Physico-Chemical Processes for Wastewater Treatment
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Lecture 39
Ion-Exchange – III

Good day everyone and welcome to these lectures on Physico-Chemical Processes for Wastewater Treatment. So, we started the ion exchange unit operations which are used for exchanging the undesired ions out of the water with respect to some ions, which may be already present in on the Ion Exchange Resin.

So, we have already discussed some of the important thing regarding the ion exchange resin, what is its structure, general structure then that structure include the basic resin bed and the crosslinking along with that the functionalities which will be generally be ionic followed by the ketonic ions which are attached to the anions.

So, this is a structure of ion exchange resin itself and then these resins may have certain selectivity and capacity. So, those capacities and selectivities are used for finding out which ion exchange resin will be good enough for our uses in the ion exchange bed.

Thereafter, we tried to learn the mode of operation of different ion exchange beds. So, in the previous lectures, we studied that there are 3 modes of operations of ion exchange beds and that included the co-current mode of operation, the counter current mode of operation and the bypass scheme.

So, in the co-current and counter current mode of operation, the ion exchange, the regeneration and the usual treatment in the co-current booth are in the same direction. So, generally from top to bottom, so, flow rates during the treatment are also from top to bottom.

Whereas, the flow rates during regeneration when some chemicals are being used also is flow from top to bottom. In the counter current case the flow rate during treatment is from top to bottom, but during the regeneration it is from the bottom to top, there is some difference is there that counter current mode of operation they have generally better efficiency in terms of regeneration during the regeneration process and also they require lesser amount of regenerating chemicals, etc.

But, the cost during the counter current mode of operation is much higher because we have to have a separate flow lines, etc. during the regeneration process. So, because of that, the counter current mode of operation is generally costlier as compared to co-current mode of operation.

Now, there is a bypass scheme also in which what we do is that we bypass some of the water that has to be treated and some fraction of the water is passed through the bed and after the treatment, the bypass water and the treated water are blended together to get a certain concentration, desired concentration of the water which will be having some particular ions present in desired quantity. So, through that we can always manipulate the concentration which is desired. So, this is another mode of operation.

Now, going further, when we are actually performing the ion exchange treatment for water usage, etc. So, we always use multiple columns we cannot perform the column, we cannot perform the treatment in 1 column, because 1 column will be in the operation maybe 2, 3 columns are in operation mode. So, 1 column will be in the regeneration mode. So, this is there.

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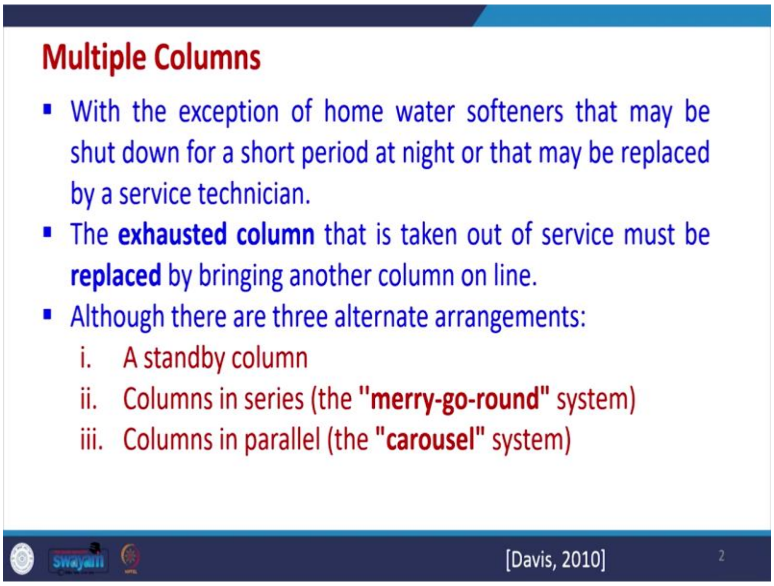

So, with the exception of home water softeners that are used in residences, etc., we always have multiple columns which are used in the industry or at larger scale of operation. And during that period what we do is that we the exhausted column which is out of service is regenerated or if we have to replace the beds, etc. we can replace the beds also. So, this is done and during when this regeneration etc., is being done of the exhausted column the treatment is being done of the other 3 columns or 4 columns.

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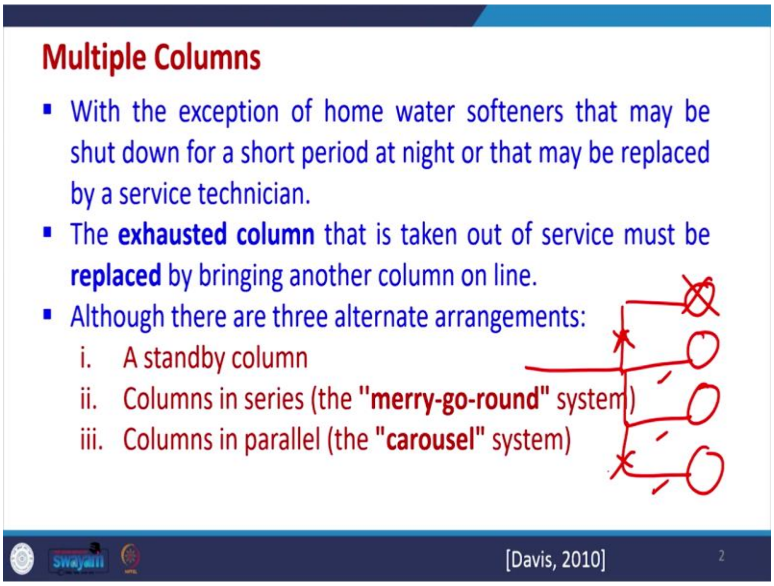

So, it is possible that we have like suppose we have 4 columns and so, and the water is coming. So, it is possible that the flow lines may be like this for all the cases, but only one column is not in service.

So, this will be closed only 3 will be in operation, but when it is regenerated. So, again the flow rate will start maybe this one will go out of service. So, through this we always use multiple columns. Now, there are different types of arrangements which are possible with multiple columns and that we can do using the flow lines. So, we can always operate the multiple columns in various modes. So, these arrangements are like that, we have some standby columns, we can use the column in series which is called as Merry-go-round system.

So, this is used when we do not achieve the efficiency which is desired in 1 column, also we can use the columns in parallel that Carousel system. So, that is possible when we have to use, treat the large amount of water. So, we cannot take the large amount of water in one system so, we perform parallel operation. So, this is there now, we will discuss each of these in a little bit more detail.

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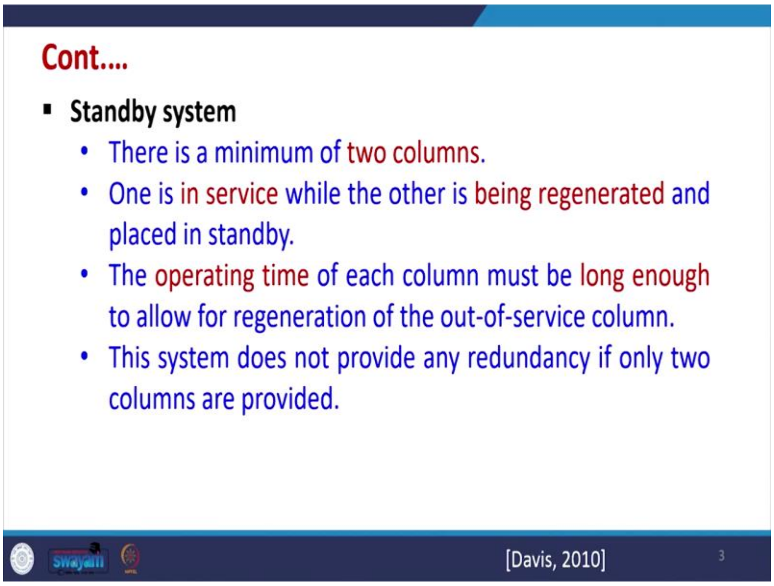

So, in the standby system, there is a minimum of two columns, one is in service, while other is being regenerated and it is placed in standby. The operating time of each column must be long enough to allow for regeneration out of the out of service column. So, we always try to see that the column which is being used for in operation, it is big enough that it should work for more than that duration which is required for regenerating the other column.

So, this is one very very important aspect, both should not be equal the out of service column should get regenerated much before the other one gets exhausted, this system does not provides any redundancy, if only two columns are provided etc., so that is there, now, columns in series also we can use and the system is called the Merry-go-round system.

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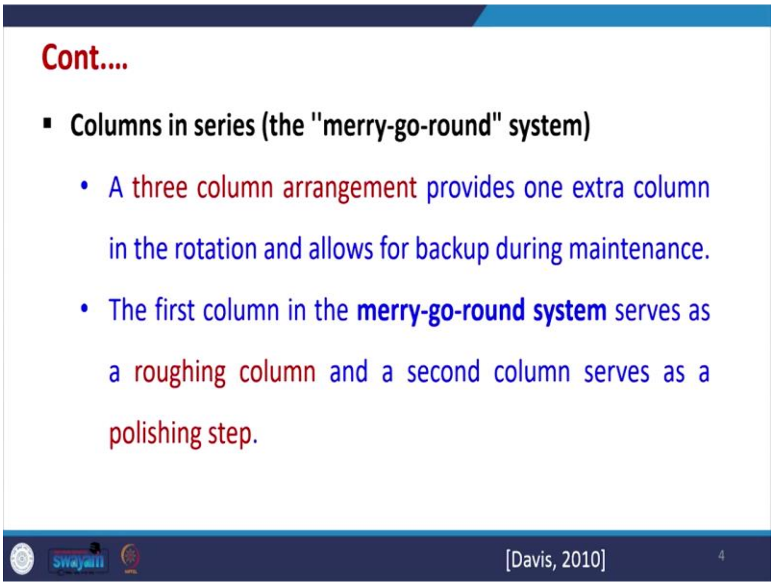

So, in this a three column arrangement may provide one extra column in the rotation and allows for backup during maintenance. The first column in the merry go round system serves as roughing column the second column serve as the polishing is step. So, we have two columns in series and one may be in the regeneration step etc. So, this through this arrangement is possible.

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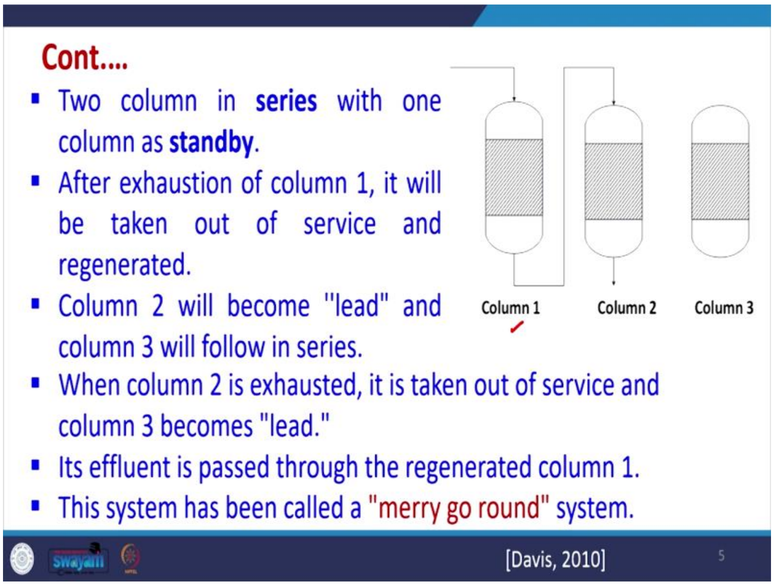

Two columns in series with one column in the standby we can see here and after exhaustion of column 1, it will be taken out of the service and regenerated and column 2 will become the lead and column 3 will become follow in series column, when column 2 gets exhausted, it will be taken out of service and column 3 will become lead and column 1 will become the in series column, this way we can go Merry-go-round with the columns.

Its effluent are passed through the regenerated column 1. So, this is there, this system is called Merry-go-round system and we can use this mode of operation for performing ion exchange of the ions from the water.

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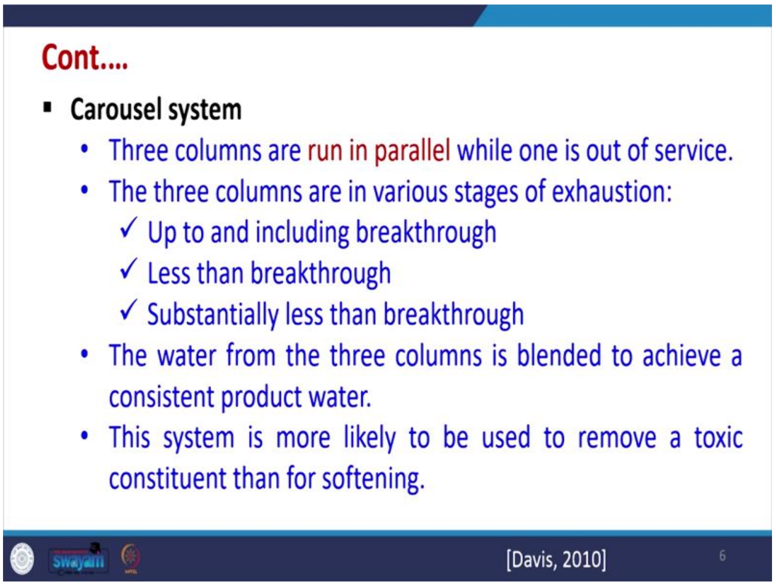

Then we have a parallel system also. In this case, we run three columns maybe run in the parallel while one is out of service. So, this mode of operation is there. So, we may have four columns 3 are being run 1 is out of service, that 3 columns are in various stages of exhaustion. So, it is possible that breakthrough curves with respect to these columns are under different stages.

So, the first column will be up to and including breakthrough, the second column will be less than breakthrough and the third column will be substantially less than breakthrough so, and after sometime the first column will reach breakthrough the second column will become like up to or including the breakthrough. So, this way we can use.

The water from the 3 columns is then further blended to achieve a consistent product water, this system is more likely to be used to remove toxic constituents than for the softening. So, this is possible and this way we can use these columns.

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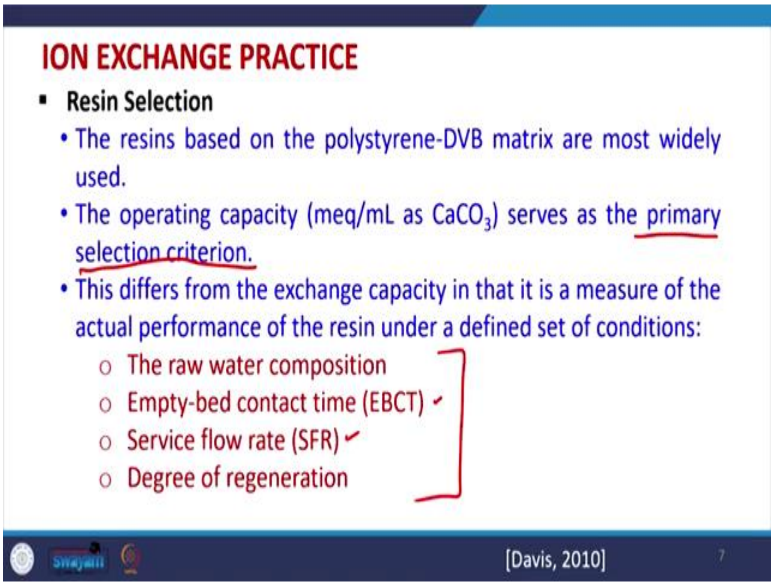

Now, how to use the ion exchange unit operation in practice. So, for actual scenario how to use in the industry sector we will discuss a little bit regarding the same now, now the resin beds generally they are based on the polystyrene-DVB matrix, these are the very very common metrics which are used as resin and the operating capacity like milli equivalent per ml of CaCO3, this is one of the primary selection criteria.

So, we have to check that what type of resins are used, in general polystyrene-DVB matrix raisins are most commonly used, and then we can use the operating capacity as one of the primary selection criteria. Now, this is different than the exchange capacity that is a measure of the actual performance of the resin.

So, if you have to find out the exchange capacity, we have to cross check the exchange capacity under certain set of conditions. So, we may have to perform lot of lab scale experiments to find out different parameters. And depending upon that we can find out the exchange capacity etc., and then we can select.

So, it is possible that we select a matrix then we perform some lab scale operations and from lab scale operations we get like what is the raw water composition that we are treating and what is the actual treatment composition which is coming out then there is another parameter which is called as Empty-bed contact time, it is similar to that we defined earlier in the absorption bed.

So, this is same then the service flow rate that is another parameter we will learn regarding this. Then what is the degree of regeneration which is possible using that regenerating chemical. So, these parameters we have to crosscheck in the lab and depending upon that those known things, we can design the actual ion exchange bed etc.

So, this is possible. So, we have to perform some preliminary testing before for actual water that has to be treated.

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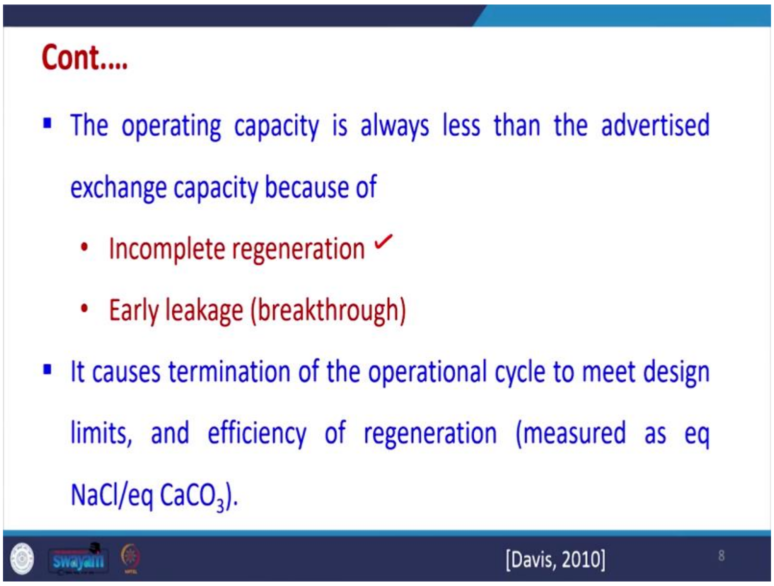

Now, the operating capacity is always less than the advertised exchange capacities whatever they tell as per the bed ion exchange resin bed, whatever they have written. So, it will always be less than because we will be getting incomplete regeneration. So, regeneration will not ever be complete.

So, we will be having in the second cycle, the efficiency will go down, it is always that some leakage etc. breakthrough may happen earlier then what has been mentioned in the bed ion exchange beads, all the parameters which have been listed by the company. So, this is possible. So, if this is there, so, it will cause termination of the operational cycle much lower than the design limits and the efficiency of regeneration will also be low. So, we always have to perform the lab scale operation before actually designing the beds etc. So, that we have to do.

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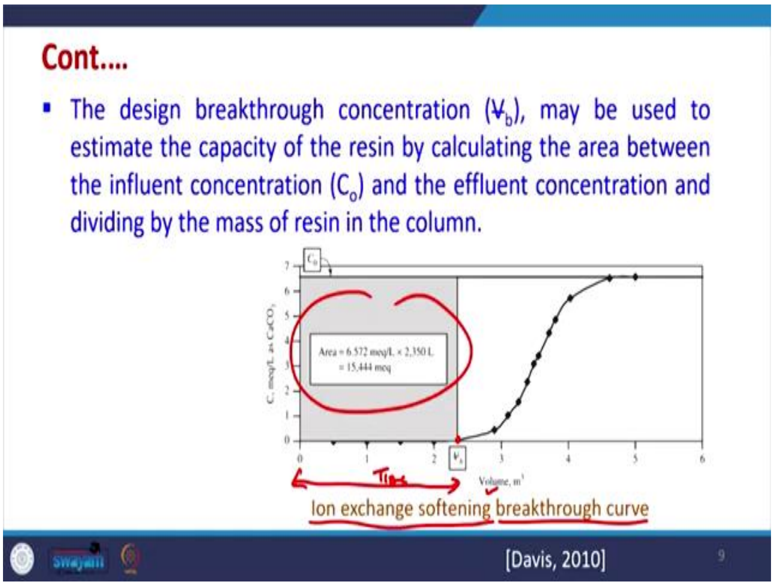

Now, one of the important factors when we are carrying out experiments is live or in the industrial scale, it is called Breakthrough curve are in total, because breakthrough is curve is also common in adsorption also we can call it ion exchange softening breakthrough curve and actually this is the area that we are going through when the we breach the concentration limit as soon as it is breached. So, we can perform the operation up to this time only. So, we can find out that time also here. And also we can find out the volume also if you multiply by the flow rate.

So, design breakthrough concentration may be used to estimate the capacity of the resin by calculating the area between the influent concentration, by calculating the area between influent concentration and effluent concentration and dividing by the mass of the resin in the column. So, through that we can find out the capacity and through that, we can determine the how much breakthrough or how much is the capacity of the bead which is there.

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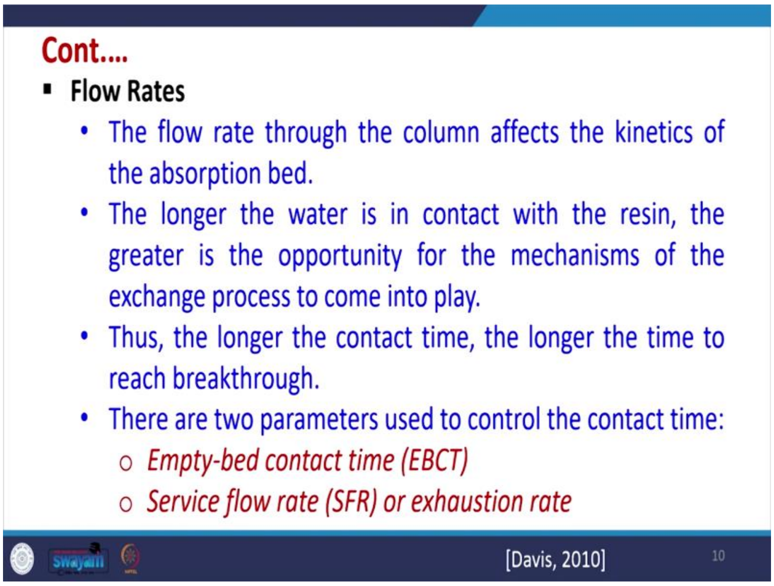

Similarly, flow rates are also important whether it is we are performing the operations at lower flow rates or higher flow rates. So, flow rates always affect the breakthrough, if flow rate is higher, then the breakthrough will be achieved much early and if the flow rate is smaller though we can achieve the breakthrough after much time it will affect the kinetics also. So, this is where the flow rate through the column affects the kinetics of the absorption bed.

The longer the water is in contact with the resin the greater is the opportunity for the mechanism of the ion exchange process to come into play. So, that is why the flow rate it becomes very very important parameter, longer the contact time longer the time to reach the breakthrough.

So, that means, we will achieve we can treat more volume of water if we have lower flow rates. So, and still the bed capacity is same. So, there are two very important parameters to control the contact time and these are called as empty bed contact time or service flow rate or exhaustion rate. So, both parameters actually affect the contact time and they are dependent upon the flow rates. So, let us understand those.

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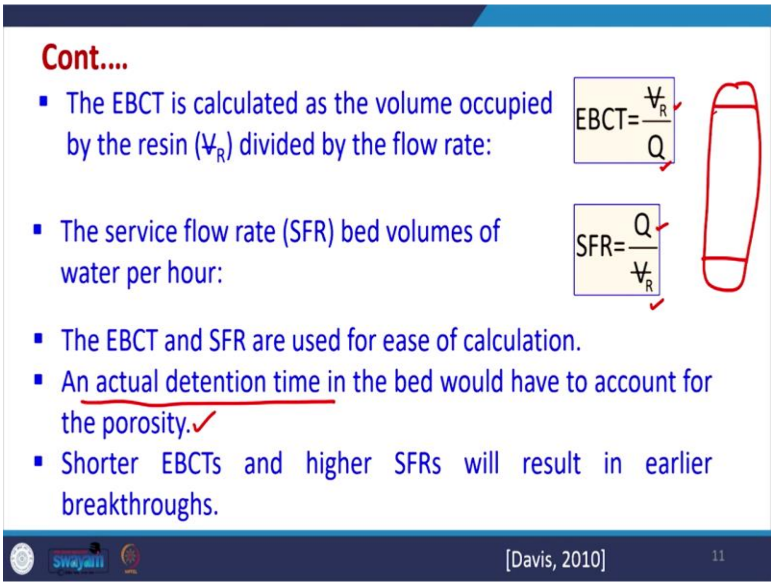

So, the EBCT is calculated as the volume occupied by the resin divided by the flow rate. So, this is the volume occupied by the resin in the bed. So, like if suppose this is the bed, so, suppose this is the volume occupied by the resin and this is the flow rate which is already there. So, this is the same as what we defined in the adsorbent bed also, so EBCT was defined in the same case.

Now, the service flow rate bed volumes of water per hour are defined like this. So, how much what is the flow rate and what is the volume or the resin itself. So, these are used differently for calculations and actual detention time in the bed would have to account for the porosity as well.

So, in the actual condition that detention time will be different because the bed will always be porous in nature, and the ion exchange resins also will be porous. So, we will be having porosity, we will be having tortuosity etc. and so, these parameters also affect the operation. Shorter EBCT and higher service flow rates will result in earlier breakthrough.

So, we always desire the vice versa, we always want the higher EBCTs and lower SFRs. So, this is what is desirable. Now, these are the important parameters that help in determining the which resin we have to use and for that, we will have to perform the operation in the lab scale as well.

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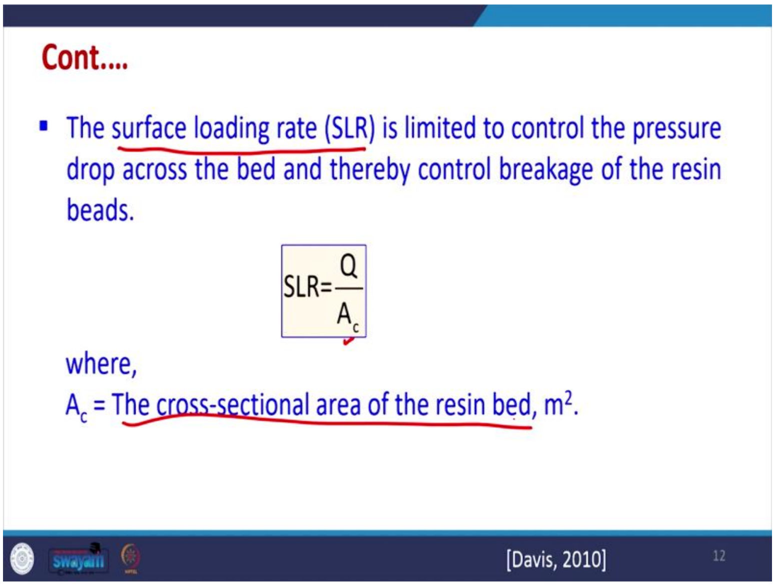

The surface loading rate (SLR) is limited to control the pressure drop across the bed and thereby control breakage of the resin beads:

$$SLR = \frac{Q}{A_c}$$

where,

A_c = The cross-sectional area of the resin bed, m^2.

In addition, there is a surface loading rate this is also very important parameter and it is done to control the pressure drop across the bed and if this is not, so, otherwise the resin beds may break. So, the performance of the resin beds may go off. So, for this we define the surface loading rate, the surface loading rate is limited to control the pressure drop across the bed and thereby controlling the checking that resins are not getting broken etc.

So, and in this case the Ac is the cross sectional area of the raisin bed. So, through that we can determine because flow rate will generally be known. So, and SLR we can always keep below the breaking limit. So, Ac we can determine.

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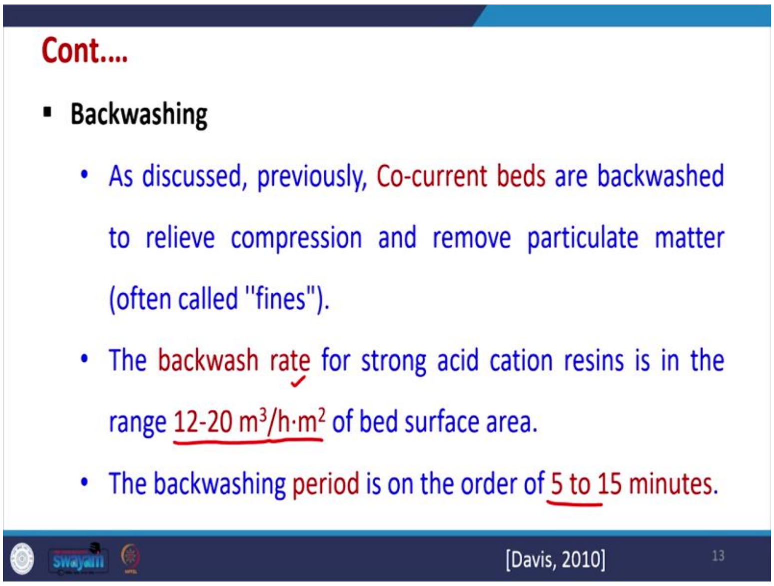

Now, during after treatment, we will be doing regeneration or backwashing. So, as discussed the co-current beds are backwashed to relieve the compression and remove the particulate matter often called as fines. So, the backwashing we may have to done and then we have to regenerate also. So, sometimes backwashing lines and regeneration lines may be same.

The backwashing rates were for strong acid cation resins is in the range of 12 to 20 meter cube per hour per meter square of the bed surface area. So, this is the general back washing rate which is kept and the period of operation may be from 5 to 15 minutes or higher this is possible depending upon the size of bed etc. through this back washing is done.

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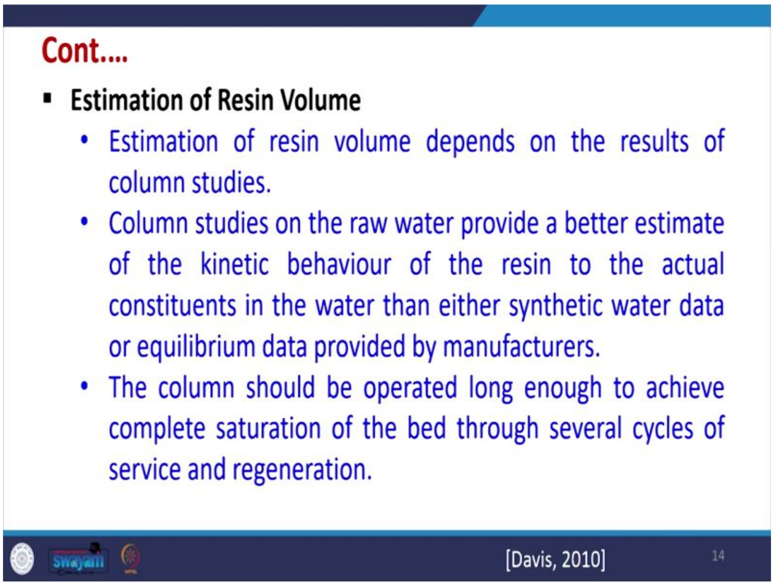

Now, how much resin volume we have to use in the bed that will has to be determined if you have to properly design a system. So, estimation of resin volume that will depend upon the results of column studies that we perform at a lab scale. So, that has to be done the column studies on raw water actually, if we have the raw water available, we can, that will provide a better estimate of the kinetic behavior of the resin to the actual constituents in the water that may be present.

So, then if you perform in synthetic water, the capacity will be different, the parameters will be coming out different, but if you actually perform the operation with actual water that has to be treated, then we will get the actual data and that will be a better design data for use of designing the column itself, the column should be operated long enough to achieve the complete saturation of the bed through various cycles of service and regeneration.

So, that also has to be cross check because that will give the idea that after regeneration are we getting the service time is decreasing or not. So, these parameters will be known. So, it will be better to operate the column in more number of cycles as much number of cycles as possible, this will give a better design data further.

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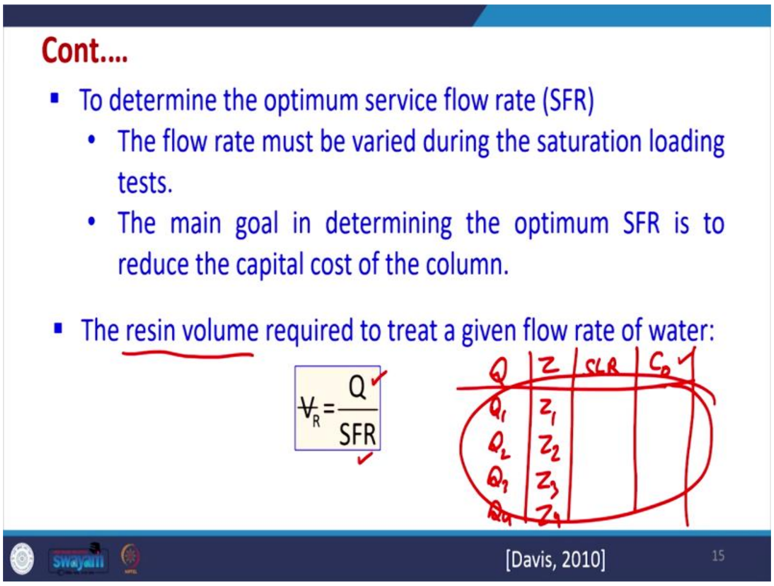

Now, data to determine the optimum service flow rate SFR the flow rate must be varied during the saturation loading tests. So, what we can do is that we can perform the generally we have to perform the test under various flow rates. So, flow rates may be Q1, Q2, Q3, Q4, etc. Similarly, we can vary the length of the bed also. So, this is possible, also the loading also we can keep differently. So, that is also possible to keep that different loading, which is there. So, under different SLRs also we can perform the operation. So, this is also possible for different SLRs we can perform the operation and also we should perform the operations and different concentrations.

So, if because, we may have to use the same resin in the series, so, the concentration variation will be there. So, we can optimize the concentration that goes into the second column. So, through that aspect this study may also be helpful. So, all these parameters may be varied at the different conditions to perform the different experiments and from all these experiments, we can properly design a system.

So, we can find out different responses, which may be there for all these operations and after that we can design the system the flow rate must be varied during the saturation loading test, the main goal is to determine the optimum service flow rate.

So, this is very very important and that may be there with respect to the capacity of the bed also, the resin volume which is required if we have already find out the optimum Q that may be determined by Q divided by SFR. So, optimum service flow rate and the Q is already there. So, this way we can find out the volume of the resin. Now regeneration that has to be performed.

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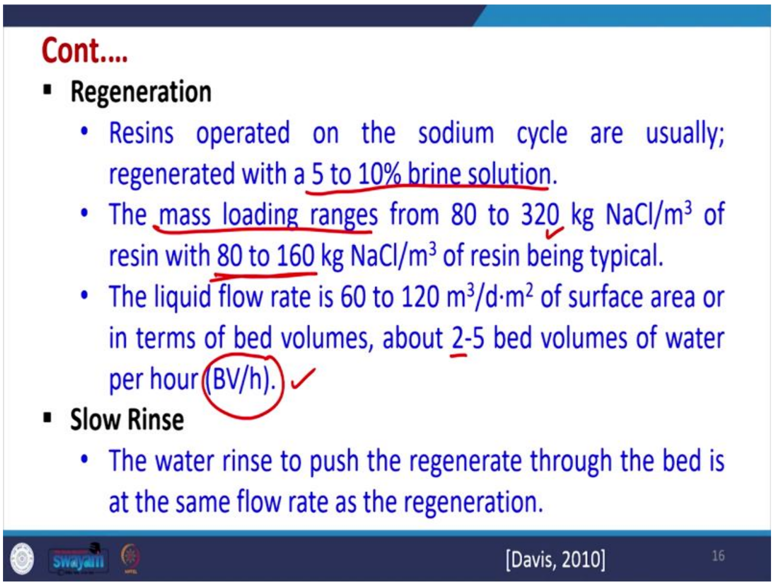

Resin operations on the sodium cycle are usually regenerated with 5 to 10 percent brine solution. So, we can vary this, but this is the brine solution range that has to be used for regenerating the resin if we are exchanging the sodium. The mass loading rates ranges they are from 80 to 332 kg NaCl per meter cube of resin with 80 to 160 kg NaCl per meter cube of resin more commonly being used.

So, we generally prefer between 80 to 160 but we can go up to 320 also. The liquid flow rates are like 60 to 120 meter cube per day per meter square of surface area or in terms of bed volume suppose we have to calculate, so, we can calculate 2 to 5 bed volumes of water per hour. So, this is a one of another unit that we can determine.

So, through this we have 3 parameters, we keep the mass loading rate in certain range, we keep, we can use the brine solution under different concentrations, and we can keep the regenerating chemical flow rate in these range. So, all these three parameters will be known. So, and through that we can perform the regeneration. Now, there is a step of slow rinsing and fast rinsing. So, for slow rinsing, the water rinse is pushed through the regenerate through the bed at the same flow rate at the regeneration itself. So, the flow rates are similar to the regeneration step itself.

Now, how much cycle time. So, this is another very important parameter. So, in between what is the cycle time that has to be there.

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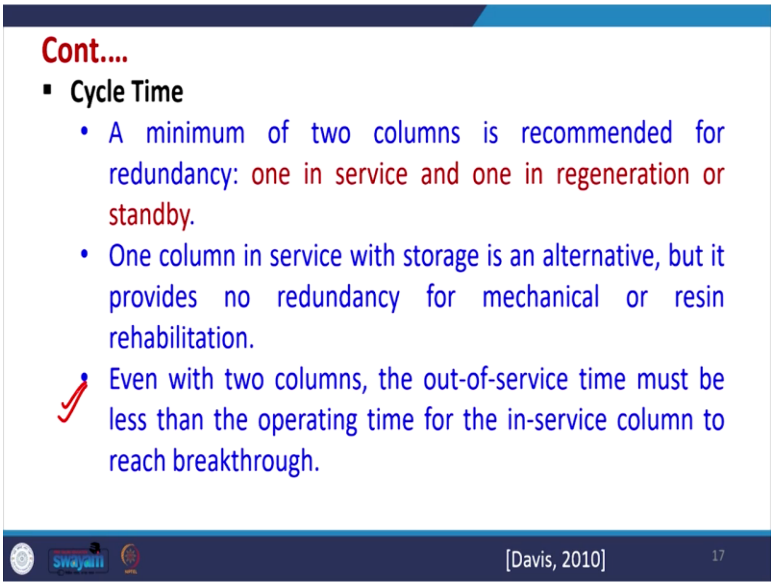

So, minimum of two columns are always recommended for any problem not to occur. So, always one column will be in service another will be in regeneration or in standby mode. So, one column in service with storage is another alternative which is possible, but it provides no redundancy for mechanical or resin rehabilitation.

Even with two columns, the out of service column must be less than the operating time for in service column to reach the breakthrough. So, this is very very important. So, in design that the in service column should work for longer duration as compared to out of service column for regeneration.

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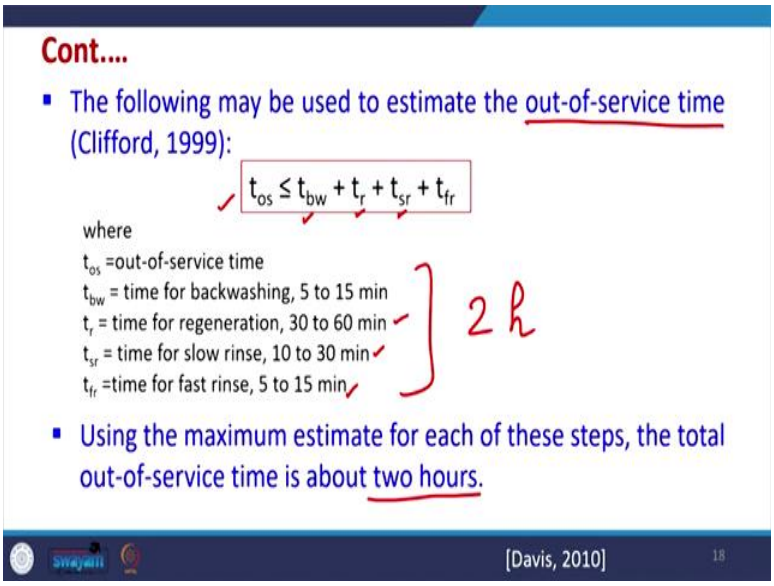

Now, the following equation may be used for finding out the out of service time. So, this is possible, so, and this total operating time out of the service time will be given like this. So, this the out of service time will be equal to time of backwashing. So, this is already we are told that it is it may be from 5 to 15 minutes or otherwise. So, the backwashing time will be there, after that, we have to perform the regeneration. So, the regeneration time will be 30 to 60 minutes.

So, this is possible. So, after regeneration what we do is that slow rinsing, the slow rinsing will be slower as compared to faster rinsing. So, again it will take 10 to 30 minutes for slow rinsing and then time for fast rinsing. So, again up to 15 minutes we will be having. So, in total if you take all the maximum values, so, 15 plus 15, 30, 30 plus 30, 60. So, we may have up to 2 hours of operation under which the column may be out of service.

Now, this 2 hours may or so, vary depending upon the size of the column that have to be, that has to be used and that will depend upon the volume of water that has to be treated. So, using the maximum estimate for each step we find that 2 hour is the maximum out of service time, but it may increase beyond that also.

So, this is the out of service time. So, through these lectures today, we learned in this lecture, a number of things and those things are like what are the mode of operations of the column then, multiple columns are used. So, they may be used in series, they may be used in parallel. So, and we have always to take care that the regeneration time, because 1 column has to be regenerated after some time.

So, that regeneration time should always be lower than the service time which is possible with 1 column. After these different modes of operation of multiple columns, we try to learn what are the different practical parameters that have to be used in the design of the column in the actual case.

So, we have to find out the capacity which has been reported by the supplier with respect to exchange resin. After the capacity is known we have to cross check that under actual condition when the raw water is being treated, what is the what are the efficiencies and what are the capacities. And in addition there is another important parameter that what is the reduction in the capacity once that particular exchange resin bed is regenerated a number of time because that will also be there and that drop will happen.

So, we have to design the column with respect to maximum drop in the efficiency which is possible with respect to the that has been reported by the supplier of the resin. So, this is possible. And for that we have to perform a lot of operations in the using the resin in lab scale, so lab scale operations may be also used for determining the breakthrough and from breakthrough we can find out the actual capacity of the beds itself.

In addition, we can perform the lab scale operations under various flow rates with different heights with different loading rates etc. to find out the optimum flow rate and from that we can find out the volume of resin that will be required for treatment etc.

And similarly, we can determine the regeneration time which is maximum possible. So, these different parameters we have studied in today's lecture, I will continue with the ion exchange resin mode. And in the next lecture we will try to understand certain design conditions which are possible and then we will perform some calculations or we will solve some numerical to better understand the ion exchange process. Thank you very much.