Wastewater Treatment and Recycling
Prof. Manoj Kumar Tiwari
School of Water Resources
Indian Institute of Technology, Kharagpur

Lecture – 45
Tertiary Treatment: Adsorption and Ion Exchange

Hello everyone and welcome to this lecture 45th for the course Wastewater Treatment and Recycling. As this week we have been discussing about the tertiary or advanced treatment options, this particular class will be talking about adsorption and ion exchange methods for the contaminants removal from wastewater at tertiary stage. Earlier we discussed the nutrient removal. So, in the adsorption and ion exchange system they both essentially kind of try to trap the dissolved impurities in the aqueous phase, from the aqueous phase on to a surface, onto a solid surface in adsorption and through an ionic interaction they kind of swap the ions in an ion exchange system.

So, we will be talking about these two processes, which are used as a tertiary scale treatment for many of the industrial applications very rare in the municipal sewage treatment plant because, the there are three treatment is usually not provided and even if, it is provided process like adsorption and ion exchange are not that frequently used, only nutrient removal and some chemical precipitation methods can be used. But in industries these process are pretty common now. Particularly the adsorption process and ion exchange if one want to go for reuse or those kind of system, so it is a method for demineralization as well ion exchange, so for people go for ion exchange before for treating waters.

Not only wastewater, in fact the raw water sources like say, ground water if it is having high TDS or those kind of thing. So, it is treated with the ion exchange system for the removal of dissolved ions so, that the water can subsequently be used for the industrial applications or industrial purpose like, in boiler or those kind of places. These are ion exchangers particularly used for softening the water, so removal of the hardness which is essentially due to the ions of calcium and magnesium. So, the ion exchanger like, zeolite or those kind of thing can be used for water softening as well. We will discuss these in the prospect of tertiary treatment of the wastewater.

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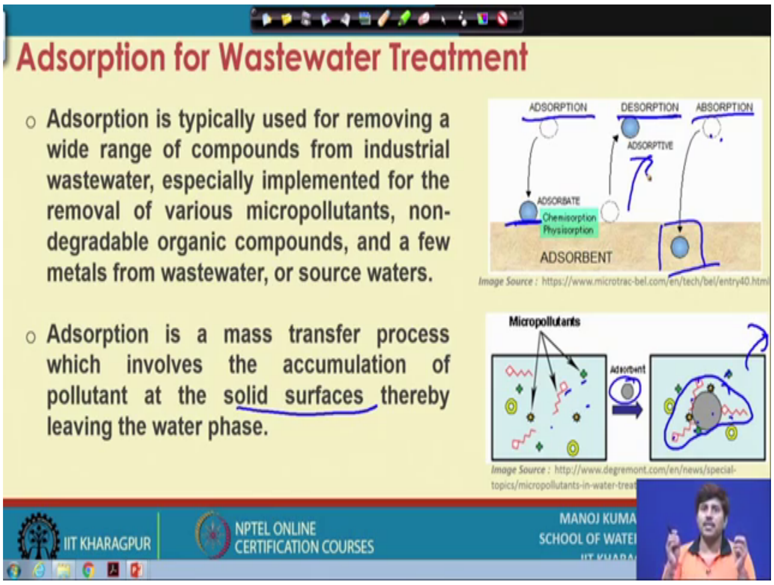

Adsorption for Wastewater Treatment

- Adsorption is typically used for removing a wide range of compounds from industrial wastewater, especially implemented for the removal of various micropollutants, non-degradable organic compounds, and a few metals from wastewater, or source waters.
- Adsorption is a mass transfer process which involves the accumulation of pollutant at the solid surfaces thereby leaving the water phase.

Image Source : https://www.microtrac-bel.com/en/tech/bel/entry40.html

Image Source : http://www.degremont.com/en/news/special-topics/micropollutants-in-water-treat

So, to begin with the absorption in the wastewater treatment is typically used for removing the wide range of compounds from industrial wastewater. Specially the kind of various micro pollutants, non degradable organic compounds, which we also called refractory organic compounds and few metal from wastewater or source water; if it is not wastewater as he said that, it can be used for water treatment as well, so, it is used for those purposes as well.

It is simply a mass transfer approach, where the particles get accumulate on to a solid surface and thereby leave the water phase so, that is essentially what happens. So, we have various micro pollutants now, when we add an adsorbent to this water what happens that, the various these particles come and interact onto the surface of these adsorbents and when we kind of make that water pass through. So, these items retain on the surface of adsorbent and the concentration of these contaminants in water reduces in the water, which passes through the adsorbent media.

So, adsorption actually is word, where there is retention takes place on the surface we have a similar word absorption where, the particle in the water phase can actually come within the body of the adsorbent. So, then, we call it absorption and if something which is adsorbed, gets back into the water phase, we call that process as desorption. So, there is adsorption means the particle coming on and attaching to the surface of the adsorbent is adsorption, when it is entering into the body of the media it is called absorption and desorption is the reverse of adsorption, so something which has attached to a solid surface gets back into the water phase.

So, adsorption is more so of a basically term, which is not only used for water treatment, it is a in general chemistry or chemical engineering it is a far more common it is used for the kind of trap meant of the gases onto the solid surface or many times at the solid liquid or gas liquid interfaces also. So, it is just a particle moving from a fluid or one phase to another phase is what will be referred as that in general terms.

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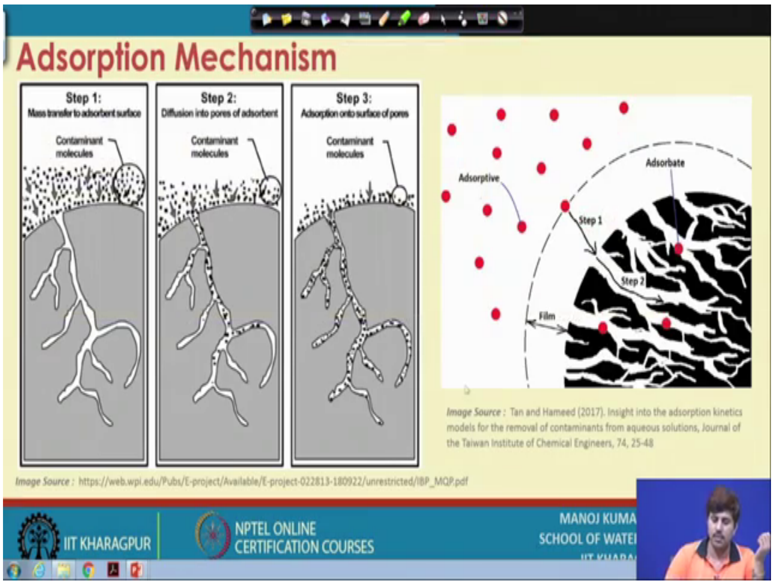

Adsorption Mechanism

Image Source : Tan and Hameed (2017). Insight into the adsorption kinetics models for the removal of contaminants from aqueous solutions, Journal of the Taiwan Institute of Chemical Engineers, 74, 25-48

Image Source : https://web.wpi.edu/Pubs/E-project/Available/E-project-022813-180922/unrestricted/IBP_MQP.pdf

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So, if we see the mechanism of adsorption, how it happens that there is let us say contaminant molecules are there, they come interact on. So, first step is a mass transfer to the adsorbent surface then, it diffuse into the pore of absorbance particularly for a porous material. And then, it gets adsorbed onto the surface of these pores various pores. So, these are the subsequent steps through which, the contaminant concentration in the aqueous phase decreases a lot, as the contaminant has contained within the adsorbent media.

So, if there is a kind of say surface film, so these are your elements they come into the surface then, they step one they move onto the layer, they diffuse actually to the surface of the exact adsorbent then, is step two they kind of diffuse into the adsorbent, penetrate into the adsorbent and then, in step three they get adsorb onto these surfaces. So, that is essentially what happens in the process of adsorption.

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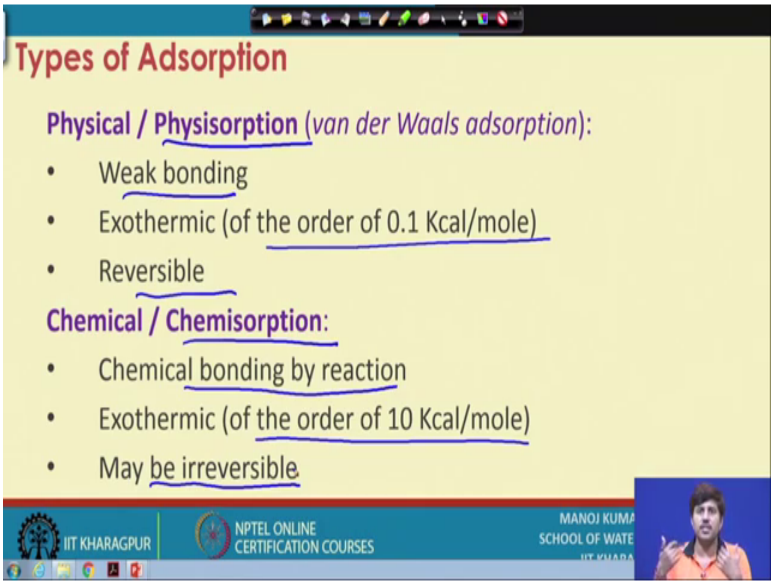

Types of Adsorption

Physical / Physisorption (*van der Waals adsorption*):

- Weak bonding
- Exothermic (of the order of 0.1 Kcal/mole)
- Reversible

Chemical / Chemisorption:

- Chemical bonding by reaction
- Exothermic (of the order of 10 Kcal/mole)
- May be irreversible

Typically adsorption is governed by may be governed by two different kind of forces. There is physical adsorption, which is primarily due to the Van der Waal forces and that is why, we can call it Van der Waal adsorption as well or commonly known as physisorption. So, that is one type of adsorption, physisorption then, there is a chemisorption or chemical adsorption where chemical bonding takes place between the adsorbent and adsorbate.

The usual adsorption processes are always exothermic mostly because, it says spontaneous it says usually adsorption is a spontaneous process, so the gibbs free energy is negative, change in the gibbs free energy is negative and the process is spontaneous. Usually it is exothermic processes, the Van der Waal forces are weaker, so, the bonding is beak weak here whereas; chemical forces are stronger. So, in majority of the cases chemisorption is far more stronger as opposed to the physisorption. They release heat of the order of 0.1 calorie per mole and while they release the heat at the of the order of 10 kilo calorie per moles both are exothermic.

Since Van der Waal forces are physical forces and if the kinetic energy of the particle increases, it will again leave back the surface, so they are reversible whereas; chemical adsorption may or may not be reversible, but depends on the nature of the reaction that has taken place. So, chemical adsorption often it is irreversible, but could be reversible as well if the nature of the forces are such that, it can be reversed.

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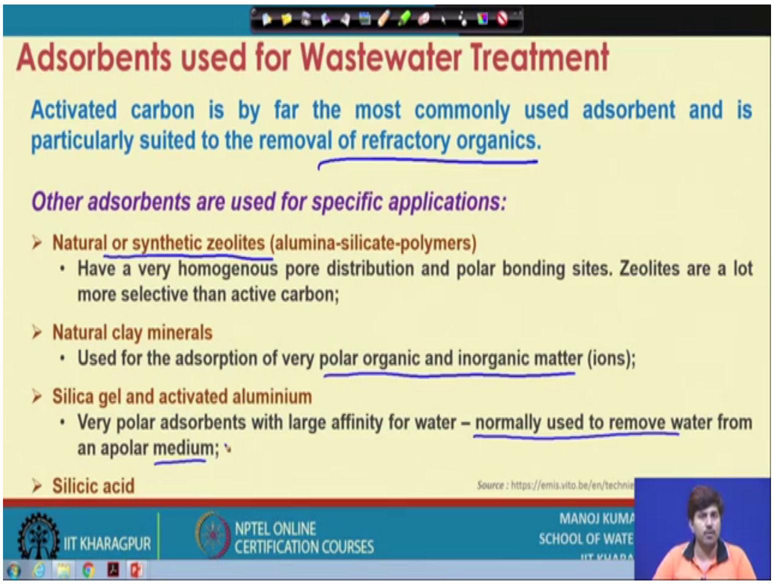

Adsorbents used for Wastewater Treatment

Activated carbon is by far the most commonly used adsorbent and is particularly suited to the removal of refractory organics.

Other adsorbents are used for specific applications:

- Natural or synthetic zeolites (alumina-silicate-polymers)
  - Have a very homogenous pore distribution and polar bonding sites. Zeolites are a lot more selective than active carbon;
- Natural clay minerals
  - Used for the adsorption of very polar organic and inorganic matter (ions);
- Silica gel and activated aluminium
  - Very polar adsorbents with large affinity for water – normally used to remove water from an apolar medium;
- Silicic acid

Source : https://emis.vito.be/en/technie

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So, for the wastewater treatment if we say the activated carbon is by far the most popular adsorbent, which is most commonly used in the wastewater treatment for the removal of, particularly for the removal of refractory organics or non biodegradable or non degradable organics. There has been other adsorbents which has also been used under specific conditions, so natural or synthetic zeolites which can be used for softening or those kind of thing, that can be used. Natural clay minerals are used for very polar organic and inorganic metals or ions adsorption.

Silica gel is used activated alumina is used for the adsorption of various elements like, arsenic or those kind of thing are adsorbed onto the activated alumina. Silicic acid can also be used so, we can use variety of materials at the adsorbent, whichever has a capacity to basically adsorb the target contaminant can be used.

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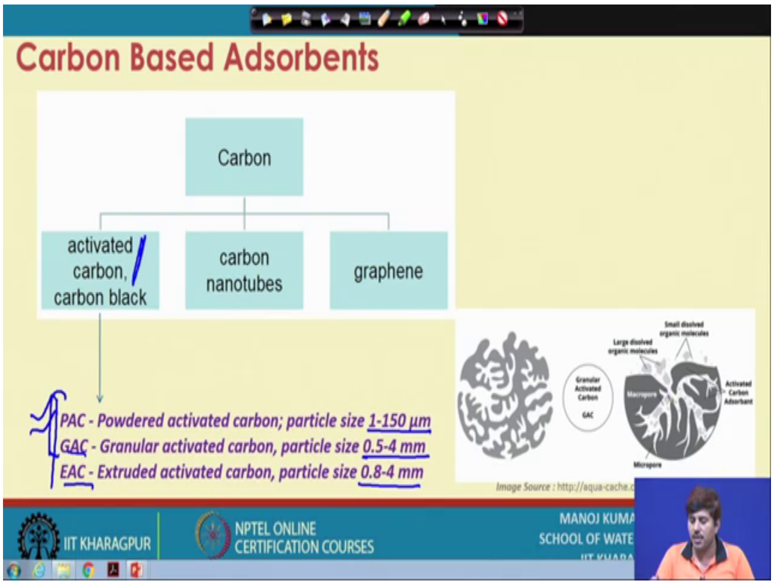

Carbon Based Adsorbents

Carbon

- activated carbon, carbon black
- carbon nanotubes
- graphene

PAC - Powdered activated carbon; particle size 1-150 µm
GAC - Granular activated carbon, particle size 0.5-4 mm
EAC - Extruded activated carbon, particle size 0.8-4 mm

Image Source : http://aqua-cache.c

However it is the activated alumina, which has by far the most uses because of its retention spectrum, because of its ability to attract more, because of its nature or pore spaces are effectively surface area. So, adsorption is a process, where they are contaminant removal is taking place on the surface. So, more the surface area or more the active surface area rather you will have high chances of contaminant getting removed. So, their carbon based adsorptions adsorbents if we see, there are activated carbon or carbon black, carbon nanotube, there are graphenes, and the activated carbon which is more popular, actually we have various different grades and types of activated carbon there is PAC, which is powdered activated carbon of the particle size 1 to 150 micro meter it is granular activated carbon.

So, that is in a granular shape, so little larger than then 0.5to 4 millimeter. And there is kind of extruded activated carbon as well, which has a little higher could have kind of 0.8 to 4 millimeter size. So, activated the powdered activated carbon and granular activated carbon are the one, which are more commonly or more frequently used. And these will have basically very fine pore so that way a lot of surface area there are lot many micro pores through which, the particle can diffusion in an get adsorbed.

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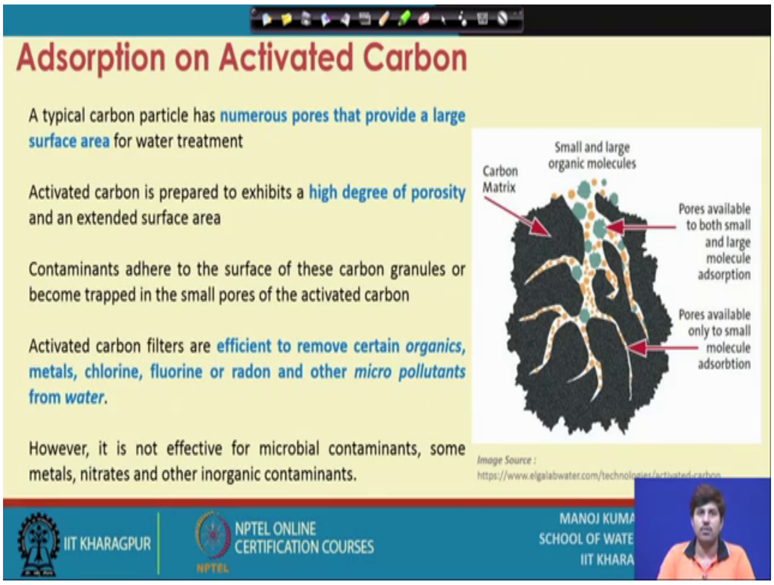

Adsorption on Activated Carbon

A typical carbon particle has numerous pores that provide a large surface area for water treatment

Activated carbon is prepared to exhibits a high degree of porosity and an extended surface area

Contaminants adhere to the surface of these carbon granules or become trapped in the small pores of the activated carbon

Activated carbon filters are efficient to remove certain *organics*, metals, chlorine, fluorine or radon and other *micro pollutants* from *water*.

However, it is not effective for microbial contaminants, some metals, nitrates and other inorganic contaminants.

Image Source : https://www.elgalabwater.com/technologies/activated-carbon

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So, if we see the kind of activated carbon, so the typical activated carbon will have numerous pores and that that is why provide a very large surface area for the treatment of water. These are prepared to exhibit kind of very high degree of porosity, so, there is a lot of scope for retaining the contaminants because, if there are not pore, so where the contaminant will retain, where they will get adsorbed. So, that is why, having a high porosity is a good thing and it then allows good flow through the water, good flow through this adsorbent media as well for the water.

So, contaminant typically adhere to these carbon granules, or become trapped in the small pores within, the activated carbon and these are efficient to remove various organic metals chlorine, fluorine, radon and various other micro pollutants that way. But it is basically, the microbial contaminants, some of the metals, nitrates and inorganic contaminants are not that nicely removed through this adsorption process.

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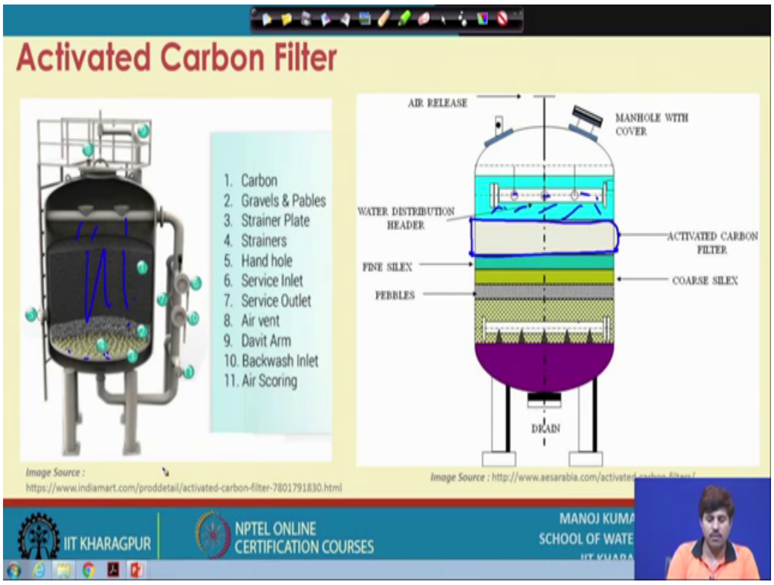

Activated Carbon Filter

1. Carbon
2. Gravels & Pables
3. Strainer Plate
4. Strainers
5. Hand hole
6. Service Inlet
7. Service Outlet
8. Air vent
9. Davit Arm
10. Backwash Inlet
11. Air Scoring

Image Source : https://www.indiamart.com/proddetail/activated-carbon-filter-7801791830.html

Image Source : http://www.aesarabia.com/activated

So, if we see the typical activated carbon filters, so we have kind of a filter will look like this. We will basically it is we have to make the water interact with the activated carbon, so we will have a layer of activated carbon for that matter. And then, we can have all those support layers various way. The water will come from the top, will be distributed from these headers, it will pass through these layers and then, will be collected the bottom and then, will drain from there.

So, typical commercial unit will look like something this, so, we have this is your carbon layer, then there are kind of granules, gravels, pebbles those kind of thing, there is just strainer plate, there are strainers then on the strainer plates there are various hand hole. So, and then there is inlet and outlet arrangement.

So, it is initially water is passed through these layers then, it is through strainers it is collected and then can be kind of taken out from the treated water and then, be taken out that way.

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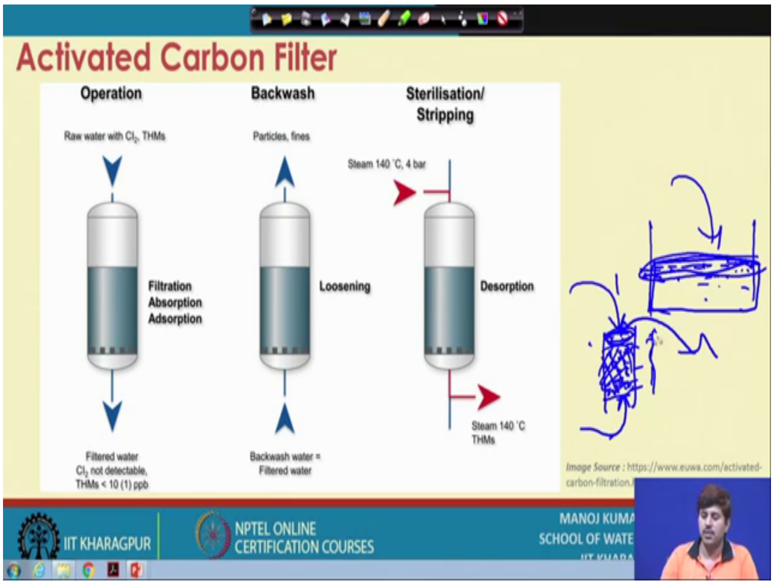

Activated Carbon Filter

Image Source : https://www.euwa.com/activated-carbon-filtration.

The filter typical activated carbon filter under operation will have flow from this way. The under backwash will usually have a reverse flow though, the back washing can also be done with this similar flow direction as well and if you want to sterilize or kind of stripping. So we can pass through a stream in order to sterilize or removing the microbial growth or microbial contamination if, it has occurred in this layer of in this kind of column or adsorbent, so that also can be done. Back wash is a process because, so as we were discussing the kind of adsorption process is the contaminant gets adsorb onto the surface.

Now, if you are keep on passing the contaminant and it is getting adsorb onto the surface, so there will be a time when kind of the capacity of the adsorbent to adsorb these contaminants will exhaust. And thereafter, if you pass the if you pass the water through this there will not be any adsorption. So, in that case either there is two option, either you change this media adsorption media, put a new one new adsorption media or the other option is you regenerate this adsorption media. So, how do we regenerate these kind of like the sites on which, the contaminants are trapped. So, we make them the contaminant again get released back into the these into some solvent, which we use for regenerate.

So, let us say like for back washing purpose, back washing is done for that or regeneration is done for that. So, we have a column where, let us say this is our adsorption media where it is packed. So, normally we are having flow like this, when your contaminants impurities get in trap in this and then, the let us say head loss decreases or the efficiency of effluent water is not turning good because, that indicates that the capacity of this has exhausted.

So, in order to regenerate it, what is done that we can pass a kind of acid solution or those kind of things in which, these contaminants have higher affinity for those solvents. So, if we pass those solvents over here, then it makes the kind of it loosens those particles, which are attached to the adsorbents. And then, it makes this system fluffy. And from here onwards, if you keep on passing, so those contaminants will come back into the again solvent phase and will, can be taken out and the adsorbent layer original adsorbent layer is up for reuse purpose again. So, that is what is back washing or regenerating the adsorbent and we can do the cleaning through a stripping or a sterilization depending on the requirements.

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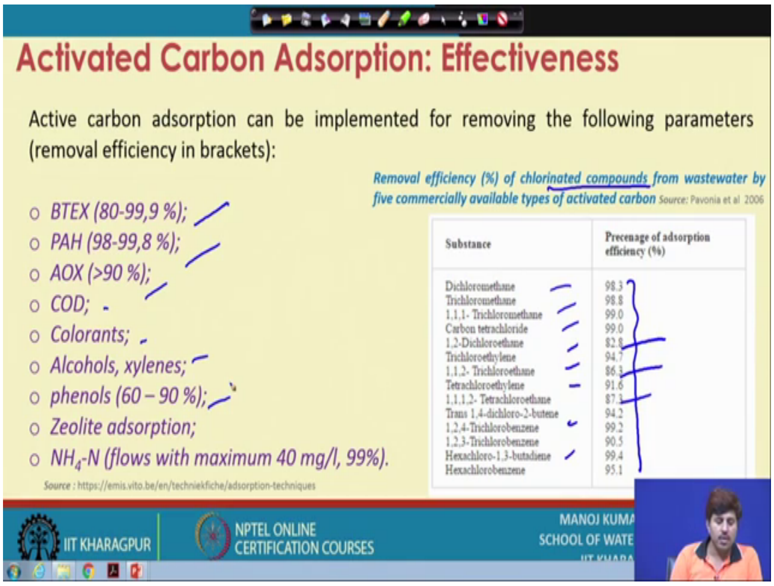

Activated Carbon Adsorption: Effectiveness

Active carbon adsorption can be implemented for removing the following parameters (removal efficiency in brackets):

- BTEX (80-99,9 %);
- PAH (98-99,8 %);
- AOX (>90 %);
- COD;
- Colorants;
- Alcohols, xylenes;
- phenols (60 – 90 %);
- Zeolite adsorption;
- NH_4-N (flows with maximum 40 mg/l, 99%).

Source : https://emis.vito.be/en/techniekfiche/adsorption-techniques

Removal efficiency (%) of chlorinated compounds from wastewater by five commercially available types of activated carbon Source: Pavonia et al 2006

Substance	Precenage of adsorption efficiency (%)
Dichloromethane	98.3
Trichloromethane	98.8
1,1,1- Trichloromethane	99.0
Carbon tetrachloride	99.0
1,2-Dichloroethane	82.8
Trichloroethylene	94.7
1,1,2- Trichloroethane	86.3
Tetrachloroethylene	91.6
1,1,1,2- Tetrachloroethane	87.3
Trans 1,4-dichloro-2-butene	94.2
1,2,4-Trichlorobenzene	99.2
1,2,3-Trichlorobenzene	90.5
Hexachloro-1,3-butadiene	99.4
Hexachlorobenzene	95.1

So, if we see the effectiveness of the activated carbon adsorption, so there has been lot of research conducted with the removal or various parameters various contaminants on the activated carbon adsorption. So, there are variety of reports that way it is not possible to compile all like for various or chlorinated compound, it is a very good, activated carbon is a very good adsorbent for chlorinated compound.

So, for variety of these chlorinated compounds, you see that efficiencies are usually greater than say 98, 99 bearing a very few. So, let us say for this it is 86, 83, 87 those kind of thing, but usually you see very high efficiency of the removal of these contaminants. For BTEX, which is benzene toluene xylene kind of compounds, so efficiency is reported from 80 to 99.9 percent, for poly aromatic hydrocarbon 98 to 99.8 percent, for AOX greater than 90 percent, it can remove cod, colorant alcohols, xylenes phenols can be reduced from 60 to 90 percent. Ammonium nitrogen with maximum flow, 40 milligram per liter can actually remove up to 99 percent. So, that way like the adsorbent is very effective in removal of a wide variety of contaminants.

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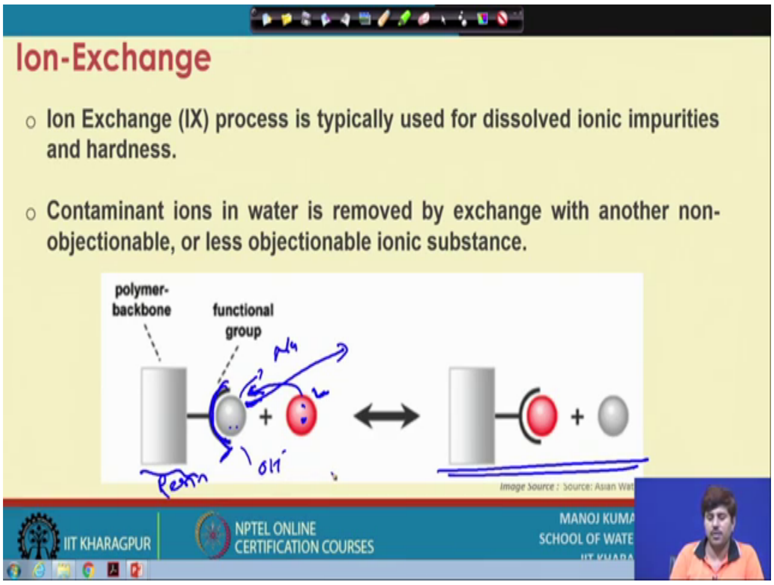

Ion-Exchange

- Ion Exchange (IX) process is typically used for dissolved ionic impurities and hardness.
- Contaminant ions in water is removed by exchange with another non-objectionable, or less objectionable ionic substance.

However the dissolved, various dissolved metals or those kind of things it has very limited applicability So, since, it the activated carbon or those kind of thing can remove variety of organics or various a polar or non polar or a few polar like depending on the choice of adsorbent quite a few polar molecule polar compounds can also be removed.

It is the metals or dissolved ions, which are not removed usually not removed from the adsorption so, they can be removed through a ion exchange system. Now ion exchange is the process, which is typically used for these dissolved ionic impurities and particularly hardness because, hardness also is caused by these dissolved organic impurities, dissolved calcium and magnesium ions. So, the contaminant ions in water, is removed by exchange with another ion which should be non objectionable or not non toxic kind of thing.

So, it is kind of swapping takes place, so what eventually happens in an ion exchange system, we have a polymer backbone through which, a functional group is there and this the original resin comes with some ion attached with this, which is not that toxic. So, let us say for say you are having sodium attached here, or you are having oh ion attached here and the red thing is your contaminant, which you are willing to remove. So, it could be any those sort of things. Let us say it is arsenic, it is chromium or those kind of thing or some organic contaminant that, some organic ion that way.

So, this is the thing that you want to remove, now what will happen that when it gets in contact with this resin, which we typically call it resin, ion exchange resin. So, as soon as it gets the water gets in the contact with the resin, this functional group has a higher affinity for this ion rather than this ion. So, what it will do, it will attach with this ion and in the process, it will release this ion back into the water. But this ion is a non contaminated ion or not contaminating ion.

So, we do not have too much of problem with getting this and released in the water to a like until unless it is an excessively high concentration like, sodium few milligram per liters of sodium or few microgram per liters of sodium, it is definitely not a problem, but even few microgram per liters of chromium or arsenic is may create severe health issues. So, that way these ions are released and this is get trapped. So, after the interaction you will see a condition turns like this from here to here. So, this is what is essentially the ion exchange process.

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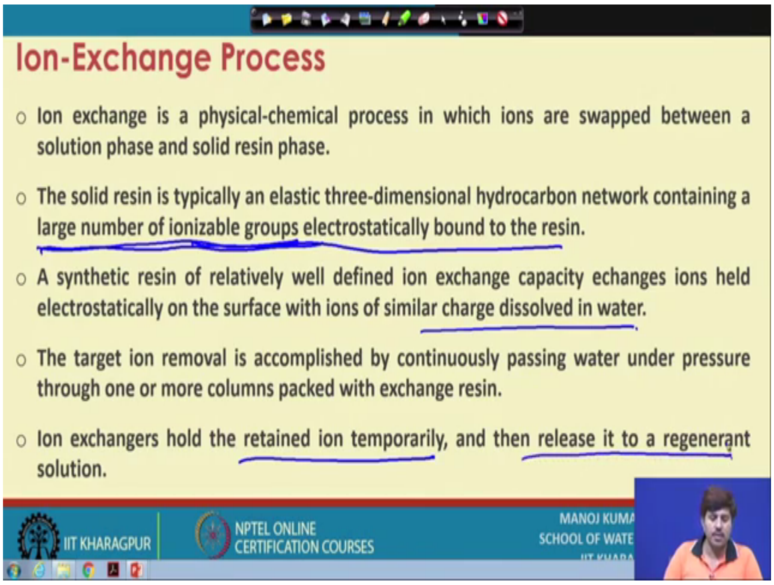

Ion-Exchange Process

- Ion exchange is a physical-chemical process in which ions are swapped between a solution phase and solid resin phase.
- The solid resin is typically an elastic three-dimensional hydrocarbon network containing a large number of ionizable groups electrostatically bound to the resin.
- A synthetic resin of relatively well defined ion exchange capacity echanges ions held electrostatically on the surface with ions of similar charge dissolved in water.
- The target ion removal is accomplished by continuously passing water under pressure through one or more columns packed with exchange resin.
- Ion exchangers hold the retained ion temporarily, and then release it to a regenerant solution.

Now, these are physicochemical process, physical chemical interaction in which, ions are swapped between a solution phase and a solid resin phase. The solid resin phase is typically a elastic 3 dimensional hydrocarbon network, which contains large number of these ionizable groups of electrostatically bound to the resin. So, these are this is important that, it should have these large number of groups because, that is what will guide about the capacity of the exchanger.

So, a synthetic resin is relatively well defined with known ion exchange capacity and then, it exchanges ions, which it helps electro statically on the surface with the ions of similar charge in the dissolved water. So, since it is exchanging, it will lead whatever it is attached to that will go to the water whatsoever contaminated ion present in the water of the similar charge will come to the resin. So, the target ion is that we removed and kind of like this ion is retained temporarily with the resin and then, once we try to regenerate the resin we will talk about how to regenerate that. So, once we try to regenerate that resin, it comes back into the solution regenerant solution that way and that way, it is removed from the water phase.

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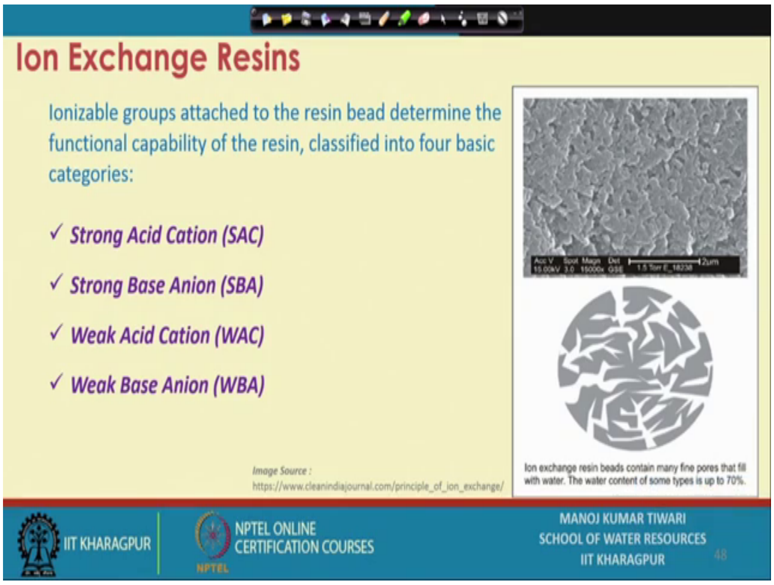

Ion Exchange Resins

Ionizable groups attached to the resin bead determine the functional capability of the resin, classified into four basic categories:

- ✓ *Strong Acid Cation (SAC)*
- ✓ *Strong Base Anion (SBA)*
- ✓ *Weak Acid Cation (WAC)*
- ✓ *Weak Base Anion (WBA)*

Image Source : https://www.cleanindiajournal.com/principle_of_ion_exchange/

Ion exchange resin beads contain many fine pores that fill with water. The water content of some types is up to 70%.

So, if we see the various ion exchange resins, there are strong acid cations, strong base cations, weak acid cations and weak base cations. So, these are the different groups for the ion exchange resin.

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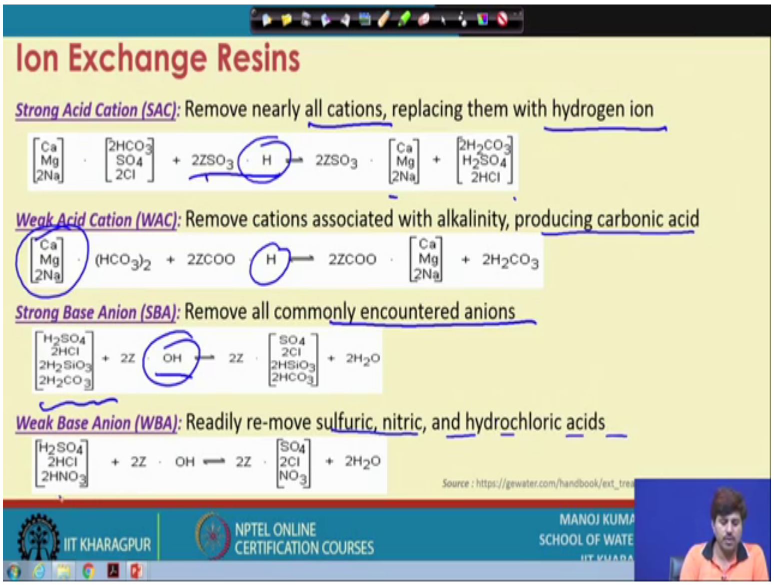

Ion Exchange Resins

Strong Acid Cation (SAC): Remove nearly all cations, replacing them with hydrogen ion

$$\begin{bmatrix}Ca\\Mg\\2Na\end{bmatrix} \cdot \begin{bmatrix}2HCO_3\\SO_4\\2Cl\end{bmatrix} + 2ZSO_3 \cdot H \rightarrow 2ZSO_3 \cdot \begin{bmatrix}Ca\\Mg\\2Na\end{bmatrix} + \begin{bmatrix}2H_2CO_3\\H_2SO_4\\2HCl\end{bmatrix}$$

Weak Acid Cation (WAC): Remove cations associated with alkalinity, producing carbonic acid

$$\begin{bmatrix}Ca\\Mg\\2Na\end{bmatrix} \cdot (HCO_3)_2 + 2ZCOO \cdot H \rightarrow 2ZCOO \cdot \begin{bmatrix}Ca\\Mg\\2Na\end{bmatrix} + 2H_2CO_3$$

Strong Base Anion (SBA): Remove all commonly encountered anions

$$\begin{bmatrix}H_2SO_4\\2HCl\\2H_2SiO_3\\2H_2CO_3\end{bmatrix} + 2Z \cdot OH \rightarrow 2Z \cdot \begin{bmatrix}SO_4\\2Cl\\2HSiO_3\\2HCO_3\end{bmatrix} + 2H_2O$$

Weak Base Anion (WBA): Readily re-move sulfuric, nitric, and hydrochloric acids

$$\begin{bmatrix}H_2SO_4\\2HCl\\2HNO_3\end{bmatrix} + 2Z \cdot OH \rightarrow 2Z \cdot \begin{bmatrix}SO_4\\2Cl\\NO_3\end{bmatrix} + 2H_2O$$

Source : https://gewater.com/handbook/ext_trea

And they have the different kind of functional attributes. So, if we see the strong acid cations they remove nearly all cations and replace them with a simple hydrogen ion. So, we will have a kind of resin like this, attached maybe, attached with the hydrogen and they can remove all these cations. So, that way your raisin will now be attached with this and this and hydrogen could be released.

We have weak acid cations which kind of associated, with the alkalinity and those carbonic acids those kind of thing which produced alkalinity that way. So, here your ion will be swapped with the alkalinity or those kind of ions, which produce hardness or like temporary hardness kind of thing, which is due to the calcium magnesium or with the carbonate or bicarbonates and it could remove the sodium also as well.

But that is not a primary target though here. The strong base and ions will similarly remove all encountered anions. So, whatsoever anions are coming in the system will usually be replaced with the OH ions and then, weak base anions where is like they will remove sulfuric nitric and those hydrochloric acids kind of thing.

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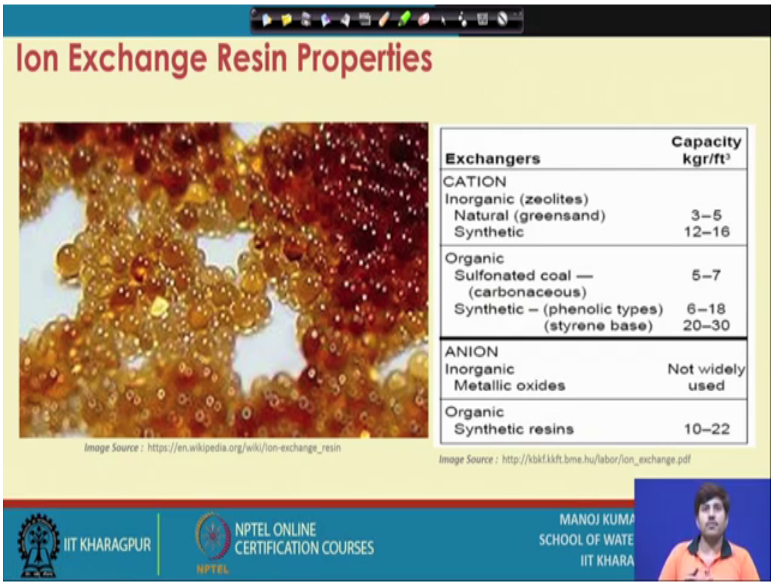

Ion Exchange Resin Properties

Image Source : https://en.wikipedia.org/wiki/Ion-exchange_resin

Exchangers	Capacity kgr/ft³
CATION	
Inorganic (zeolites)	
Natural (greensand)	3–5
Synthetic	12–16
Organic	
Sulfonated coal — (carbonaceous)	5–7
Synthetic – (phenolic types)	6–18
(styrene base)	20–30
ANION	
Inorganic	
Metallic oxides	Not widely used
Organic	
Synthetic resins	10–22

Image Source : http://kbkf.kkft.bme.hu/labor/ion_exchange.pdf

So, that way these different types of resin have their different functional attributes. The resin comes with the specified properties, so like your cation exchangers there are inorganic like, natural zeolite, greensand has a capacity of this much, then there is another synthetic will have capacity of this much, there are organic exchanger there are anion exchanger. So, they will come with a specified capacity and a typical kind of resin, the particularly the granulated resin will look like this, what is there on the screen now. So, that is how the raisins look like.

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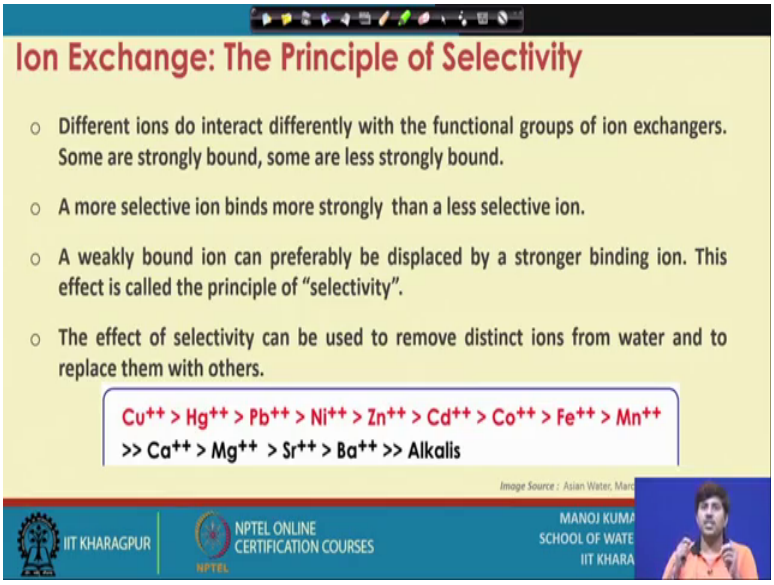

Ion Exchange: The Principle of Selectivity

- Different ions do interact differently with the functional groups of ion exchangers. Some are strongly bound, some are less strongly bound.
- A more selective ion binds more strongly than a less selective ion.
- A weakly bound ion can preferably be displaced by a stronger binding ion. This effect is called the principle of "selectivity".
- The effect of selectivity can be used to remove distinct ions from water and to replace them with others.

$Cu^{++} > Hg^{++} > Pb^{++} > Ni^{++} > Zn^{++} > Cd^{++} > Co^{++} > Fe^{++} > Mn^{++}$
$>> Ca^{++} > Mg^{++} > Sr^{++} > Ba^{++} >>$ Alkalis

Image Source : Asian Water, Marc

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These raisins the ion exchange is a process which works, on a principle of selectivity. So, generally we will not have just one single ion in the water particularly, in the wastewater. So, waste water, it will have a variety of ions and the different ions do have the different potential to interact with the functional group of the ion exchange resins. So, some will be strongly bound, some will be less strongly bound the one which kind of bounds more strongly will be selected beforehand by the resin, by the functional group of the resin.

So, those like more selective ions will bind first and then, it will go to the less selective ions or the ions which bond with the less which have lesser strength for binding with those functional group. So, if resin comes with a weakly bound ion that will be preferably displaced by the stronger ions there even if in the water system, let us say, we have a ion exchange resin which is in the process of removal something it has bind with one contaminant, but if in the water there comes it comes in the vicinity of other contaminants, which can actually bind more strongly, so it will release even that contaminant and bind with the other.

So, it all depends on the like, how is the selectivity. So, this effect of selectivity can be used to kind of remove the distinct ions from the water and to replace them with the other. So, there is a preferential zone like, who binds first with words like typically a copper will bind before, Hg will bind before, led will bind before, nickel will bind before zinc. So, that way we can have a series of selectivity or preferences, who will bind first with the resins present in there.

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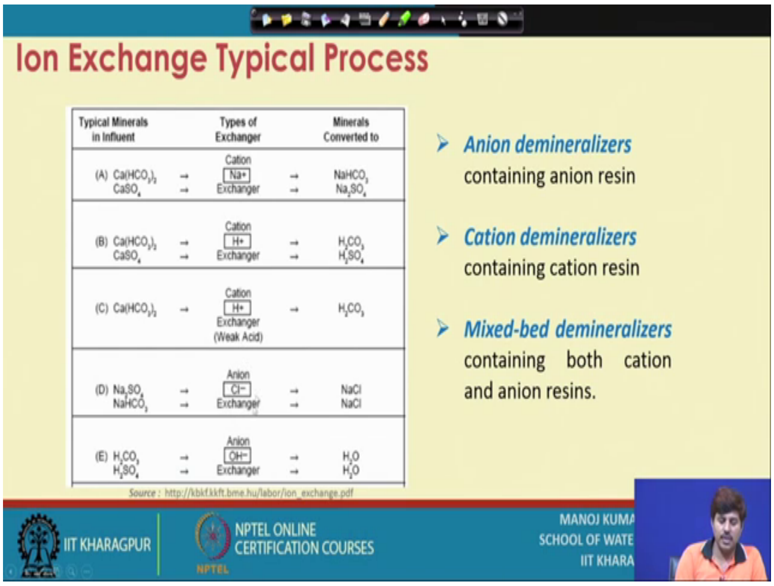

Ion Exchange Typical Process

Typical Minerals in Influent		Types of Exchanger		Minerals Converted to
(A) $Ca(HCO_3)_2$ $CaSO_4$	→ →	Cation $\boxed{Na^+}$ Exchanger	→ →	$NaHCO_3$ Na_2SO_4
(B) $Ca(HCO_3)_2$ $CaSO_4$	→ →	Cation $\boxed{H^+}$ Exchanger	→ →	H_2CO_3 H_2SO_4
(C) $Ca(HCO_3)_2$	→	Cation $\boxed{H^+}$ Exchanger (Weak Acid)	→	H_2CO_3
(D) Na_2SO_4 $NaHCO_3$	→ →	Anion $\boxed{Cl^-}$ Exchanger	→ →	NaCl NaCl
(E) H_2CO_3 H_2SO_4	→ →	Anion $\boxed{OH^-}$ Exchanger	→ →	H_2O H_2O

Source : http://kbkf.kkft.bme.hu/labor/ion_exchange.pdf

- ***Anion demineralizers*** containing anion resin
- ***Cation demineralizers*** containing cation resin
- ***Mixed-bed demineralizers*** containing both cation and anion resins.

The ion exchange typical processes if we see, so there are anionic demineralizers or anionic ion anionic ion exchange resins, cation demineralizers, which contains cation resins and there are mixed by demineralizes, which contains both anion and cation resins. And depending on kind of type of the mineral in the effluent, we can select what kind of exchanger we need. Cation exchanger with sodium cation exchanger, with hydrogen cation exchanger, with hydrogen or anion exchanger, with chlorine anion exchanger, with these things and that way we can basically kind of select and eventually what minerals it converts to.

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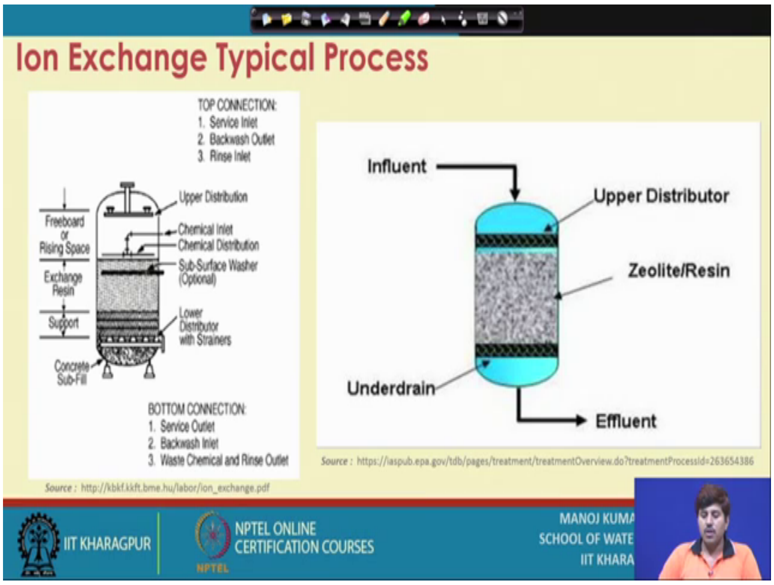

Ion Exchange Typical Process

Source : http://kbkf.kkft.bme.hu/labor/ion_exchange.pdf

Source : https://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?treatmentProcessId=263654386

If we see the typical process of the ion exchanger so, again it is done in a pressurized system. Ion exchange is a pretty fast, so we do not need much residence time. It is a kind of instantaneous process, as the ion it is a chemical bond. So, as ion comes into the like vicinity of pro contaminant with which, it can bind more effectively, the raising will release that ion and bind with other. So, it is just a matter of contact and we do not need a large contact period for that.

So, we can achieve that in a like pressurized conditions with quite rapid flow So, what typically happens that, there will be resin here, the influent will be passed from the up, it will be distributed through the resin and through an underdrain system it will be collected and it will be passed through. So, that is what is the basic process and in and around we can basically, put in all other different mechanisms to deal with that.

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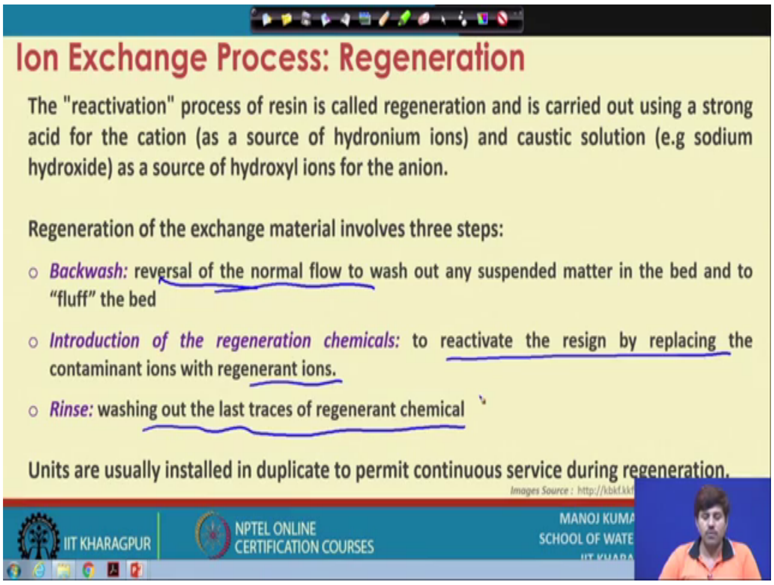

Ion Exchange Process: Regeneration

The "reactivation" process of resin is called regeneration and is carried out using a strong acid for the cation (as a source of hydronium ions) and caustic solution (e.g sodium hydroxide) as a source of hydroxyl ions for the anion.

Regeneration of the exchange material involves three steps:

- *Backwash:* reversal of the normal flow to wash out any suspended matter in the bed and to "fluff" the bed
- *Introduction of the regeneration chemicals:* to reactivate the resign by replacing the contaminant ions with regenerant ions.
- *Rinse:* washing out the last traces of regenerant chemical

Units are usually installed in duplicate to permit continuous service during regeneration.

Images Source : http://kbkf.kk

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The ion exchangers needs to be reactivated or regenerated, the resin needs to be regenerated. And regeneration is essentially the process of activation of the resin again, reactivation of the resin again, which is carried out using a strong acid for the cation, as a source of hydronium ions. And a caustic solution like, sodium hydroxide as a source of hydroxyl ions for the anions.

This regeneration of the exchange material involves like three different steps. So, first thing is, backwashing where kind of the normal flow is reversed. So, reversal of the normal flow to wash out any suspended material, which is there in the bed and make that bed fluff. So, kind of like ease or lose out the bed that way and then, we introduce the regeneration chemical, which like as we said that could be like, for cation resin it could be strong acid or for caustic solution for a kind of, if you want to regenerate it for the anions. So, that way then, what is like this regenerate solution is passed to reactivate the resin by replacing the contaminant ion with the regenerant ion, as we were targeting and then it is rinsed. So, finally, washing out the traces of the regenrant chemical if there is any and then, it is again up for the reuse.

So, units are usually installed in duplicate to permit the continuous service during operation because, otherwise if you have stopped the unit for regeneration during that period, you may see no flow or that kind of thing or if some unit fail, so how to basically deal with that so, that is to be seen.

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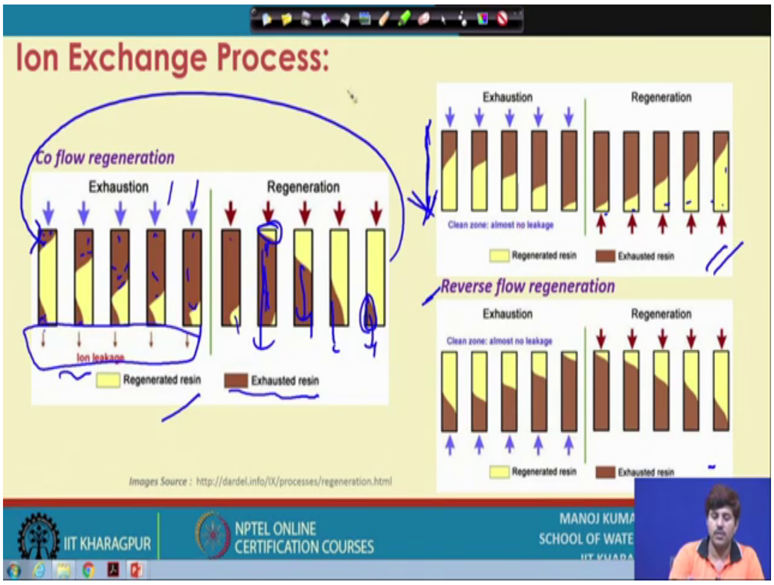

Ion Exchange Process:

Images Source : http://dardel.info/IX/processes/regeneration.html

This process of regeneration and process of normal service run or normal flow can be in the same direction or can be in the reverse direction. So, it is always preferred to have such process in the reverse direction. So, which is called counter current kind of system or reverse flow regeneration in the co flow regeneration what happens that, the this is say direction of my flow. So, these are the exhausted ions which has there in the water. So, initially as it will be getting entrapped from the top and slowly slowly it will cover over there.

But so, almost things are covered. When we try to regenerate this, so what happens that, again it will start losing from the bottom. Like here we are kind of putting the fresh solution here, so initially release of the ions will be from here and it will keep on going down. So, your entire resin that will be covered and by the time, you regenerate you will be having like this. So, you there might be a little this thing left in the bottom that way and when you start again when you basically recycle this back, so what you see trap meant starts from this. But since there are some contaminant or some ions are there present in the bottom.

So, there might be a possibility of ion leakage and that is why, this kind of co flow systems are not that preferred whereas, reverse flow are more preferred where, we are exhausting it from the top and then, we are regenerating it from the bottom. So, there is no chance of accumulating anything in the bottom because regeneration is from this side only. So, there is no kind of possibility of ion leakage. It can be in the other direction, if you have having a up flow kind of systems we are flowing from the top, but then we have to regenerate from the bottom. So, either way it is good, this is more energy preferable because then, water flows in the downward direction, so the gravity can also be utilized, up flow will always have more energy exhaustive systems. So, that way this regeneration the reverse flow regeneration is preferred as oppose to the co flow regeneration.

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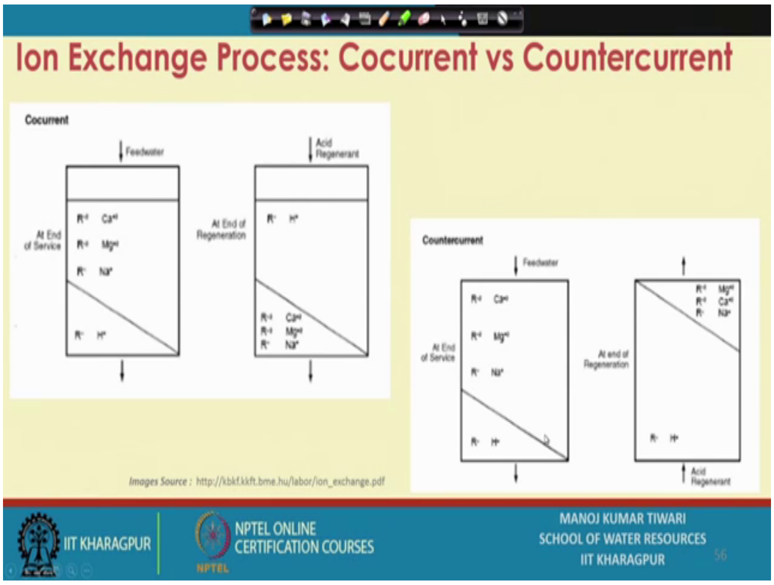

Ion Exchange Process: Cocurrent vs Countercurrent

Images Source : http://kbkf.kkft.bme.hu/labor/ion_exchange.pdf

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And these are that we called co current and counter current kind of system So, co current system, when you are having feed water and regenerant in the same direction, in the counter current system when we are having feed water from one direction and acid regenerant in the other direction.

So, that way we can kind of set up and as we were just discussing that counter current systems are preferred over co current systems.

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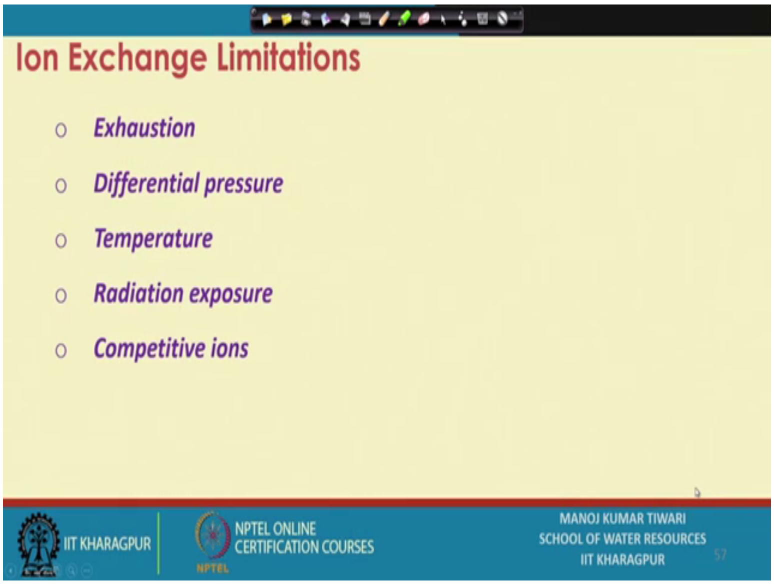

Ion Exchange Limitations

- Exhaustion
- Differential pressure
- Temperature
- Radiation exposure
- Competitive ions

So, there are a few limitations of the ion exchange systems, there are few with the your adsorption system as well. So, the capacity of the ion exchanger can get exhaust and then, we or similarly for the adsorbent can get exhaust and then, we have to kind of regenerate them.

Now, this regeneration can takes place to several cycles, but like it cannot work for infinite time period. So, after several cycles of regeneration, after kind of each cycle of regeneration, the capacity of the ion exchanger or capacity of the adsorbent decreases a little and when the capacity goes below threshold, we have to discard that. So, that is one issue then, ion exchangers particularly working at differential pressures, under pressurized systems. The adsorption processes can also be under pressurized system or can actually be under gravity flow system as well.

Then there is issues of temperature, so if the temperature are high these process will not be suitable because, they will have higher solubility, higher kinetic energy into the system and this binding and attaching to the functional group or for that matter adsorbent as adsorption as well. So, if your molecules have higher kinetic energy, so they will not get easily adsorb onto the surface.

So, it is better than at lower temperature and the higher temperature are not good for ion exchange or adsorption processes. Then there is a possibility of radiation exposure, if we are dealing with those kind of thing and the one of the major problem is in the form of competitive ions because, as we said that water matrix may have variety of ions and it is not always like the if, you are targeting with some contaminant ion and what if the adsorption is preferrings adsorption or for that matter ion exchange is preferring, some other ion which is non target ion.

So, if, those kind of ions are present with non target ions which are having higher affinity, so that becomes a problem. They compete with the target ion and then removal of the target ion or removal of the target contaminants will decrease that way. So, these are the systems which are typically used as a tertiary treatment for industrial wastewater, as we discussed in the beginning of this class.

So, we will conclude the discussions here for this class and in the next class, we will talk about the another type of tertiary treatment or advanced treatment systems, will discuss membrane processes and how they are used for the removal of various contaminants from the wastewater.

Thank you.