}{\text{Eq. weight of } Ca^{++}} = \frac{C_{Ca^{++}\text{ as }CaCO_3}}{\text{Eq. weight of } CaCO_3}$$

$$\frac{57}{20} = \frac{C_{Ca^{++}\text{ as }CaCO_3}}{50} \Rightarrow C_{Ca^{++}\text{ as }CaCO_3} = 142.4 \text{ mg/L as } CaCO_3$$

Cont....

Similarly

$Mg^{++} = 48$ mg/L

$$\frac{48}{12} = \frac{C_{Mg^{++}\text{ as }CaCO_3}}{50} \Rightarrow C_{Mg^{++}\text{ as }CaCO_3} = 200 \text{ mg/L as } CaCO_3$$

$Na^{+} = 26.5$ mg/L

$$\frac{26.5}{23} = \frac{C_{Na^{+}\text{ as }CaCO_3}}{50} \Rightarrow C_{Na^{+}\text{ as }CaCO_3} = 57.6 \text{ mg/L as } CaCO_3$$

Cont....

Similarly

HCO_3^- as $CaCO_3$ = 240 mg/L

$SO_4^{-2} = 154$ mg/L

$$\frac{154}{48} = \frac{C_{SO_4^{-}\text{ as }CaCO_3}}{50} \Rightarrow C_{SO_4^{-}\text{ as }CaCO_3} = 160 \text{ mg/L as } CaCO_3$$

So, now, we have to perform different calculations first we have to cross check that what is the chemical constituents which are present in the raw water. So, we have to find out the numerical value with respect to each. So, already in milligram per liter they have been given. So, we have to dry bar graph type of thing so, that we can find out the total hardness etc., for this particular raw water.

Now, the second problem which is given in that draw a bar graph showing the probable makeup of the chemical constituents in the treated water. So, we had to find out after treatment the chemical constituents which were there, how much of them have been removed and what is their composition in that treated water.

Then after that, we had to find out that what volume are treated water is produced per cycle. So, this also we have to check now, since, it is given that 4 percent of the soften water, only 4 percent of the soften water is used for regeneration.

So, this idea, have to use and we have to show in the bar graph that what will be the makeup of the chemical composition in the regenerated waste. So, this is also we have to check. So, we have to find out chemical composition in the raw water, we have to find out that chemical composition in the treated water, we have to find out the chemical composition in the regenerated water and in addition we have to find out that what volume of treated water is produced per cycle.

This is a very realistic version which is possible under any condition and sometimes we may have to perform these calculations. And for doing this, we only need to know all these parameters beforehand. So, this may require that we may have to test the water from some testing agency and we should know the parameters with respect to resins also. So, though if both things are known, we can perform these calculations.

So, to calculate all ions as calcium carbonate, so, we had only 57 milligram per liter of calcium carbonate which is given. So, what we do is that, we convert this into what is the amount in milligram per liter as CaCO3. So, for doing this, we use this particular equation. So, here the concentration of calcium equivalent weight of calcium is used.

Now, for CaCO3 the concentration of calcium as Ca plus plus in CaCO3 an equivalent weight of CaCO3 and we have to find out actually this, because we want the concentration to be converted as CaCO3. So, using this formula, so, we put because this is 57, this is 20 for calcium, and for equivalent weight for calcium carbonate is 50 because its actual total atomic weight is 100, so total molecular weight is 100, so 100 divided by valency 2 we have 50. So, we can perform the concentration calculation it will be coming out as 142.4 milligram per liter CaCO3, so, we converted one of them.

Now, going further similarly, we can calculate with respect to magnesium. So, for magnesium 48 divided by 12 so, calcium magnesium CaCO3 divided by 50 so, it comes out to be 20 milligram per liter as CaCO3 similarly, for sodium we convert it comes out to be 57.6 milligram per liter as CaCO3 remember for sodium we have 23 as its equivalent weight, because it is only a single valency ion.

Now, similarly for bicarbonate and bicarbonate is already 240 milligram per liter, sulfate has been given as 154 we convert sulfate also and it comes out to be 160 milligram per liter as CaCO3 and we perform these calculations using the data already known to us these are very simple calculations.

So, we have performed all the calculations we converted each of these values into concentration as CaCO3. So, this is what is given an Alkalinity as CaCO3 was already given. So, we have assumed the Alkalinity as CaCO3 is because of bicarbonate because a pH is around 7.2 only, so we have assumed that.

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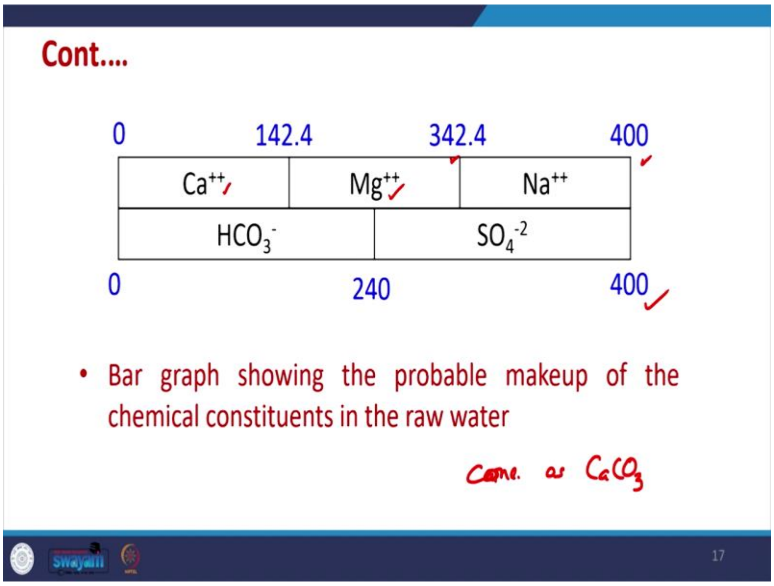

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Similarly

HCO_3^- as $CaCO_3$ = 240 mg/L

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$$\frac{154}{48}=\frac{C_{SO_4^- \text{ as } CaCO_3}}{50} \Rightarrow C_{SO_4^- \text{ as } CaCO_3} = 160 \text{ mg/L as } CaCO_3$$

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- Calculation of constituents in the regeneration wastes

$$\frac{342.4 \text{ mg/L Total Hardness}}{17.12 \text{ (mg/L)/(grain/gal)}}$$

$= 20$ grain/gal Total Hardness

$= 20 \times 264.172 = 5283.33$ mg/L Total Hardness

$$\Rightarrow \frac{28000 \text{ grain/ft}^3 \times 15 \text{ ft}^3}{20 \text{ grain/gal}} = 21{,}000 \text{ gal treated per cycle}$$

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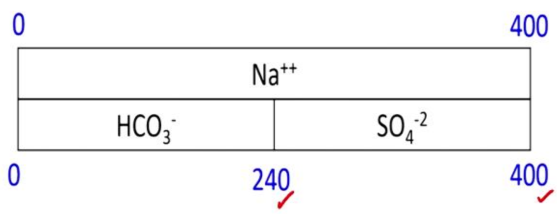

- Bar graph showing the probable makeup of the chemical constituents in the treated water

So, this is, using this data now, we perform remember this type of bar graph we have discussed in initial lectures when we studied the water quality. So, when we studied different types of ions, we performed how to draw this type of curve and through that we can find out that what is the calcium hardness, what is the magnesium hardness, whether it is carbonate hardness or non-carbonate hardness. So, through that we can determine.

Now, if we perform the calc, we now draw this bar graph, one side we use all the cations, so, we have cations calcium 57. Now, we have converted that into 200 milligrams per liter as CaCO3. So, we have calcium which is 142.4, Magnesium 200, 57.6 is sodium. So, these are the cations.

Now Anions we have 240 plus 160 so Anions is 400 only because we have only 240 and plus 160. So, if we add together we have 400 and we can cross check for cations also, so 142.4 plus the magnesium so it will become 342.4 and plus sodium it is 400. So, we find that okay, there is actually no error with respect to calculation. So, the bar graph showing the probable makeup of the chemical constituents in terms of concentration, concentration as CaCO3, so remember these are the concentration as CaCO3 we have reported here.

Now, we have to report the chemical constituents in the treated water. So, this is the second objective which is there. Now, after treatment, this is the, if similar to this if you perform the calculations, it will be like this only because, the 240 is the none of the anions will get removed because this is a cation-exchange. So, here sodium cycle is getting there.

So, sodium will come into the solution and everything will get removed. So, we are assuming that 100 percent efficiency they are operating and there is no leakage etc., and the operation is before the breakthrough time. So, every ion will get removed. So, because of that, after treatment, the bar graph will look like this.

So, we will still be having 40 milligrams per liter as CaCO3 and every calcium and magnesium will get removed, but sodium will increase because sodium will come out from the resin itself. So, thus we have more sodium and this will be the bar graph after the treatment. So, we have performed calculation and found out the chemical constituents in the treated water. Now, we have to find out that what will be the chemical composition in the regeneration waste.

So, for performing this we have to find out that how much gallon of water is being treated per cycle, because the regenerated cycle is 5, 4 percent of the treated water, which is there, for performing determining how much amount of water has been treated per cycle, we have to perform some calculation and that calculation is what is the total hardness and what is the capacity of the hardness of the, our system because we are using only 15 feet cube of the grains.

So, this is so, near that we are using only 15 feet cube of resin. So, that data is available. So, what we do is that initially we convert that total hardness into 20 grains per gallon and grain is another unit which is like mass unit. So, that can be and from that data, we know that grain and feet cube also there is a relationship.

So, only some minor calculations are being performed here. So, we convert this 342 milligram per liter total hardness into 20 grain per gallon total hardness by using this particular unit which is available in the literature and we can find out very easily and here 17.12 milligram per liter is equal to 1 grain per gallon.

So, this is known to us. So, using this, this 342.4 milligram per total hardness is equivalent to 20 grains per gallon total hardness. Now, this is known to us. Now, what we do is that we use this data to find out the amount of water treated, we have 15 feet cube of the resin. Now, this 15 feet cube needs to be converted into grain.

So, for converting this we know that 1 feet cube is equal to 28,000 grain. So, if you multiply together the feet cube feet cube goes off. So, we have 28,000 grain into 15 and if we divide by 20 grain per gallon, so, grain, grain also goes off we have only gallon.

So, we know by calculation that 21000 gallon of water will be treated in this system per cycle because the total hardness in the water is 342.4 and it can be removed fully because we know only 15 feet cube of the resin is being used. So, this is the calculation we can perform.

Now once 21,000 gallon of water is known and only 4 percent of that being used. So, that means if we divide 21,000 by 25 or only we can perform calculation 4 upon 100 into 21,000. So, we can do like this. So, we will be finding that 840 gallon of regenerated waste has to be used.

So, that is already given in the question itself. Now, this regenerated waste will contain the calcium and magnesium which was removed earlier. So, that factor and 4 percent concentration factor is 25 so, that means because we are only using 4 percent of the treated volume. So, that means, the amount of concentration will increase 25 times.

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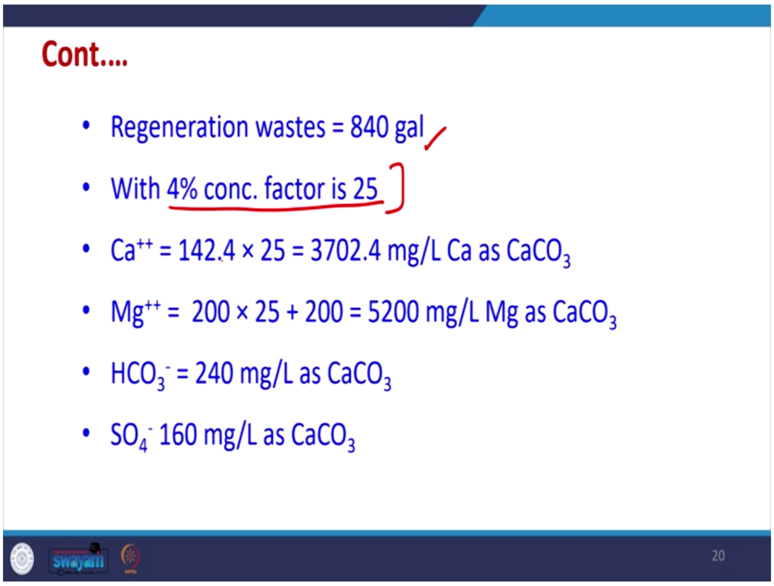

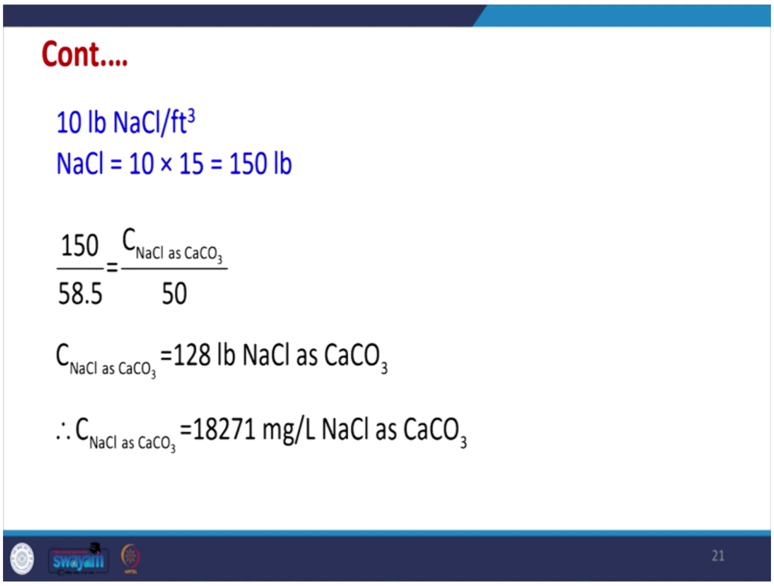

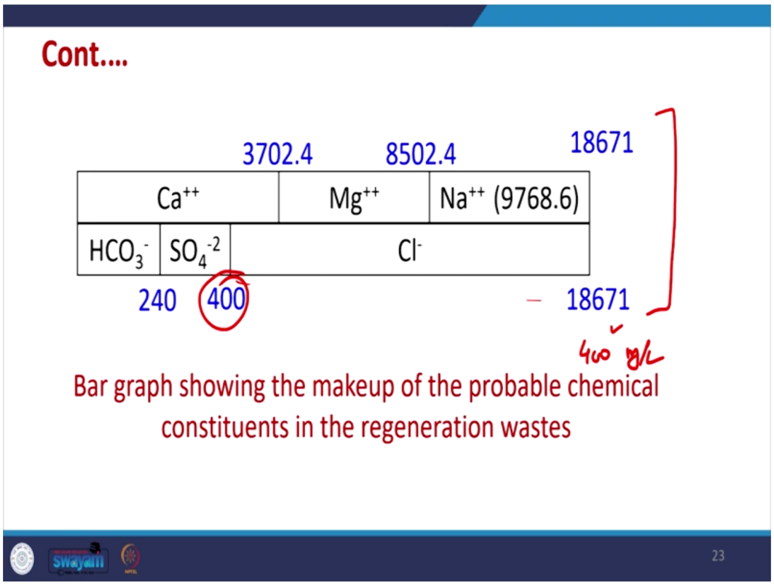

So, using this idea, the concentration earlier was 142.4 so, it will become 142.4 into 25 so, this is the calculation. Similarly, for magnesium here additional 200 has been used for performing some idea with respect to magnesium which will be there. So, that is 5200 so, we have just taken it could be 5200 also. Now, similarly, the all this bicarbonate and the sulfate which is there. So, already they are given 240 and 160.

So, if we use this data and already it has been given that 10 lb of NaCl has to be used for per feet cube of the resin. So, that means 10 into 15 that means 150 lb of NaCl will be used. Now, for performing calculation again we do. So, the calculation of NaCl comes out to be 18271 milligrams per liter of NaCl as CaCO3.

So, we have performed all the calculations Na we have calcium, magnesium, sulfate and bicarbonate also and if we use all the data and we convert all the data this sodium as CaCO3 has been converted as into milligram per liter as CaCO3 using this calculation and similarly chloride has been converted because NaCl as CaCO3 will be there and we can subtract the HCO3 and sulfate as CaCO3. So, by subtracting this will be the chloride and this will be the sodium which will be there and if both are known, we can perform this calculation and the overall picture will look like this in the chemical constituents that will be present in the regenerated waste.

So, you can tentatively see, earlier before treatment and after treatment we had the limit of only 400 milligram per liter and after treatment, it has become 18,671 so the regenerated waste it has lot of ions present and treatment and disposal of this ion becomes a very very challenging issue and the calculations have been performed here and written here, so earlier only 400 and this amount, this much amount of ions have been added in the regenerated water because of the use of NaCl, concentrated NaCl.

So, these are the calculations that we can perform for all these type of problems. So, Ion-Exchange calculations are simpler. And we can use the design criteria you can, we can use the mass balance condition, we can use the capacity etc., to perform all these calculations.

So, through this we end this particular section on ion-exchange. We will start another unit operation which is used for treatment of water via various methods and so we will continue in the next lecture with respect to another section. Thank you very much.