① TECHNOLOGY OF WATER

P.E.S.C.E.

Natural sources of water:

The important Natural sources of water supply for domestic and industrial use are:

1) Rain water
2) Surface water — Flowing water as in rivers & streams
   — Flowing water as in ponds & lakes.
3) Ground water: well water and spring water.
4) Sea water.

Common impurities or classification of impurities present in Natural water.

The common impurities present in Natural water are.

1) Dissolved gases like O_2, CO_2 and H_2S
2) Suspended particles like sand and clay (inorganic) & vegetable and animal matter (organic). They include colloidal particles like silica also
3) Dissolved salts such as bicarbonates, chlorides and sulphates of metals like Na, K, Ca, Mg, Fe & Al.
4) Disease causing bacteria (pathogenic bacteria)

Standards or Requisites of water for Domestic use:

Water used for domestic purpose is mainly for drinking, cooking, washings. This water must be clear, colourless, odourless and pleasant to taste, such water which is safe and good to drink is called potable water: This water must be essentially free from.

1) Suspended & colloidal particles like sand and clay.
2) Excess of dissolved salts of metals like Ca & Mg
3) Disease causing bacteria.

Standards of requisition of water for industry and Domestic use:

Water is used in industries mainly for producing steam which is essential for generating power. A device or vessel used for converting water into steam is called boiler & it is generally made up of sheets of Iron or steel. This water must be essentially free from.

i) Dissolved gases like O_2, CO_2 & H_2S
ii) Suspended & colloidal particles like sand & clay
iii) Dissolved salts of metals like Ca, Mg, Fe & Al.

Dissolved gas cause corroxion in boilers & the other impurities form scales in boilers.

Hardness of water:

Hardness of water is that characteristic which prevents lathering of soap. Hardness of water is mainly due to the presence of soluble salts such as bicarbonates, chlorides, & sulphates of metals like Ca & Mg. Hardness of water is of two types 1) Temporary hardness.
2) permanent hardness.

Temporary hardness is due to the presence of only bicarbonates of Ca & Mg and it can be easily removed by boiling the water.

permanent hardness is due to the presence of chlorides and sulphates of Ca & Mg and this cannot be easily removed.

Formation and causes for the formation of scales and sludges in Boilers:

When water is heated in boilers, water evaporates continously and the concentration of the dissolved salts increases. When the concentration of these salts reach saturation point. They are thrown out of water in the form of a precipitate. If the precipitate form a loose & pasty mass. It is called a sludge. The sludge can be easily removed by blowing down the boiler. If the precipitate deposit as a hard & adherent layer on the inner walls of the boiler. It is called boiler scales. Boiler scales cannot be easily removed even by using a hammer & a chisel. The important causes for the formation of scales and sludges in boilers are.

1) Decomposition of $Ca(HCO_3)$ soluble: When water is heated bicarbonates of Ca & Mg decompose giving insoluble carbonates which are precipitated.

Eg: $Ca(HCO_3) \xrightarrow{Heat} CaCO_3 \downarrow + H_2O + CO_2 \uparrow$

2) Depotition of $CaSO_4$: The solubility of salts like calcium sulphate decrease with the increase of temp & hence are precipitated and form scale in boilers.

3) Presence of silica: The presence of silica even in small quantities react with Ca & Mg ions of water to form insoluble Ca & Mg silicates which are precipitated.

$$SiO_2 + Mg^{2+}/Ca^{2+} \longrightarrow Mg(SiO_2)_2$$

4) Hydrolysis of Mg salts: It undergo. hydrolysis. at a higher temperature giving insoluble hydroxides and mineral acids. Insoluble hydroxides may form scale and mineral acid corrode the boiler

Eg: $MgCl_2$ is undesirable in boiler feed water

Magnesium chloride undergoes hydrolysis gives Magnesium hydroxides which may form scales and aid corrode the boiler.

$MgCl_2 + 2H_2O \rightleftharpoons Mg(OH)_2 + 2HCl$

Chemical Nature & composition of boiler scales:

Boiler scales are hard and adherent layer formed on the inner walls of the boiler. They can't be easily removed & they have corrosive effect on the boiler metals. Boiler scales generally contain

i) carbonates of ca & mg
ii) Silicates of ca, mg & Al
iii) Sulphates like $CaSO_4$ whose solubility decrease with the increasing of temp.
iv) Suspended & colloidal particles which are co-agulated and trapped in the precipitate of other salts.

Boiler scales:

Defn: Boiler scales are hard and Adherent layer formed on the innerwalls of the boilers when water containing impurities is converted into steam.

Harmful & ill Effects of boiler scales:

1) Boiler scales are hard & adherent layer formed on the innerwalls of the boiler. They cannot be easily removed & they have corrosive effect on the boiler metal.

2) Boiler scales are bad conductor of heat. Thus the heat supply from outside is not fully utilized & a large quantity of fuel has to be used. This results in the wastage of fuel & wastage of fuel increases with the increase in thickness of the scale.

3) Since boiler scales are bad conductors of heat, Most of the heat supplied heats the boiler. Hence the boiler becomes red hot & its strength decreases.

4) At high temperature cracks are formed in boiler scales due to the uneven expansion of scales Thus steam comes in contact with red hot iron (boiler) liberating hydrogen. Hence boiler further weakens & the H_2 liberated will produced high pressure in the boiler this may result in the bursting of the boiler.

$$3Fe + 4H_2O \longrightarrow Fe_3O_4 + 4H_2 \uparrow$$

Thus the formation of scales in boilers results in the wastage of fuel: lowering of boiler safety decrease in efficiency and dangerous explosion

Methods for preventing the scale formation in boilers & treatment of boiler feed water.

The various method used for preventing scale formation in boilers are devided into types:

① Internal conditioning methods or Internal treatment.
② External conditioning methods or External treatment.

1) Internal conditioning methods:

In these methods scale formation in boilers is prevented by adding certain chemicals to water inside the boiler i.e. these methods are used inside the boiler. The chemicals added react with the scale forming salts to form more soluble salts or to those compounds which form a sludge. The sludge can be easily removed by blowing down the boiler. Some of the important internal conditioning methods commonly used are

① colloidal treatment
② phophate treatment
③ calgon treatment or threshold conditioning.

① **colloidal treatment:**

In this method scale formation is prevented by adding colloidal substances like Kerosine, tanins and Agar-Agar to water inside the boiler. The colloids get coated over scale forming particles & thus prevent their co-agulation Hence, scale forming particles may remain suspended in water & form a sludge which can be easily removed.

② **phosphate treatment:**

In this method, scale formation is prevented by adding sodium phosphate to water inside the boiler. Sodium phosphate reacts with the scale forming Ca & Mg salts & convert them into insoluble Ca & Mg phosphates. These phosphate form a sludge & hence can be easily removed.

Eg: $2Na_3PO_4 + 3CaCl_2 \longrightarrow 2Ca_3(PO_4)_2 \downarrow + 6NaCl$

In this method, sodium salts of orthophosporic acid (H_3PO_3) like primary (NaH_2PO_4), secondary (Na_2HPO_4) & Tertiary (Na_3PO_4) sodium phosphates are used. The selection of a particular phosphate depends on the pH of water. For Example If boiler feed water is highly acidic, Alkaline tertiary sodium phosphate is used

③ **Calgon treatment & Threshold conditioning:**

In this method, scale formation in boilers is prevented by adding calgon to water. Addition of very small quantities of calgon to water entering the boiler is called threshold conditioning. Calgon is the commercial name for sodium hexameta phosphate. $(NaPO_3)_6$. $Na_2[Na_4(PO_3)_6]$ calgon reacts with the scale forming calcium & magnesium salts to form highly soluble & stable complex compounds which are not precipitated. Calgon controls corrosion by acting as a corrosion inhibitors.

$3CaSO_4 + [Na_2Na_4(PO_6)_3] \longrightarrow Ca[Ca_2(PO_6)_3] + 3Na_2SO_4$.

corrodion by acting as a corrodion inhibitor.

Eg:- $3CaSO_4 + Na_2[Na_4(PO_4)_3] \longrightarrow Ca[Ca_2(PO_4)_3] + 3Na_2SO_4$

2] External conditioning methods or methods of softening of water:

In these methods, scale formation in boilers is prevented by treating the water before it is fed into the boiler. In these methods, all the scale forming Ca & Mg salts which are also responsible for hardness of water are removed. Hence these methods are also known as methods of softening of water.

Some of the important external conditioning methods commonly used are:

1) Lime-Soda process.
2) Ion-Exchange process. ✓

1) Lime-Soda process: [Lime or slaked lime = calcium hydroxide = $Ca(OH)_2$
Soda or soda ash = Sodium carbonate = Na_2CO_3]

In this method, all the scale forming & hardness causing calcium and magnesium salts present in water are removed by adding calculated quantities of lime & soda. The insoluble compounds which are removed by filteration. Lime & soda precipitate Ca salts as calcium carbonate and Mg salts as magnesium hydroxides. The functions of lime & soda are given below.

Functions of Lime: [$Ca(OH)_2$]

1) Lime removes temporary hardness of water which is due to bicarbonates of Ca & Mg.

$$Ca(HCO_3)_2 + \underset{\text{Lime}}{Ca(OH)_2} \longrightarrow 2CaCO_3\downarrow + 2H_2O$$

$$Mg(HCO_3)_2 + \underset{\text{Lime}}{2Ca(OH)_2} \longrightarrow Mg(OH)_2\downarrow + 2CaCO_3\downarrow + 2H_2O$$

ii) Lime removes permanent hardness which is due to chlorides and sulphates of Magnesium. by forming insoluble magnesium hydroxide. but here an equivalent amount of calcium salts are introduced to water.

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

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

Lime

iii) Lime Neutralise free acids & precipitate dissolved CO_2 as calcium carbonate.

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

Lime

iv) Lime removes Iron & Aluminium salts by forming insoluble hydroxides.

Functions of Soda : (Na_2CO_3)

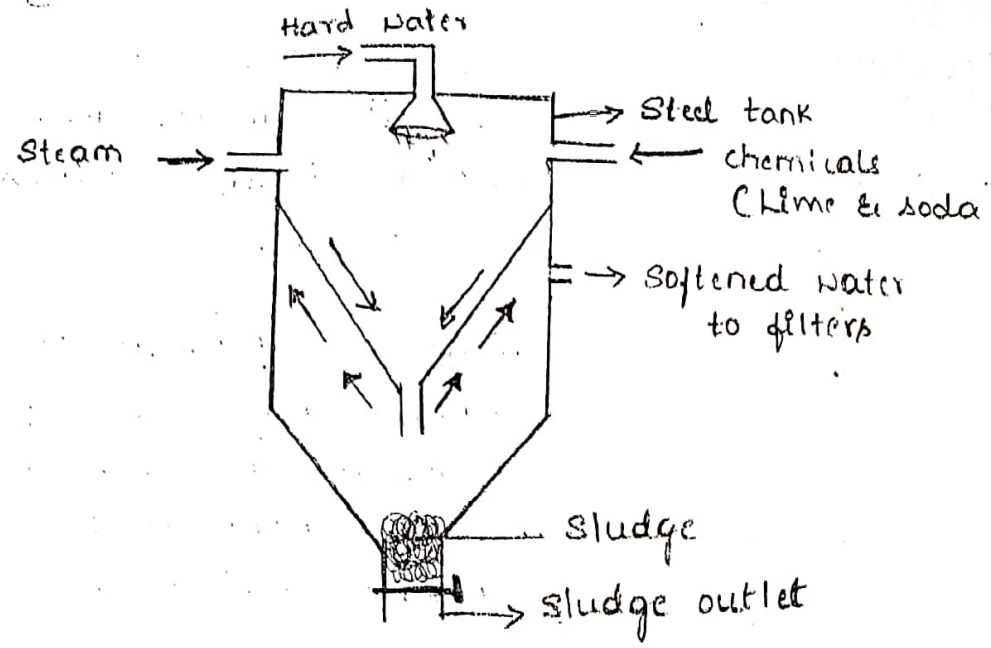
Soda. i.e. sodium carbonate removes permanent hardness of water which is due to chlorides and sulphates of calcium. Thus calcium salts introduced to water during the treatment of Lime are also removed.

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

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

When this process is carried out at room temperature it is called cold Lime-soda process. When this process is carried out at a higher temperature. It is called hot lime-soda process

The hot Lime-soda process which is commonly used is explained as follows.



The apparatus consists of a big steel tank having an inner clay vertical chamber. The upper end of the inner chamber is in the form of a funnel & the lower end is open. Hard water and chemicals - lime & soda are introduced into the inner chamber where they get mixed steam is sent into the inner chamber. by the time of mixturing all the above reactions will be complete & the precipitated matter like $CaCO_3$ & $Mg(OH)_2$ settle down. The softened water comes out continously from the top & it is sent into filters. The hot lime-soda process has the following advantages over the cold process:

(1) The reactions will be completed within about 15 mint where as the cold process requires 3-4 hrs.

(2) The precipitates formed are coarser & more granular & hence settle down rapidly. This filtration becomes easier

(3) Since the precipitate settle rapidly, addition of coagulants is not necessary.

[a] Lime is used along with soda in lime-soda process even though soda alone can remove both the types of hardness. Give reason:

soda i.e. sodium carbonate precipitate calcium & magnesium salts as insoluble $Ca(CO_3)$ & $Mg(CO_3)$. But $Mg(CO_3)$ is slightly soluble in water & hence hardness due to mg. salts cannot be completely removed.

Ion-Exchange process or Deionisation or Demineralisation:

In this method, synthetic organic high polymers called resins are used for removing all the scale forming and hardness causing salts present in water. In this process, all the cations & anions of dissolved mineral salts are removed by the mechanism of exchange of ions. two types of resins are used in this process.

1) Cation - Exchange Resins:
2) Anion - Exchange Resins:

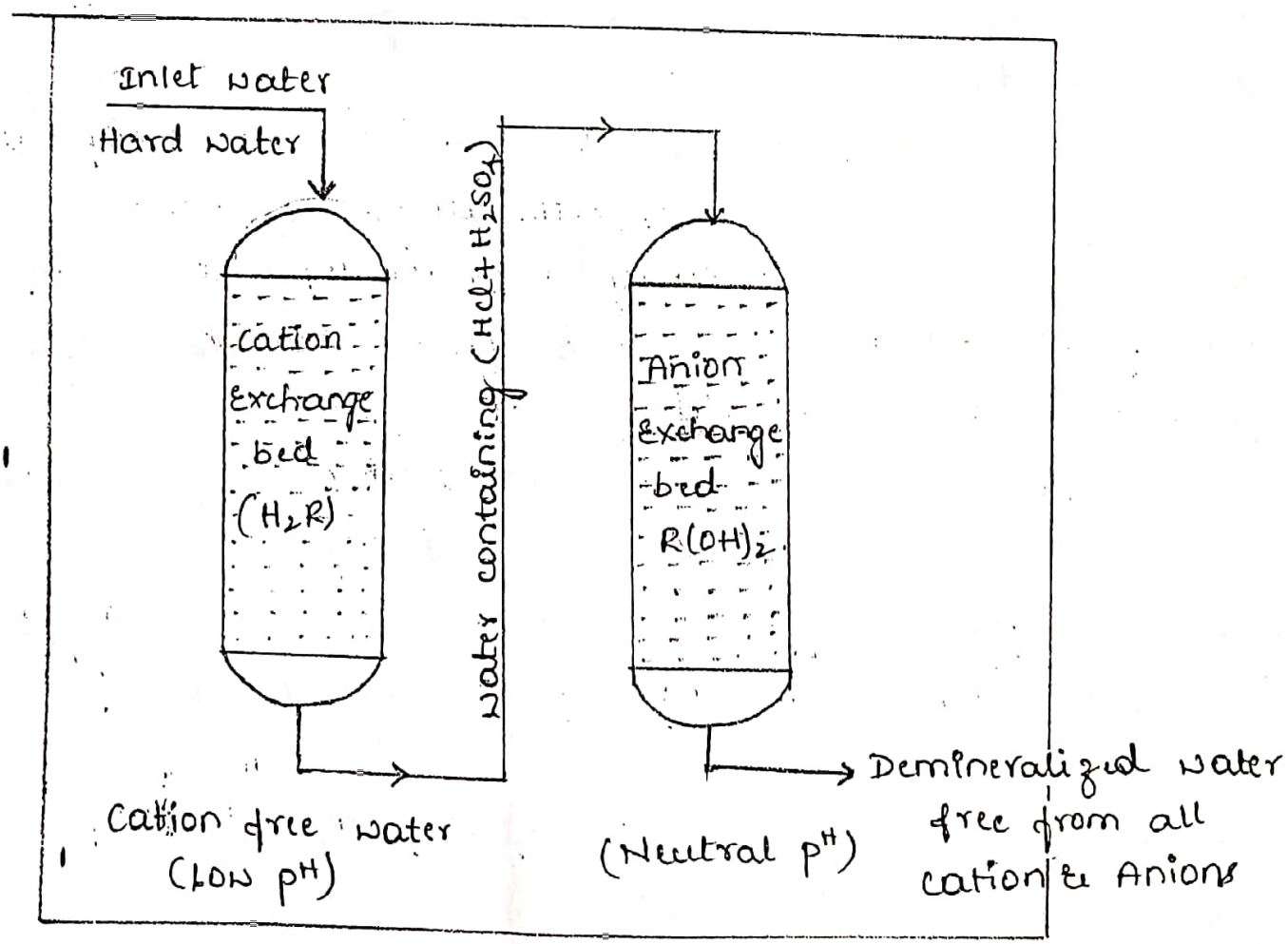


Fig: Ion Exchange process of hard water.

1) Cation - Exchange Resins: H_2R

These resins are represented by general formula H_2R where R - stands for complex organic part of the resins These resins are capable of Exchanging their hydrogen ions with other cations. Hence when hard water is passed through these resins, all the cations of dissolved salts like Na, Ca & Mg are replaced by hydrogen ions as follows.

$$CaCl_2 + H_2R \longrightarrow CaR + 2HCl$$

$$MgSO_4 + H_2R \longrightarrow MgR + H_2SO_4$$

Hard water — Water free from cations

This water coming out of these resins is free from cations but contains anions of dissolved salts the Exhausted cation - Exchange resin is regenerated by passing strong hydrochloric acid.

Eg:- $2HCl + CaR \longrightarrow H_2R + CaCl_2$

Exhausted c.c.r — Regenerated c.e.r — Waste water

2) Anion - Exchange Resin : $R(OH)_2$:-

These resins are represented by the general formula $R(OH)_2$ where R stands for complex organic part of the resin. These resins are capable of exchanging their hydroxyl anions with other anions. Hence when - hard water free from cations are passed through these resins all the anions dissolved salts - like chlorides & sulphates are replaced by hydroxyl one as follows.

$$2HCl + R(OH)_2 \longrightarrow RCl_2 + 2H_2O$$

$$H_2SO_4 + R(OH)_2 \longrightarrow RSO_4 + 2H_2O$$

Water free from cation — A.E.R — Exhausted a.e.r — pure & soft water

Thus water coming out of these resins is completely free from both cations & anions of dissolved salts & it is as pure distilled water. The Exhausted (a.e.r) is regenerated by passing conc^n sol^n of NaOH)

For Eg: $2NaOH + RCl_2 \longrightarrow R(OH)_2 + 2NaCl$

Exhausted A.C.R — Regenerated A.C.R — Waste water

Advantages & Merits of Ion-Exchange process.

1. This process gives water which is as pure as distilled water
2. This process can be used to purify highly acidic & basic water [alkaline water]

Disadvantages & Demerits of Ion exchange process:

1. The equipment & chemicals used in this process (resins) are costly.
2. If water contains durbility & excess of dissolved salts the output of the process will be reduced.

✓ Purification of water for Town supply & municipals supply & For Domistic use:

Water required for domestic purposes is mainly for drinking, cooking and washing this water must be clear, colourless, odourless & pleasant to taste. this water must be essentially free from

(i) Suspended & colloidal particles like sand & clay
(ii) Excess of dissolved salts of metals like calcium and Magnesium.
(iii) Disease causing bacteria.

The purification of water for town supply involves four stages.

1) Sedimentation
2) Co-agulation
3) Filtration
4) Sterlization & Disinfection.

① Sedimentation:

The setting of suspended particles under the influence of gravity is called sedimentation. the raw water is allowed to settle in big cement tanks for about 8 to 12 hrs. The suspended particles other than colloidal & micro-organisms settledown the clear water is sent into a co-agulation tank.

② Coagulation:

Generally the setting of finely suspended and colloidal particles takes a very long time. Hence to increase the rate of setting of these particles. Certain chemicals called coagulants are added to H_2O. The commonly used coagulants are Alum [$K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$] Ferrous sulphate & sodium Alluminate.

These coagulants undergo hydrolysis giving gelatinous precipitate of hydroxide. This ppt adsorb and entangle all the finely suspended & colloidal particles to form bigger particles which eailly settle down. The coagulants undergo ionisation giving poitive & negative ions. These ions Neutralise the oppositely charged colloidal particles & thus help in their co-agulation. The clear water is sent into a filteration tank

③ Filtration:

After sedimentation & co-agulation water is sent into a filteration tank to remove other suspended & floating particles. the filters commonly used are gravity sand filters. These filters consists of layers of coarse gravel fine gravel, course sand & fine sand placed one above the other. When water is passed through the filters. all the suspended & floating particles are retained in the sand-bed and filtered water collects at the bottom. When the filteration becomes slow than sand bed is removed, cleaned and reused. the filter water is finally sent into sterlization tank to remove disease causing bacteria & other microorganisms.

④ Sterlization or Disinfection:

The process of destroying disease causing bacteria & other micro-organisms from water is called sterlization. chemicals used for this purpose are called sterlizing agents. They are bleaching powder ($CaOCl_2$) chlorine, U-V rays & ozone. U-V rays and ozone are costly & Hence are used to limited for large scale treatment, chlorine is used & bleaching powder is used for a small scale treatment.

$CaOCl_2$ reacts with water giving lime & liberating chlorine. This chloride reacts with water giving hypochlorous acid. This HOCl combines with an enzymes in the cells of organisms & Thereby destroy the organisms. chlorine also helps in removing undesirable colour, smell & taste water.

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

$$Cl_2 + H_2O \longrightarrow \underset{\text{Hypochlorous acid}}{HOCl} + HCl$$

$HOCl$ + Germs ⟶ Germs are killed or destroyed.

$HOCl$ + Bacterias ⟶ Bacterias are killed or destroyed.

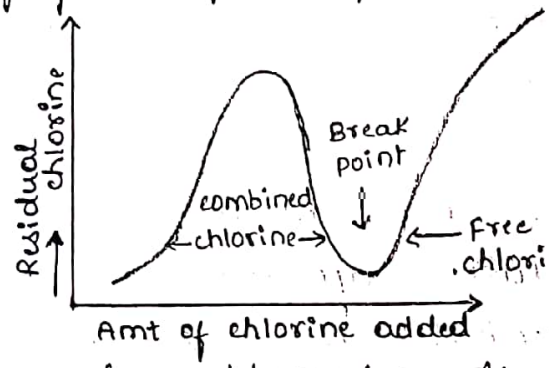
The residual chlorine is removed by exposing H_2O to sunlight & by adding NH_3. A mixture of chlorine and Ammonia form chloramine. This chloramine is better sterlization agent than chlorine. chloramine doesnot give any irritating odour and gives good taste to water.

$$Cl_2 + NH_3 \longrightarrow \underset{\text{chloramine}}{ClNH_2} + HCl$$

Break point chlorination:

It is also known as free residual chlorination and it is a specialised method of chlorination for treating highly polluted water. This process involves addition of sufficient amount of chlorine to oxidise

Organic matter and other impurities leaving behind mainly free chlorine to destroy disease causing bacteria. When the amount of chlorine is added to water is gradually increased. The result obtained can be represented graphically as follows



When chlorine is added to water, there is a proportionate increase in the amount of residual chlorine in the begining this chlorine oxidizes and removes organic matter and combine with ammonia ~~and~~ to form chloramine. As a result of this, the amt of residual chlorine suddenly decreases. But further addition of chlorine gives a proportionate increase in the amt of residual chlorine. This chlorine destroy the disease causing bacterias and other microorganisms. The addition of chlorine at the dip or break is called "Break point chlorination"

This process helps in the removal of undesirable smell, colour & taste from water.

Desalination :-

Sea water contains large quantities of dissolved salts out of which sodium chloride is in Excess Hence it is unsuitable for domestic, industrial and agricultural purposes, water containing dissolved salts with a peculiar [peculiar] salty taste & Hence it is called Brackish water.

Desalination is a process of partial or complete removal of NaCl from sea water some of the important methods used in desalination of water are.

1) Flash Evaporation & distillation.
2) Freezing
3) Electrodialysis ✓
4) Reverse osmosis ✓

1] Flash Evaporation or Distillation:

It is the best method available for removing dissolved salts and other impurities from sea water. When sea water is evaporated only pure water distills over leaving behind the dissolved salts. The modified form of distillation is called Flash Evaporation & it makes use of multistage evapourators consisting of about 50 units. Each unit is maintained at a slightly lower temp^{e} & pressure than the previous unit. When sea water is heated in these units, a portion of sea water undergoes flash evapouration & the disalinate is condensed. the residual water is heated at lower pressure and subjected to flash Evaporation when sea water moves from one unit to the other. It is progressively desalinated & the residual water carries the dissolved salts. Thus desalinated water & concentrated sea water are collected at the opposite ends. This process is costly and commonly used in ships.

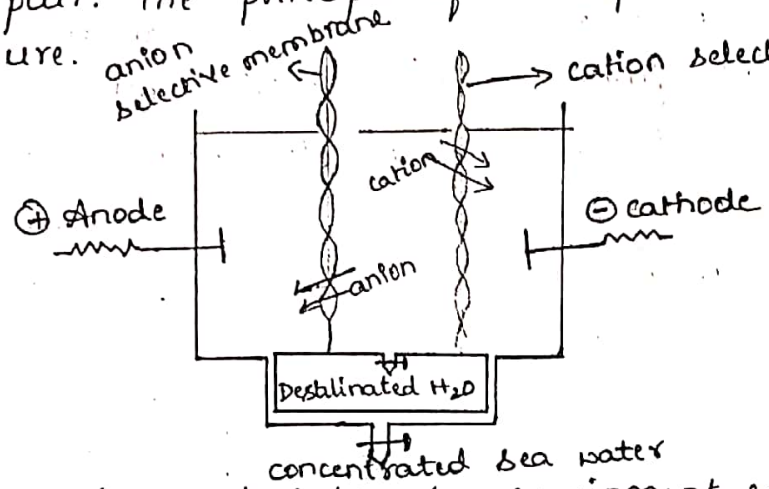
2] Freezing:

When sea water is cooled only pure water crystallises out in the form of ice leaving behind the dissolved salts in the liquid. The crystals of ice are separated washed to remove adhering salts & melted to get pure water. This process has the following disadvantages a) It is highly expensive & can be successfull only at cold climates
b) The crystals of ice formed are small in size & hence difficult to separate.

Electrodialysis :

It is one of the important methods used in the desalination of water. The process of separation of electrolytes from sea water using electric field is called electrodialysis.

Electrodialysis : In this process, all the cations & anions present in sea water are removed by passing direct current (DC) and using electrodes and rigid plastic thin membrane pair. The principle of this process is illustrated in the figure.

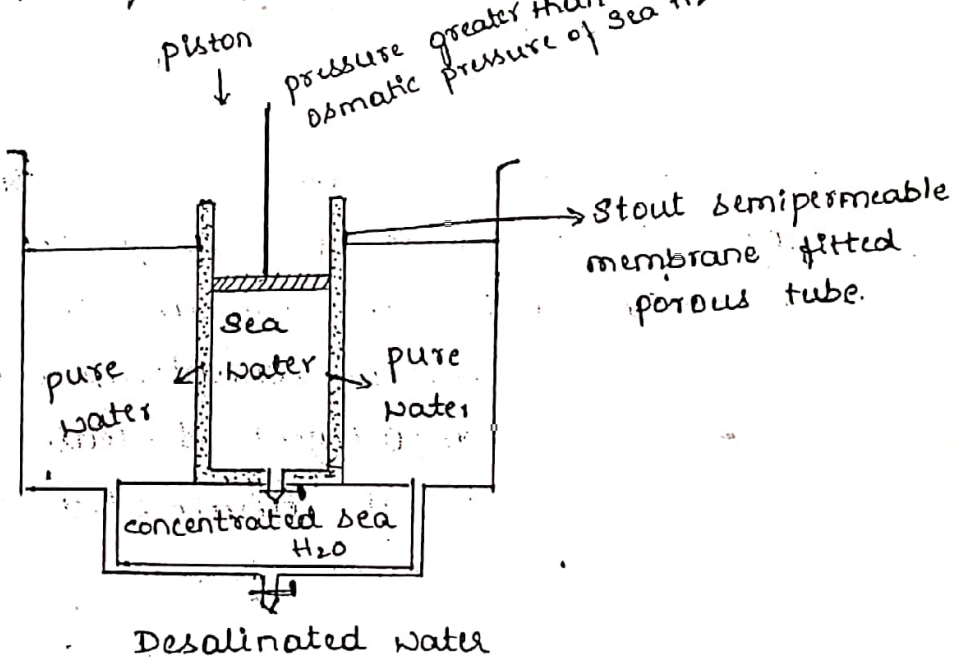


Sea water is sent into the equipment & D.C is passed through the electrodes. The cations of dissolved salts pass through the membrane & move to the cathode. The anions of dissolved salts pass through the membrane & move to the anode thus, the concentration of dissolved salts in the central compartment decreases & it increases in the side compartments. The desalinated water is removed from the central compartment from time to time & it is replaced by fresh sea water this process is costly and difficult to operate.

* [membrane - polystyrene based polymers containing sulphonic acid group (cation selective) & tetra ammonium chloride group (anion selective) they are highly conducting & resistant to chemical attack]

A) Reverse osmosis:

It is one of the important & commonly used method in the desalination of water. When two sol^{ns} of unequal concentrations are separated by a semipermeable membrane, the solvent flows from dilute to concentrated side due to osmosis. The phenomenon of osmotic flow depends on the concentration gradient existing across the membrane However, if hydrostatic pressure greater than the osmotic pressure of the solution is applied on the concentrated side. the solvent flow reverses i.e. the solvent flows from concentrated to dilute side across the membrane. this is the principle of reverse osmosis & in this process pure water (solvent) is separated from dissolved salts (solutes) from sea water. The principle of this process is illustrated in the figure.



Sea water is sent into the equipment and pressure of the order of 15-40 Kg cm^{-3} is applied with the help of a piston Due to reverse osmosis. pure water (solvent) passes through the membrane and collects in the two side compartments. Thus the concentration of dissolved salts increases in the central compartment. The concentrated sea water is removed. from the central compartment from

Time to time & it is replaced by fresh sea water. The desalinated water is taken out from the side compartments.

This process has the following advantages over the other methods -

1) It is simple & easy to operate & the cost is low.
2) The maintainance cost of this process is entirely on the replacement of the membrane. The life time of the memberane is high & it can be easily replaced within few minutes without affecting the regular water supply.
3) This process can remove all the cations & anions of dissolved salts colloidal particles & organic matter of ~~high~~ molecular weight.

* [memberane → Thin films of cellulose acetate are fixed on either sides of perforated tube]