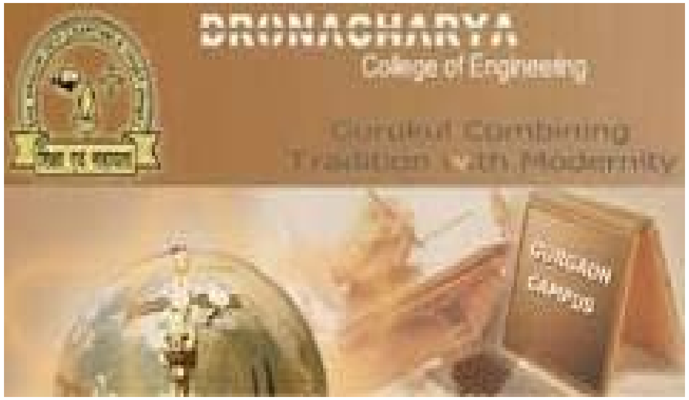


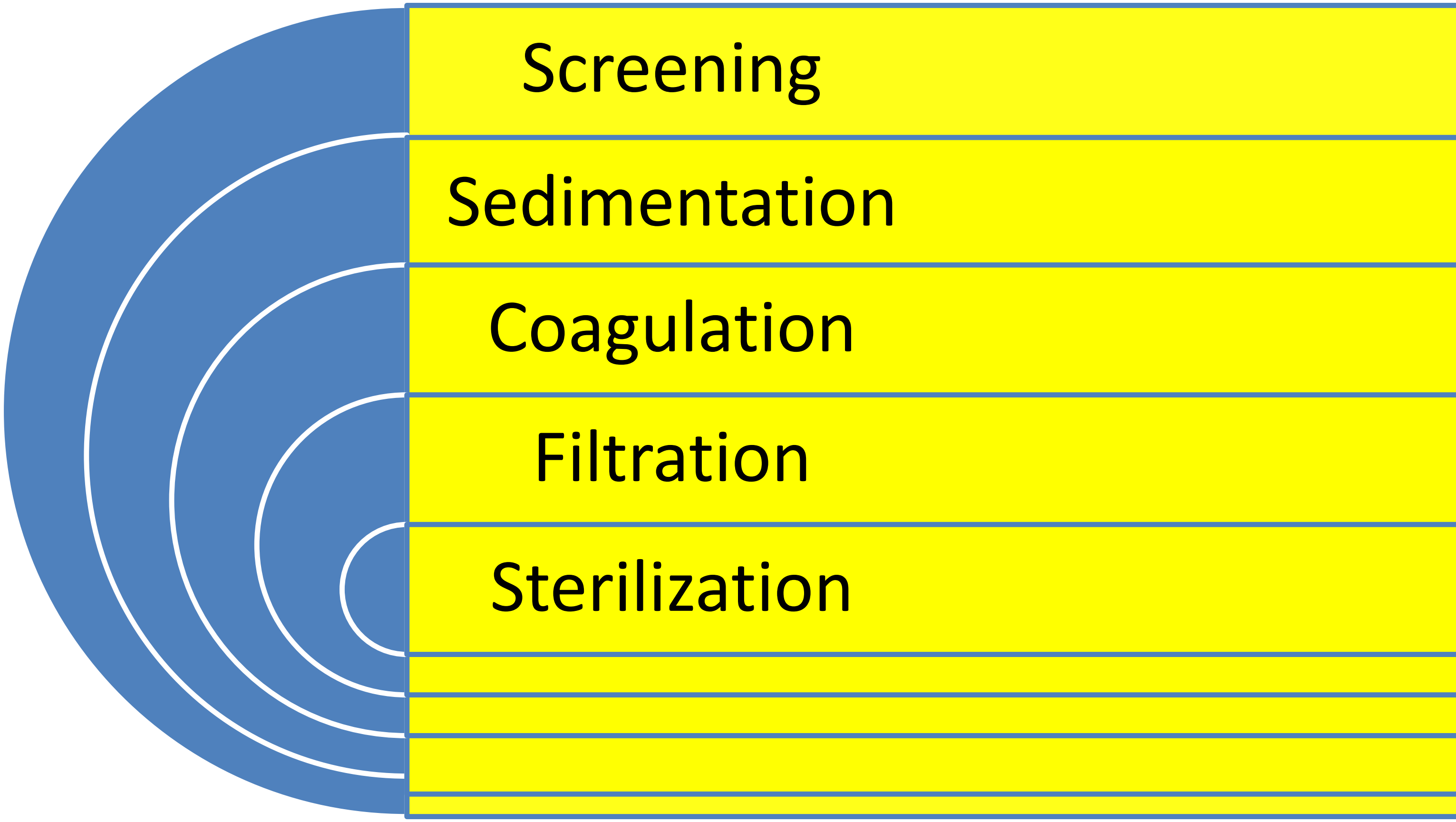
WATER AND ITS TREATMENT

PART - II

Water quality standards

1. should be clear and odourless.
2. It should be pleasant to taste
3. It should be perfectly cooled.
4. It should be free from disease producing bacteria
5. Its turbidity should not exceed 10 ppm.
6. It should be free from dissolved gases like H_2S.
7. It should be free from minerals such as Pb, As, Cr and Mn salts.
8. pH should be in the range of 7 – 7.5
9. Chloride and Sulphate content should be less than 250 ppm.
10. Fluoride content should be less than 1.5 ppm
11. Total dissolved solids should not be more than 500ppm.

Domestic water treatment



Screening

Removal of floating matter through screens

Sedimentation

The process of allowing water to stand undisturbed for some time in order to facilitate the settling down of co-suspended particles under the action of gravity is called sedimentation

It removes approximately 70-75% of impurities

Coagulation

Process by which the fine suspended and colloidal particles are removed from the water by the addition of suitable chemicals (coagulants)

Aluminium sulphate (Potash Alum ($K_2SO_4Al_2(SO_4)_3.24H_2O$)

$$Al_2(SO_4)_3 + Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3\downarrow + 3CaSO_4 + 6CO_2$$

Sodium Aluminate ($NaAlO_2$)

$$NaAlO_2 + 2H_2O \longrightarrow Al(OH)_3\downarrow + NaOH$$

$$6NaAlO_2 + Al_2(SO_4)_3 + 12H_2O \longrightarrow 8Al(OH)_3\downarrow + 3Na_2SO_4$$

Ferrous Sulphate ($FeSO_4.7H_2O$)

$$FeSO_4 + Mg(HCO_3)_2 \longrightarrow Fe(OH)_2\downarrow + MgCO_3 + CO_2 + H_2O$$

$$4Fe(OH)_2 + 2H_2O + O_2 \longrightarrow 4Fe(OH)_3\downarrow$$

Filtration

Process of removing the remaining colloidal matter, most of bacteria and other micro organisms by passing the sedimented water through suitable filters.

Commonly used filter: Rapid sand gravity filter
Two types of filters
a) Gravity type filters and b) Pressure type filters

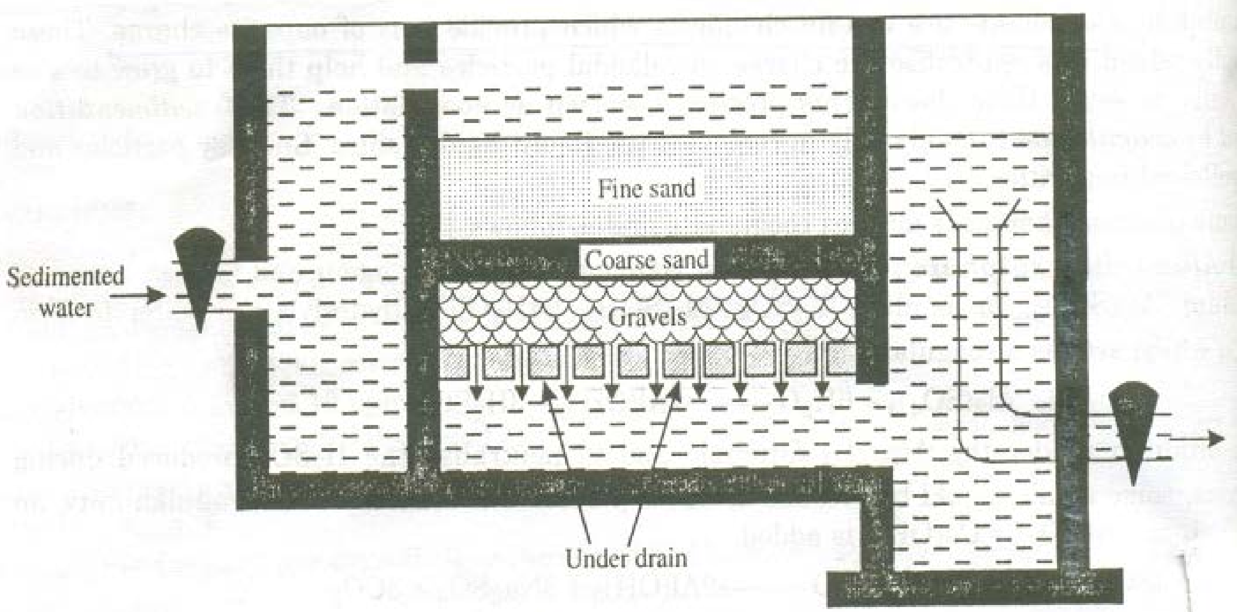


Fig. 4.1. Sand Filter.

Sterilization (Disinfection)

- Boiling
- Chlorination
- By ozone
- By Ultra-violet radiation

1. Boiling:

- ❑ Simple Sterilization method
- ❑ Harmful bacteria are killed

Limitations

- Expensive for municipal supply
- Taste of water changes
- Large quantity of fuel is required
- Kills pathogenic bacteria during boiling but does not protect the water against future infection

2. Chlorination

Chlorine used

(i) As a gas or concentrated aqueous solution

$Cl_2 + H_2O \longrightarrow HCl + HClO$ ….OCl^- ---capture membrane

$HClO \longrightarrow HCl + [O]$………oxidation of bacteria

(ii) As bleaching powder

Hypochlorous acid is formed which kills the enzyme which is essential for the metabolic processes of the micro organisms present in water.

$CaOCl_2 + H_2O \longrightarrow Ca(OH)_2 + Cl_2$

$Cl_2 + H_2O \longrightarrow HCl + HOCl$

$HClO \longrightarrow HCl + [O]$

Drawbacks

- **Introduces Ca in water thereby increasing hardness**
- **Excess amount produces bad smell in water**
- **Storage is difficult because it is unstable**

(iii) As Chloramine (NH_2Cl)

$$Cl_2 + NH_3 \longrightarrow NH_2Cl + HCl$$

Better germicidal than chlorine

$$NH_2Cl + H_2O \longrightarrow HOCl + NH_3$$

$$HOCl \longrightarrow HCl + [O]$$

Advantages

1. Gives good taste to water
2. Does not produce bad smell in water
3. Removes irritating smell due to excess of chlorine
4. Provides a greater lasting effect than chlorine

Super chlorination

Addition of excess amount of chlorination for disinfection of water

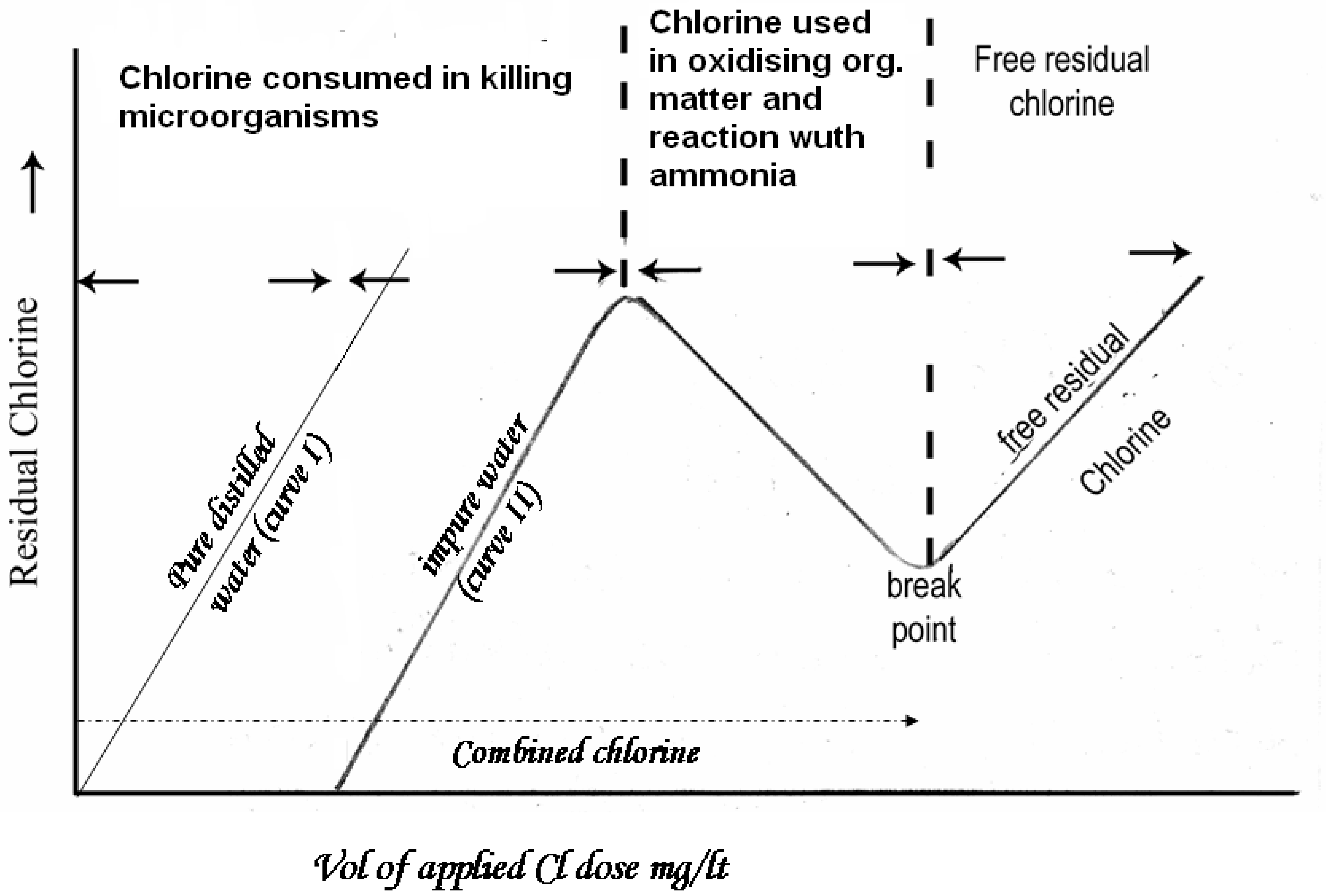
-removed by treating with calculated amount of NH_3

Break point chlorination

Break point chlorination refers to the addition of chlorine to water in amounts sufficient to

1. **kill all the micro organisms**
2. **to completely destroy organic matter by oxidation**
3. **Oxidation of free ammonia, if present**
4. **and to leave behind some free chlorine to continue the disinfecting action during storage (against further contamination by disease causing bacteria.)**

A plot of the dosage of chlorine against the residual chlorine in water gives a curve



3. By Ozone

Process is called ozonisation

$$O_3 \longrightarrow O_2 + [O] \text{ (powerful oxidising agent)}$$

Advantages

(i) It removes colour, odour and taste of water simultaneously

(ii) It does not produce any residue

(iii) Excess dose is not harmful because it is unstable and decomposes into oxygen

4. By Ultra-violet radiation

Exposed to UV rays from an electric mercury vapour lamp immersed in water

Advantages

(i) No chemical is required

(ii) No bad effect during treatment

(iii) Produce no odour in water

(iv) Takes very small time But very expensive

Assignment

- What are the different methods for domestic water treatment?
- Describe shortly sterilization of water?

Desalination

Any process that removes dissolved salts (particularly NaCl) from water.

On the basis of salinity water is graded as follows

Fresh water	**salinity <1000mg/lt**
Brakish water	**salinity is1000-35000mg/lt**
Sea water	**salinity>35000mg/lt**

Technologies for Desalination process

Reverse Osmosis

Electrodialysis

Reverse Osmosis

Principle

The flow of the solvent from a dilute solution to a more concentrated solution through semi-permeable membrane under the applied pressure

Process:

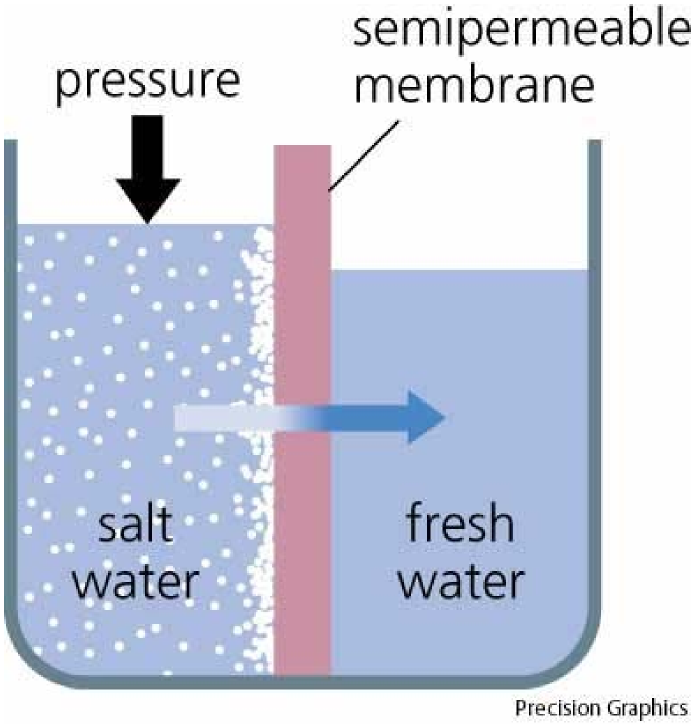
Sea water is taken in a chamber separated by a cellulose – acetate membrane. A pressure of about 15 to 40 Kg Cm^{-2} is applied on the sea water side in order to force the pure water alone present in it through the semi permeable membrane leaving behind all the dissolved salts.

Membranes : polymethacrylate and polyamide polymers

Advantages

1. **Process removes ionic, non-ionic as well as colloidal impurities**
2. **Resultant water may be used for high pressure boiler**
3. **Very low capital and operating cost**

Therefore suitable for converting sea water in to drinkable water

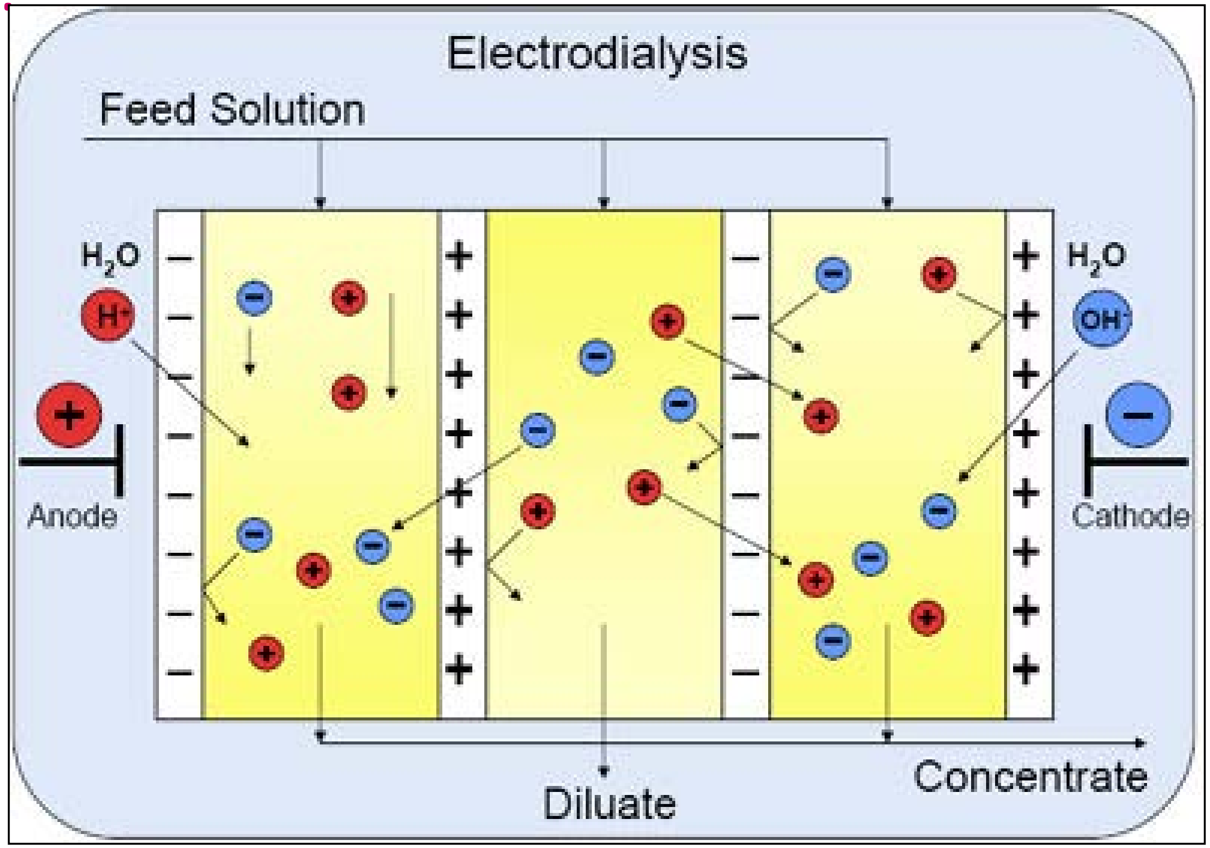


Electrodialysis

Principle:-

An electrochemical process whereby electrically charged particles, ions, are separated from saline water through selective membrane by applying an electric field.

Process:-



Advantages

1. **Compact equipment**
2. **Installation is economical**
3. **Cost of operation depends on cost of electricity**

Softening of hard water – External treatment

- Lime soda process
- Zeolite Process
- Ion-exchange Process
- Mixed-Bed demineralisation Process

Lime soda process

Very important method

Principle : The lime soda process involves the chemical conversion of all the soluble hardness causing salts by the addition of soda (Na_2CO_3) and lime [$Ca(OH)_2$]into insoluble precipitates which could easily be removed by settling and filtration

Functions of lime

Removes

1. temporary hardness

2.permanent Mg hardness

3.dissolved Fe, Al salts

4.Dissolved CO_2 and H_2S gases

5.Free mineral acids

Present in water

a) Removal of temporary Ca and Mg hardness

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3 \downarrow + 2H_2O$$

$$Mg(HCO_3)_2 + 2Ca(OH)_2 \longrightarrow 2CaCO_3 \downarrow + Mg(OH)_2 \downarrow + 2H_2O$$

b) Removal of permanent Mg hardness

$$MgCl_2 + Ca(OH)_2 \longrightarrow Mg(OH)_2 \downarrow + CaCl_2$$

$$MgSO_4 + Ca(OH)_2 \longrightarrow Mg(OH)_2 \downarrow + CaSO_4$$

c) Removal of dissolved Fe and Al salts

$$FeSO_4 + Ca(OH)_2 \longrightarrow Fe(OH)_2\downarrow + CaSO_4$$

$$2Fe(OH)_2 + H_2O + 1/2O_2 \longrightarrow 2Fe(OH)_3\downarrow$$

$$Al_2(SO_4)_3 + 3Ca(OH)_2 \longrightarrow Al(OH)_3\downarrow + 3CaSO_4$$

d) Removal of dissolved CO_2 and H_2S gases

$$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3\downarrow + 2H_2O$$

$$H_2S + Ca(OH)_2 \longrightarrow CaS\downarrow + 2H_2O$$

e) Removal of free mineral acid

$$2HCl + Ca(OH)_2 \longrightarrow CaCl_2\downarrow + 2H_2O$$

$$H_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4\downarrow + 2H_2O$$

Functions of Soda

During the removal of Mg^{2+}, Fe^{2+}, Al^{3+}, HCl and H_2SO_4 by lime, permanent calcium hardness is introduced in the water due to formation of calcium salts
The permanent calcium hardness thus introduced on account of the treatment of water with lime and the permanent calcium hardness already present in water before lime treatment are removed by soda

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + 2NaCl$$

$$CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + Na_2SO_4$$

The chemical reactions involved in the lime soda process are quite slow. Moreover, the precipitates formed particularly of $CaCO_3$ and $Mg(OH)_2$ are fine and have a tendency to form supersaturated solutions. This results in after deposition of these precipitates later in the pipes and boiler tubes leading to their clogging and corrosion.

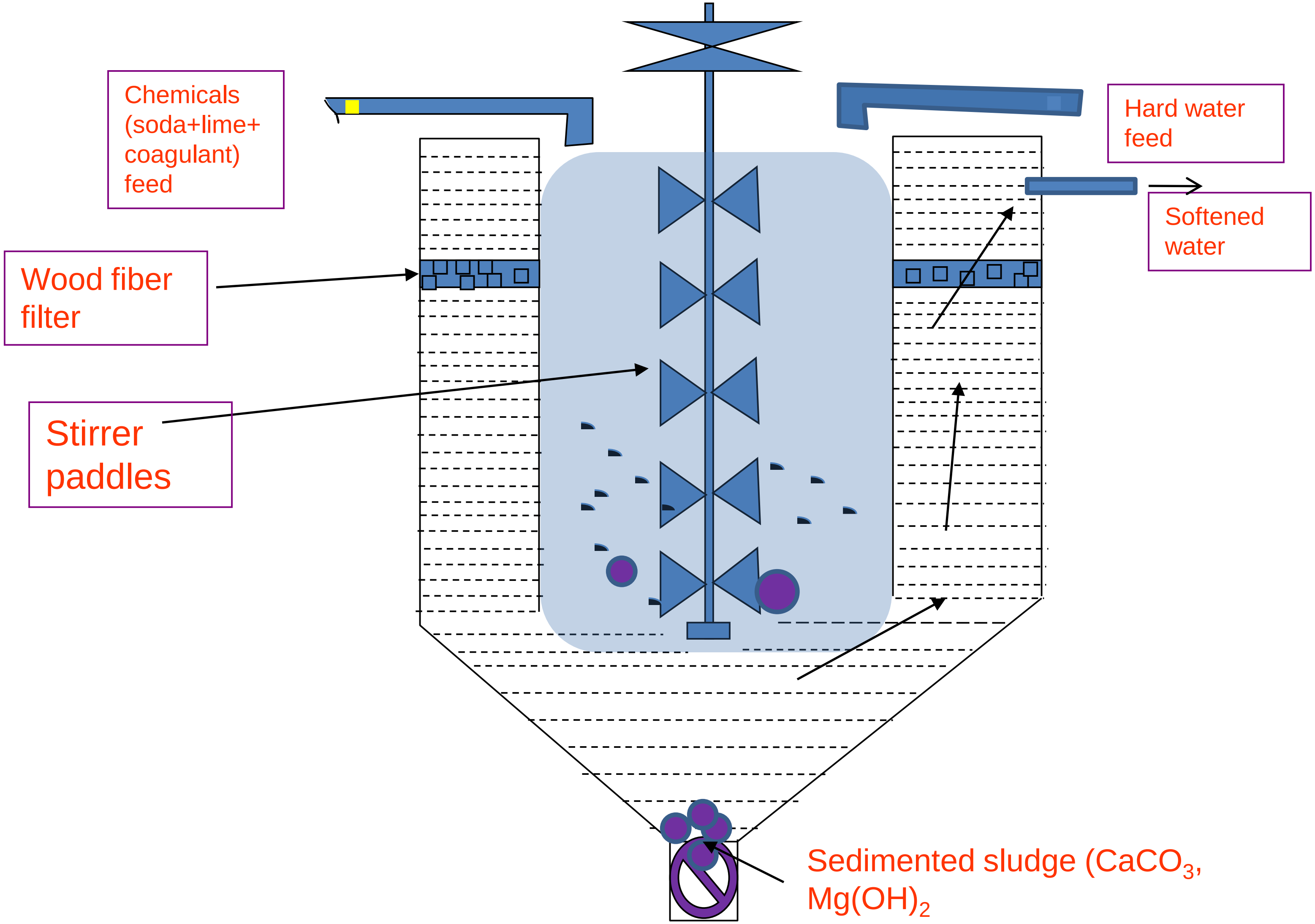
Some essential points to overcome above problem

a) **Thorough mixing of chemicals and water;**
b) **Allowing proper time for the completion of reactions**
c) **The use of accelerators such as active charcoal; and**
d) **The use of coagulants such as alum or $NaAlO_2$.**

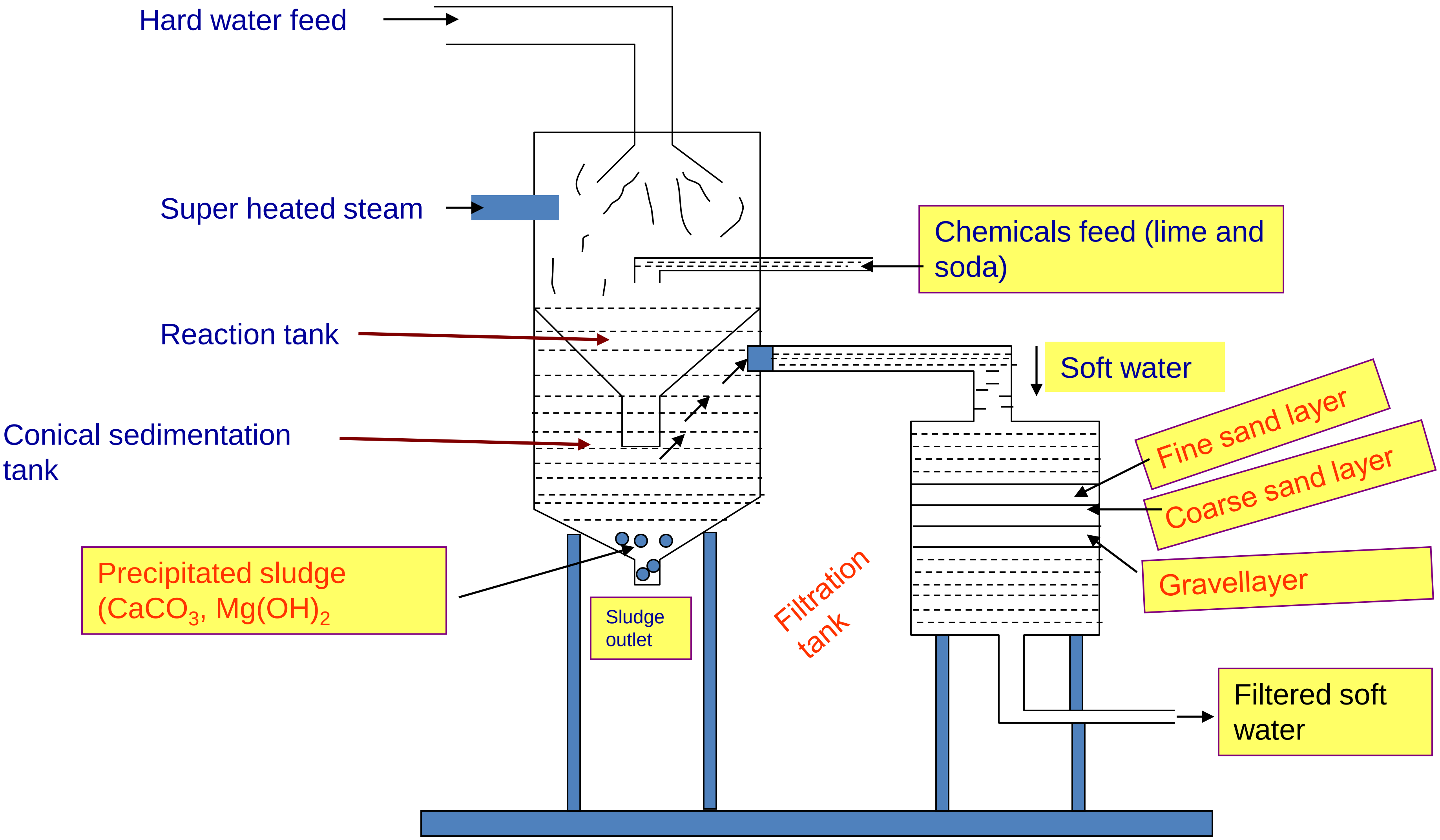
Process is further divided in to two types

1. Cold lime soda process
2. Hot lime soda process

Continuous cold lime soda softener



Continuous Hot Lime soda Process



Advantages

1. Economical
2. Hot lime soda process is much faster than the cold lime soda process
3. During this process pH value of water is increased hence the corrosion of pipe is reduced
4. Besides the removal of hardness, the quantity of minerals in water is also reduced
5. Due to alkaline nature of water, amount of pathogenic bacteria in water are also removed
6. Requires less amount of coagulants

Disadvantages

1. The softened water is not completely free from hardness (15-30ppm of hardness still remains)
2. Disposal of large amount of sludge is a problem
3. Careful operation and skilled supervision is required for efficient treatment of water

Differences between the cold and hot lime-soda processes

S.No	Cold lime soda process	Hot lime soda process
1	It is done at room temperature(25-30^{o} C)	It is done at elevated temperature(94-100^{o}C)
2	It is a slow process	It is a rapid process
3	The use of coagulants is must	Coagulants not needed
4	Filtration is not easy	Filtration is easy as the viscosity of water becomes low at elevated temperatures
5	Softened water has residual hardness around 60ppm	Softened water has residual hardness of 15-30ppm
6	Dissolved gases are not removed	Dissolved gases such as CO_2 are removed to some extent
7	Low softening capacity	High softening capacity

NUMERICAL PROBLEMS

1. **First of all calculate the amount of all substances present in the water sample in terms of $CaCO_3$ equivalent**
2. **Add all $CaCO_3$ equivalent of substances to get total hardness**
3. **Substances like NaCl, KCl, Na_2SO_4, SiO_2, Fe_2O_3 etc do not impart any hardness, therefore , these do not consume any soda or lime. Hence these should not be taken into consideration for calculating the lime and soda requirements.**
4. **When the impurities are given as $CaCO_3$ or $MgCO_3$.The amount expressed as $CaCO_3$ does not require any further conversion. However the amount of $MgCO_3$ should be converted into $CaCO_3$ equivalent**

Lime requirement

The amount of lime required for softening of water =

74/100 (temporary Ca hardness + 2 X temporary Mg Hardness + Permanent Mg hardness + CO_2 + HCl + H_2SO_4 + Fe^{2+} + Al^{3+} + HCO_3^- - $NaAlO_2$); All expressed in terms of $CaCO_3$ equivalents

The amount of lime required for softening of water = **106/100 (permanent Ca hardness + Permanent Mg hardness + HCl + H_2SO_4 + Fe^{2+} + Al^{3+} - HCO_3^- - $NaAlO_2$) All expressed in terms of $CaCO_3$ equivalents**

Following points are to be noted-

1 equivalent of HCO_3 require 1 equivalent of lime which simultaneously produces 1 equivalent of CO_3^{2+}, which may be regarded as equal to 1 equivalent of soda.

$$Ca(OH)_2 + 2HCO_3 \rightarrow \mathbf{CaCO_3} + H_2O + CO_3^{2+}$$

This is why corresponding quantity of HCO_3 in equivalent has been substracted in the calculation of soda requirement.

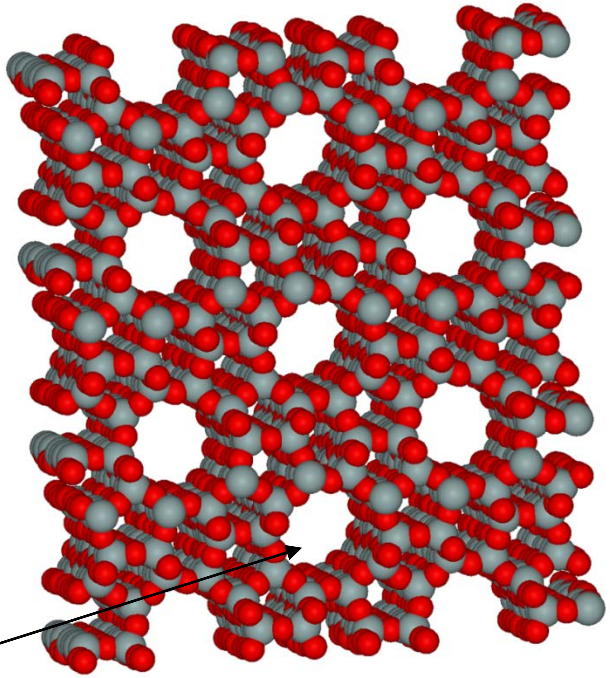
2. $NaAlO_2$ require neither lime nor soda . 1 equivalent = 1 equivalent of OH^-

Zeolite process (permutit/boiling stone)

Zeolite are hydrated sodium alumino siticates $Na_2O.Al_2O_3\ xSiO_2.yH_2O$. (x=2-10 and y=2-6) **<u>(inorganic salts)</u>**. They work as water softners by replacing the calcium and magnesium ions in water with the sodium ions in zeolite.

Zeolite → **Natural zeolites**

Zeolite → **Synthetic zeolites**



Micro pores of Zeolite

Porous Structure of zeolite

1. Natural zeolites

Non-porous, amorphous and durable

e.g. $Na_2O.\ Al_2O_3.3SiO_2.2H_2O$ (Natrolite)

$CaO.Al_2O_3.4SiO_2.4H_2O$ (Laumonite)

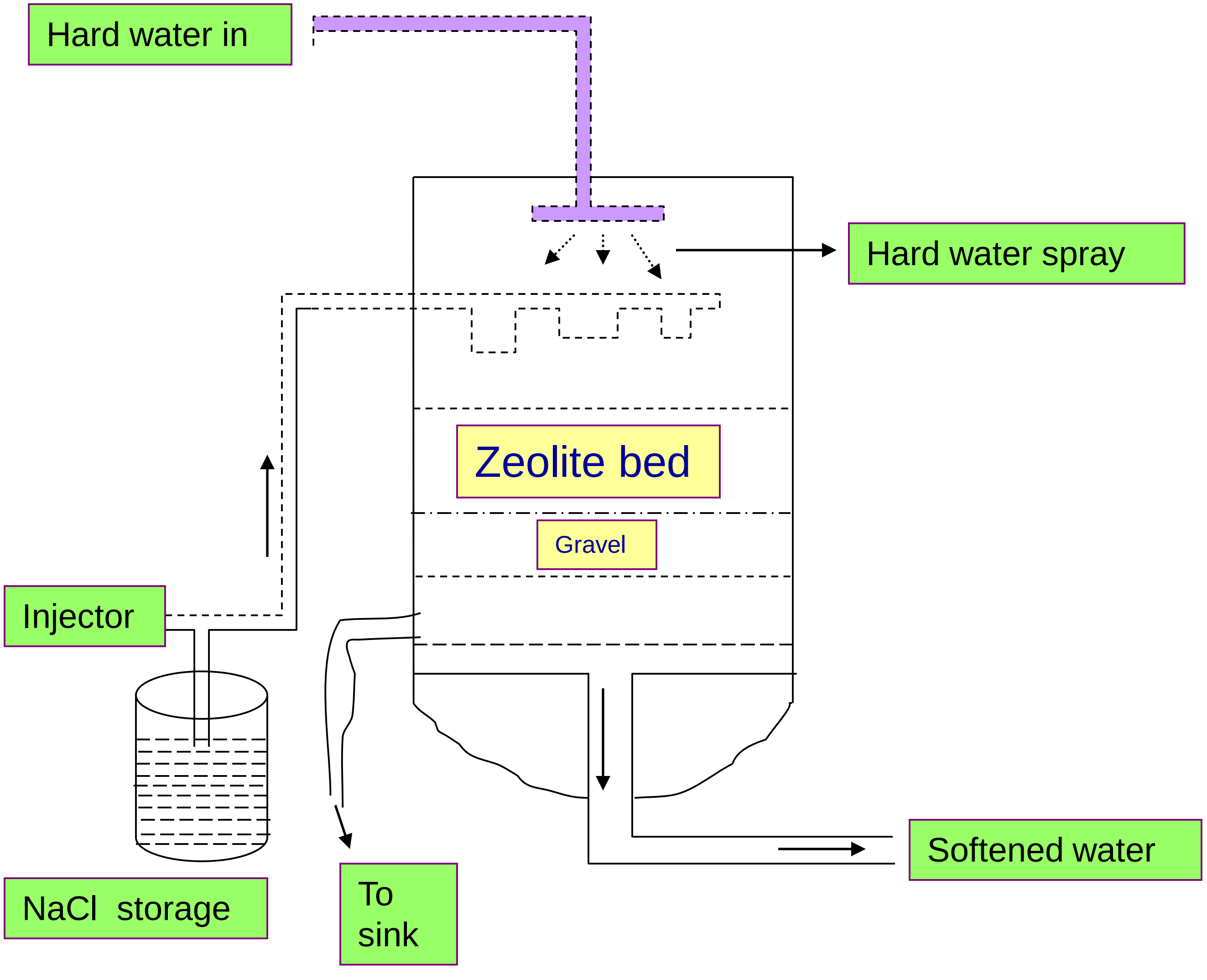
2. Synthetic zeolites

Gel like structures, generally porous

Na_2CO_3, Al_2O_3 and SiO_2 heated together

$Na_2O.Al_2O_3\ xSiO_2.yH_2O$. (x=2-10 and y=2-6)

Zeolite softener



In this process hard water is allowed to pass through a bed of zeolite at a specified rate. Then the sodium ions present in the zeolite bed continuously replace the calcium and magnesium ions present in water and hence the water becomes soft.

$Na_2Ze + Ca(HCO_3)_2 \rightarrow CaZe + 2NaHCO_3$
$Na_2Ze + Mg(HCO_3)_2 \rightarrow MgZe + 2NaHCO_3$

Regeneration

When the zeolite bed becomes exhausted it requires regeneration. This is achieved by passing 10% NaCl solution through it.

$CaZe + 2NaCl \rightarrow Na_2Ze + CaCl_2$

Advantages

1. Almost complete removal of hardness (10ppm)
2. It is compact
3. Requires only less time for softening
4. No sludge formation since no precipitate is formed
5. Can work under pressure also

Disadvantages

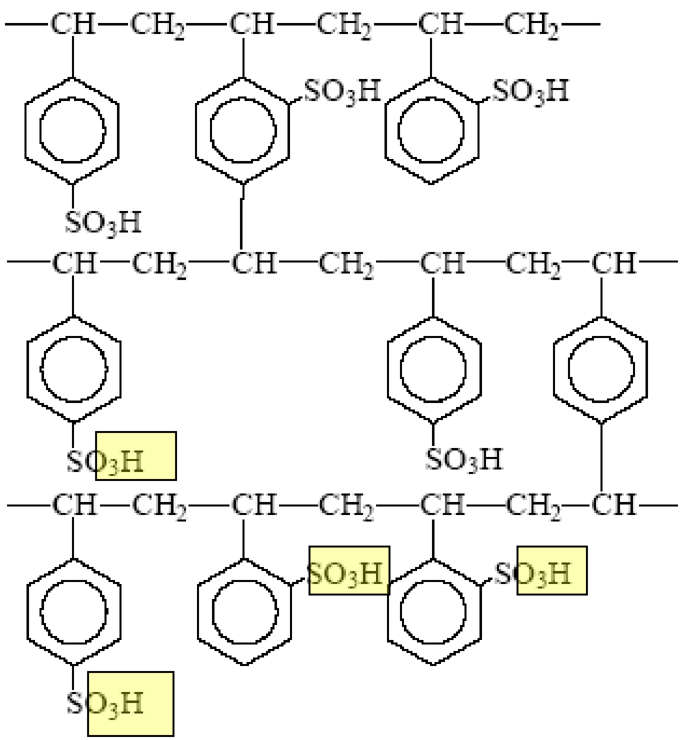
1. More sodium salt concentration in softened water.
2. Turbidity containing water cannot be used
3. Process exchange only Ca^{2+} and Mg^{2+} ions but cannot exchange HCO_3^- and CO_3^{2-} ions. So cannot be used in boilers
4. If Fe^{2+} and Mn^{2+} are present in large quantities. They form respective zeolites so zeolites cannot be regerated
5. Water consisting of high alkalinity or acidity cannot be used because zeolite is deccomposed

Ion Exchange Method

Ion exchange resins are insoluble cross linked long chain <u>organic polymers</u> having a microporous structure where acidic or basic functional groups attached to the chain are responsible for the ion exchange capacity. Cation exchange resins contain acidic functional groups like –COOH, -SO_3H etc. while anion exchange resins contain basic functional groups like –OH, -NH_2 etc.

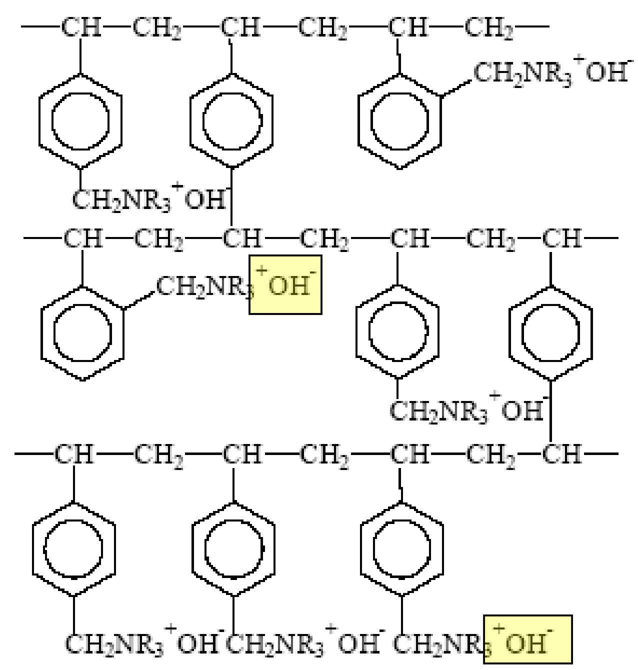
Structure of Cation and Anoin exchange resins

Cation exchange resin



A strongly acidic sulphonated polystyrene cation exchange resin

Anion exchange resin



A strongly basic quaternary ammonion anion exchange resin

$R = CH_3$

The hard water is allowed to pass through a cation exchange column to remove all the cations like Ca^{2+}, Mg^{2+} etc.

$$2resinH^{+} + Ca^{2+} \rightarrow (resin)_2Ca^{2+} + 2H^{+}$$

$$2resinH^{+} + Mg^{2+} \rightarrow (resin)_2Mg^{2+} + 2H^{+}$$

Afterwards the water is allowed to pass through an anion exchange resin column to remove anions like SO_4^{2-}, Cl^- etc.

$$resinOH^{-} + Cl^{-} \rightarrow resinCl^{-} + OH^{-}$$

The H+ and OH- ions so produced from the cation and anion exchange resins combine to become water

$$H^{+} + OH^{-} \rightarrow H_2O$$

Water thus coming out of the ion exchanger will be free from both cations and anions and hence called demineralised water.

Regeneration

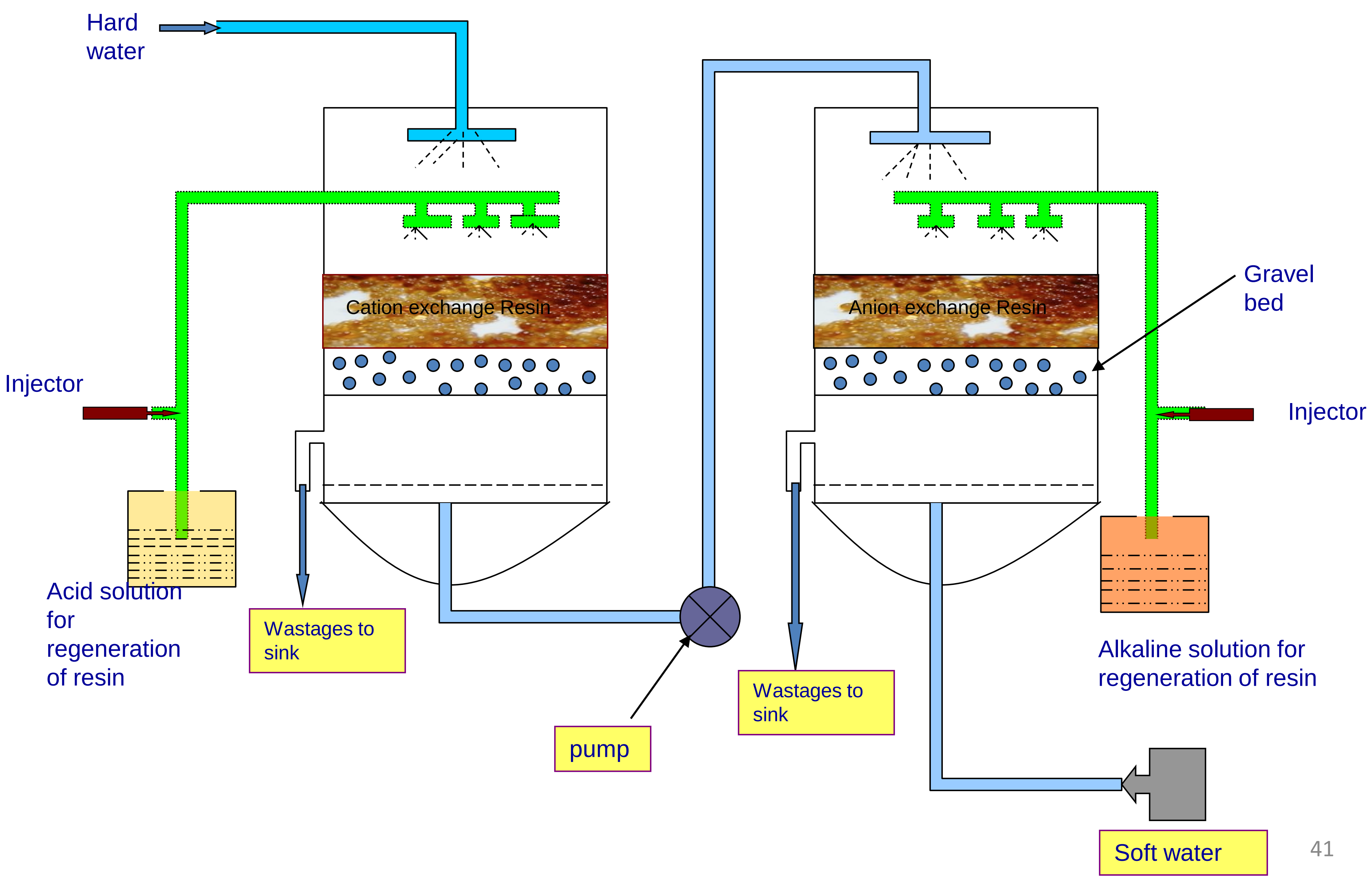
exhausted cationic resin is regenerated by treating with moderately concentrated HCl or H_2SO_4

$$Ca(resin)_2 + 2HCl \longrightarrow 2resinH^{+} + CaCl_2$$

exhausted anionic resin is regenerated by treating with moderately concentrated NaOH solution

$$resinCl^{-} + NaOH \longrightarrow resinOH^{-} + NaCl$$

Ion exchange purifier or softener



Advantages of the process

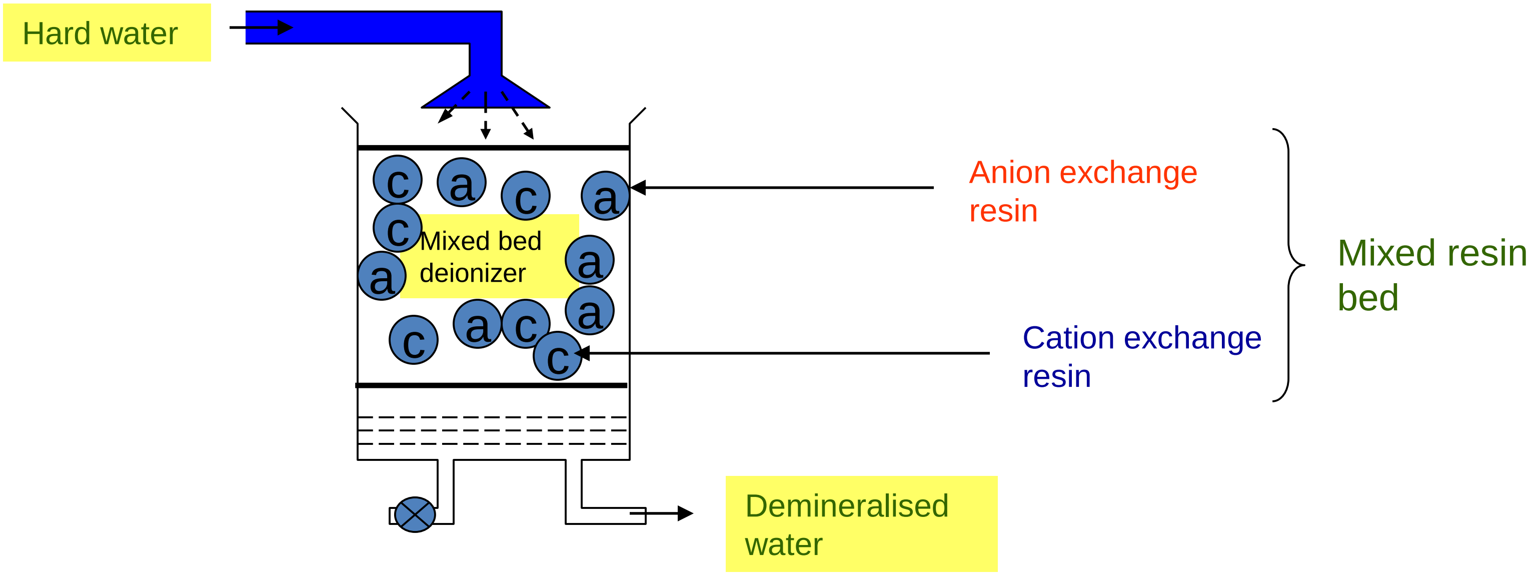
1. This process may be used to soften highly acidic or alkaline water
2. The resultant water is of very low hardness (about 2ppm) and is suitable for high pressure boilers

Limitations

1. Resin is quite expensive. Hence the process is costly
2. On treating the turbid water efficiency of the process reduce

Mixed bed demineralisation

1. It is a single cylindrical chamber containing a mixture of anion and cation exchange resins bed
2. When the hard water is passed through this bed slowly the cations and anioins of the hard water comes in to contact with the two kind of resins many number of times
3. Hence, it is equivalent to passing the hard water many number of times through a series of cation and anion exchange resins.
4. The soft water from this method contains less than 1ppm of dissolved salts and hence more suitable for boilers



Regeneration

Mixed bed is back washed which separates out two resins as they

possess different densities

Separately they are regenerated

Then used freshly