External Treatment

Lime-soda Process

Zeolite Process

Ion-exchange Process

LIME-SODA PROCESS

- The soluble calcium and magnesium salts in water are chemically converted into **insoluble compounds.**
- Done by adding calculated amounts of lime $Ca(OH)_2$ and soda Na_2CO_3.
- Resulting calcium carbonate $CaCO_3$ and magnesium hydroxide $Mg(OH)_2$ get precipitated and are filtered off.

LIME-SODA PROCESS

Permanent Hardness:

- $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2NaCl$
- $MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaSO_4$
- $Ca^{2+} + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2Na^+$

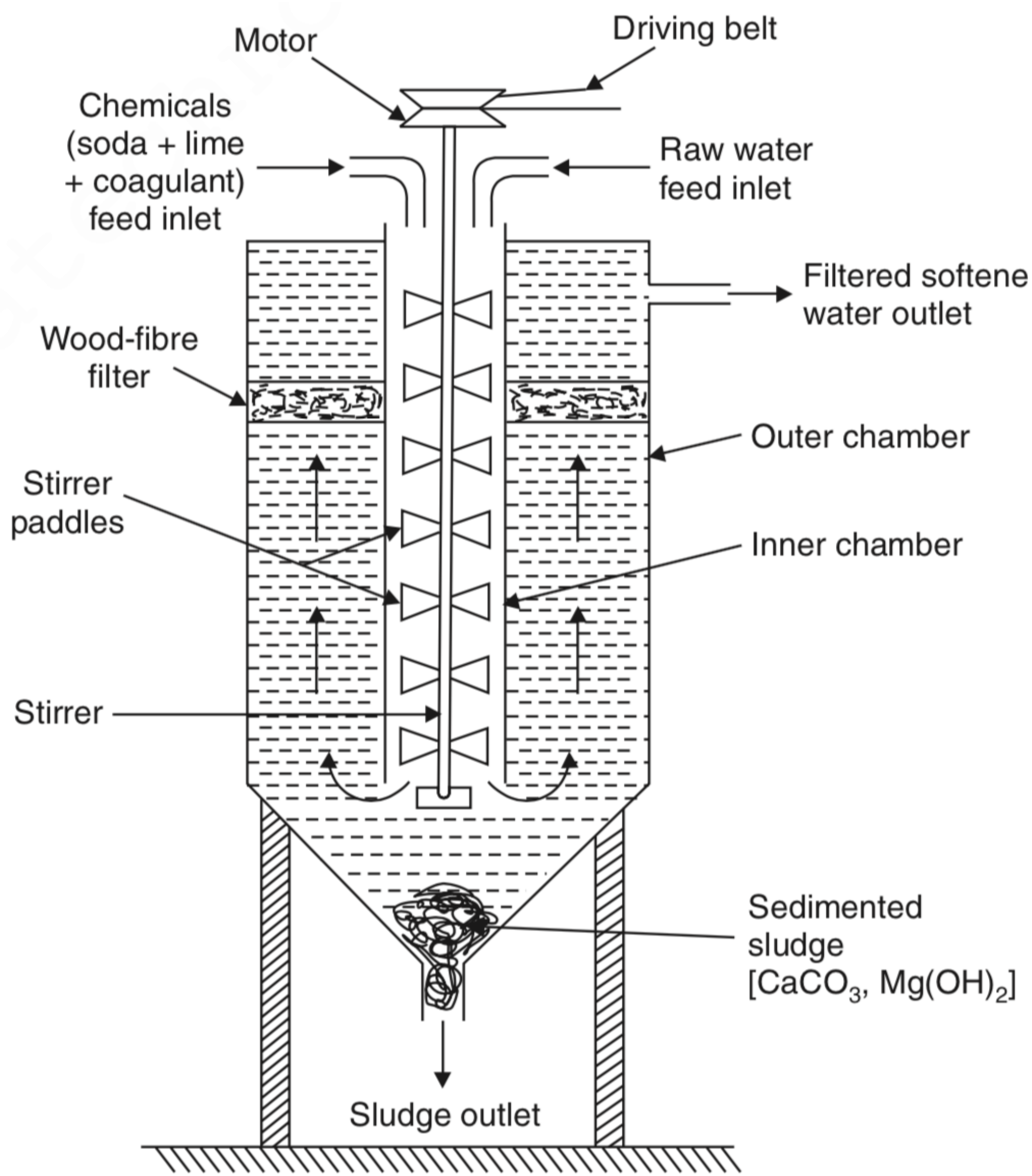
Temporary Hardness:

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

COLD LIME-SODA PROCESS

- Calculated quantity of chemicals (lime and soda) is mixed with water at room temperature.
- At room temperature, the carbonates of metal ions are precipitated as fine powder and settle down very slowly.
- Coagulants (Like Alum, aluminum sulphate, sodium aluminate, etc.) are added to grow the size of carbonates and settle down quickly.

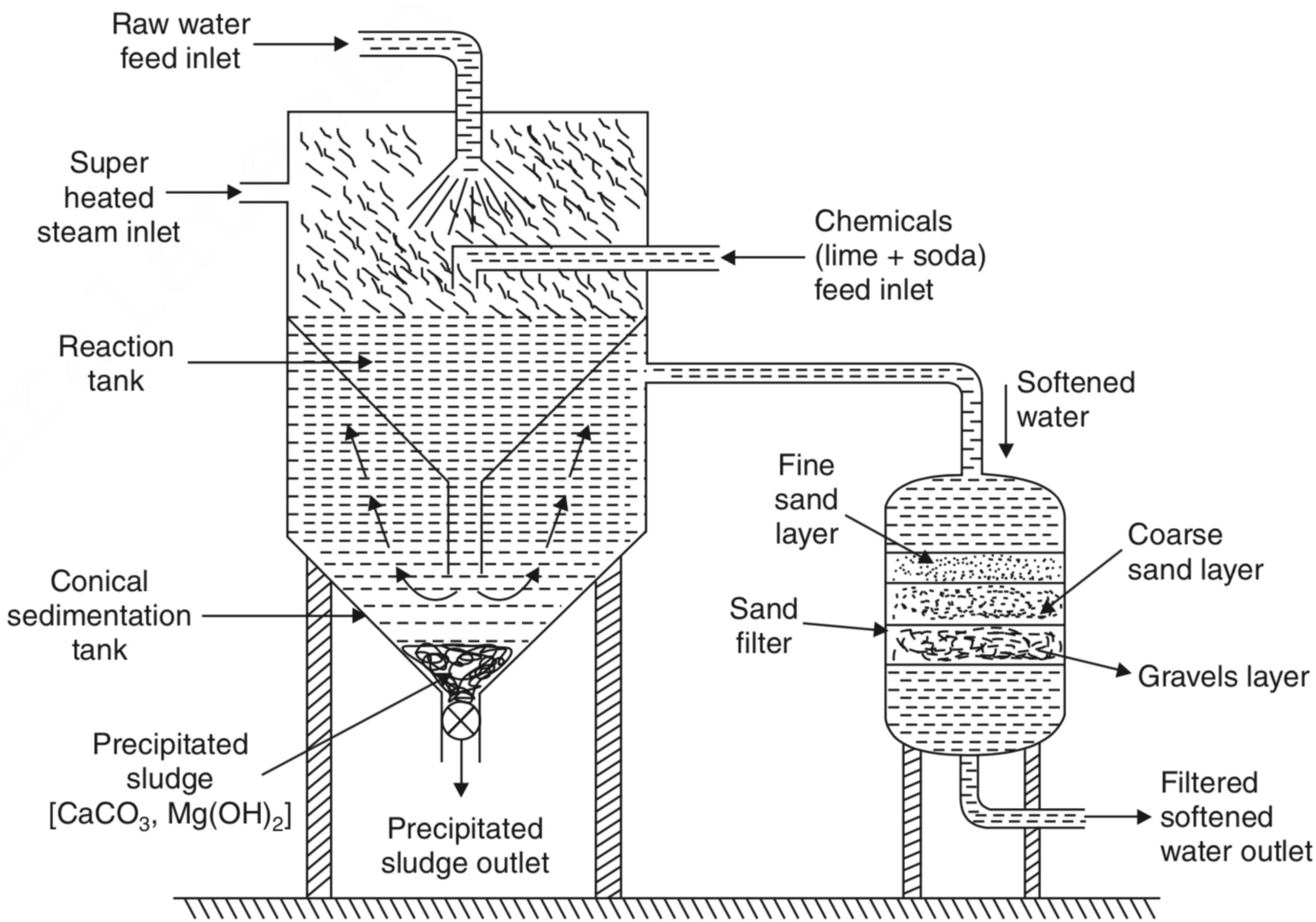
Schematic Diagram of Cold Soda Lime Softener



HOT LIME-SODA PROCESS

- Involves treating water with softening chemicals at temperature of 90 to 100 °C.
- Since hot process is operated at a temperature close to the boiling point of the solution, so
  - the reaction proceeds faster;
  - the softening capacity of hot process is increased to many fold;
  - the precipitate and sludge formed settle down rapidly and hence, no coagulants are needed;
  - much of the gases (Such as CO_2 and air) driven out of the water;
  - Viscosity of softened water is lower, so filtration of water becomes much easier. This in-turn increases the filtering capacity of filters.

Schematic Diagram of Hot Soda Lime Softener



Advantages of LIME SODA Process

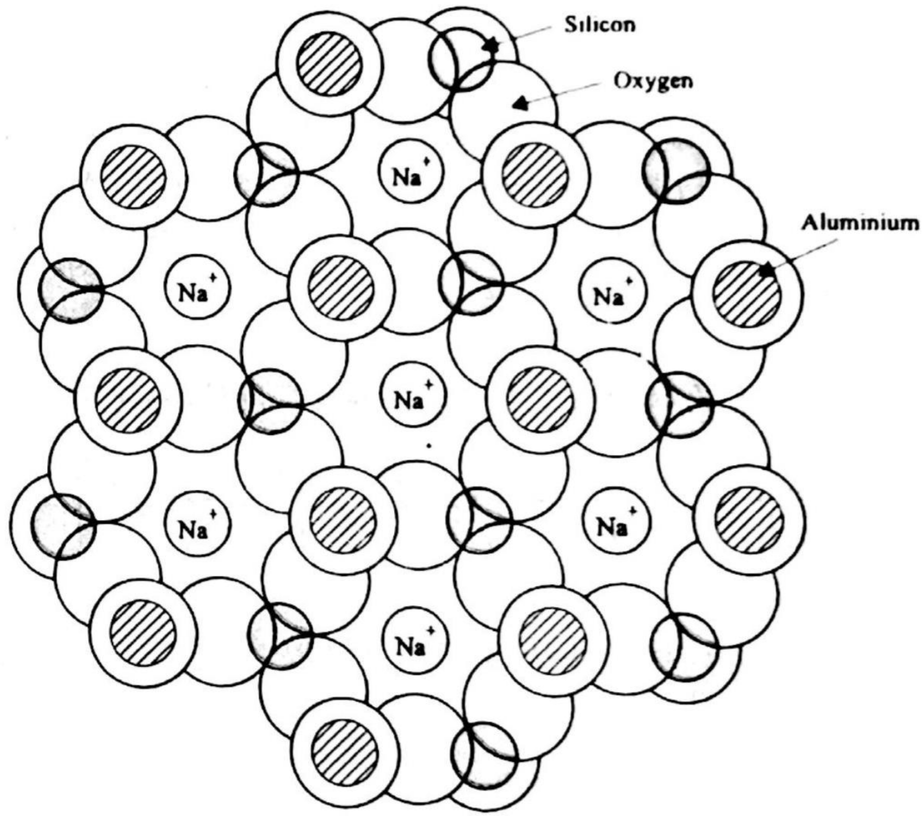
- It is a very economical
- If this process is combined with sedimentation via coagulation, lesser amounts of coagulants shall be needed.
- The process increased the pH value of the treated water, thereby corrosion of the distribution pipes is reduced.
- Besides the removal of hardness, the quantity of minerals in the water are reduced.
- To certain extent, iron and manganese are also removed from the water.
- Due to alkaline nature of treated- water, amount of pathogenic bacteria's in water is considerably reduced.

Disadvantages of LIME SODA Process

- For efficient and economical softening, careful operation and skilled supervision is required.
- Disposal of large amounts of sludge (insoluble precipitate) poses a problem. However, the sludge may be disposed off in raising low-lying areas of the city.
- This can remove hardness only up to 15 ppm, which is not good for boilers.

Zeolite Process

- Hydrated sodium alumino silicate minerals: $Na_2O_. Al_2O_3. xSiO_2, yH_2O$ where x = 2-10 and y = 2-6.
- Zeolite is capable of exchanging reversibly its *sodium ions* with hardness-causing ions in water.

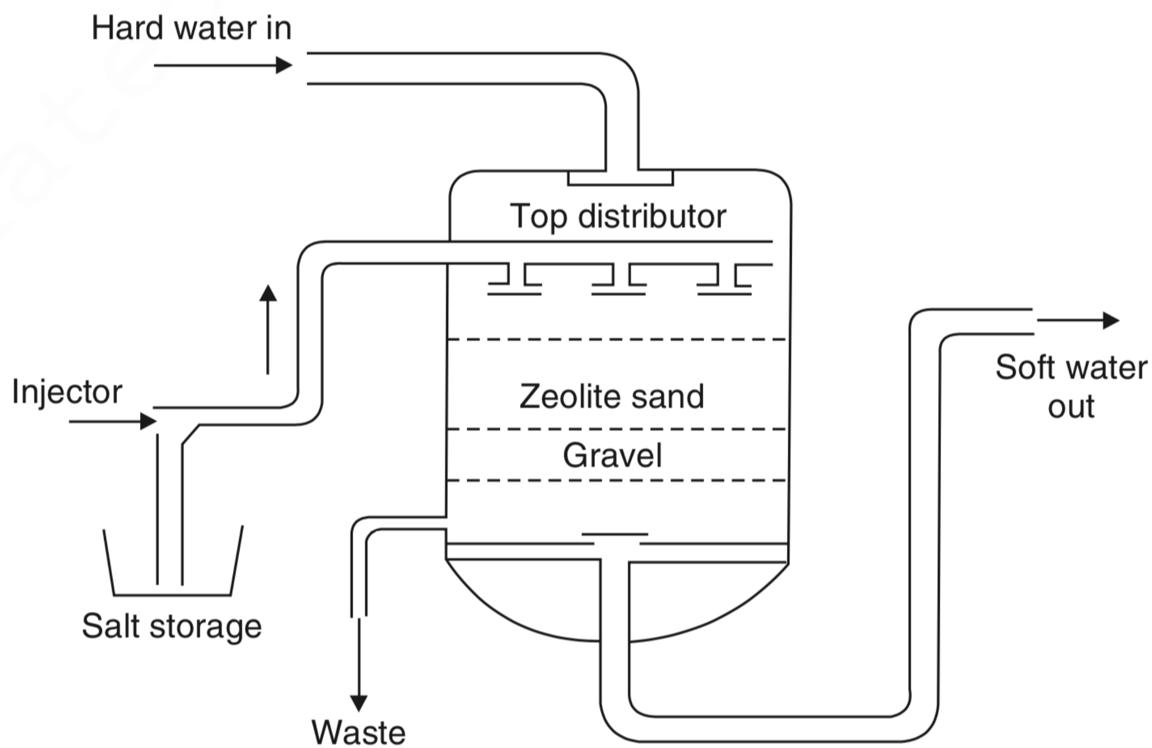


Zeolite are two types:

- Natural zeolites are non-porous, e.g. Natrolite $Na_2Al_2Si_3O.\ 2H_2O$
- Synthetic zeolites posses gel structure and higher exchange capacity than natural Zeolites.

Schematic Diagram of Zeolite Softener

- Hard water is percolated at a specified rate through a bed of zeolite; kept in a cylinder.
- The Hardness causing ions (Ca^{2+}, Mg^{2+}etc.) are retained by the zeolite as CaZe and MgZe; while the outgoing water contains sodium salts.



Zeolite Process

- $Na_2Ze + Ca(HCO_3)_2 \rightarrow CaZe + 2NaHCO_3$
- $Na_2Ze + Mg(HCO_3)_2 \rightarrow MgZe + 2NaHCO_3$
- $Na_2Ze + CaCl_2$ (or $CaSO_4$) $\rightarrow CaZe + 2NaCl$ (or Na_2SO_4)
- $Na_2Ze + MgCl_2$ (or $MgSO_4$) $\rightarrow MgZe + 2NaCl$ (or Na_2SO_4)

Zeolite Process

ADVANTAGES:

- The hardness is removed almost completely
- Equipment occupying a small space
- Requires less time

DISADVANTAGES:

- Treated water contains more sodium salts than in lime soda process
- The method only replaces $Ca^{2+} and\ Mg^{2+}$ ions by Na^{+} ions leaves all the anions.

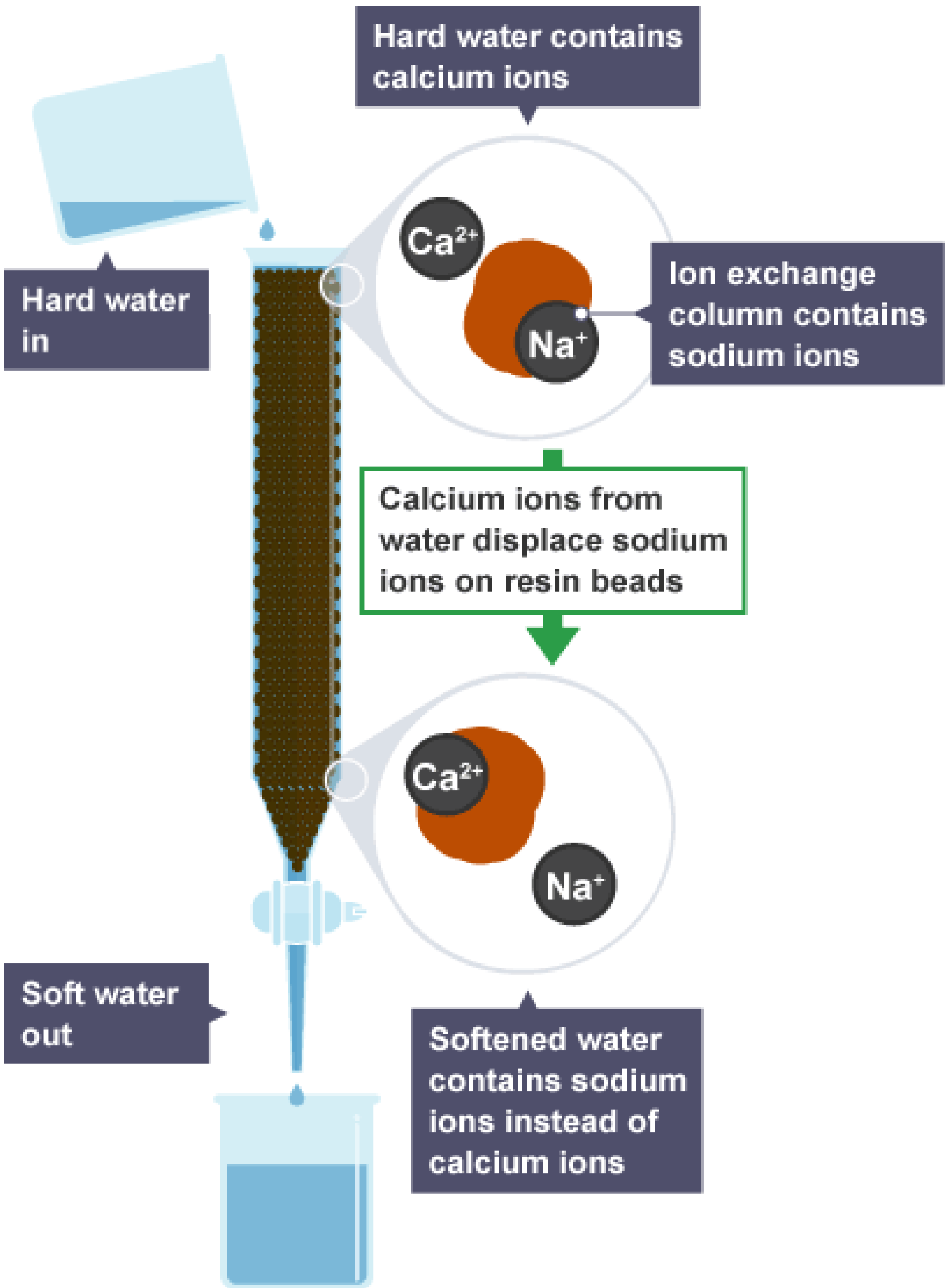
ION EXCHANGE PROCESS

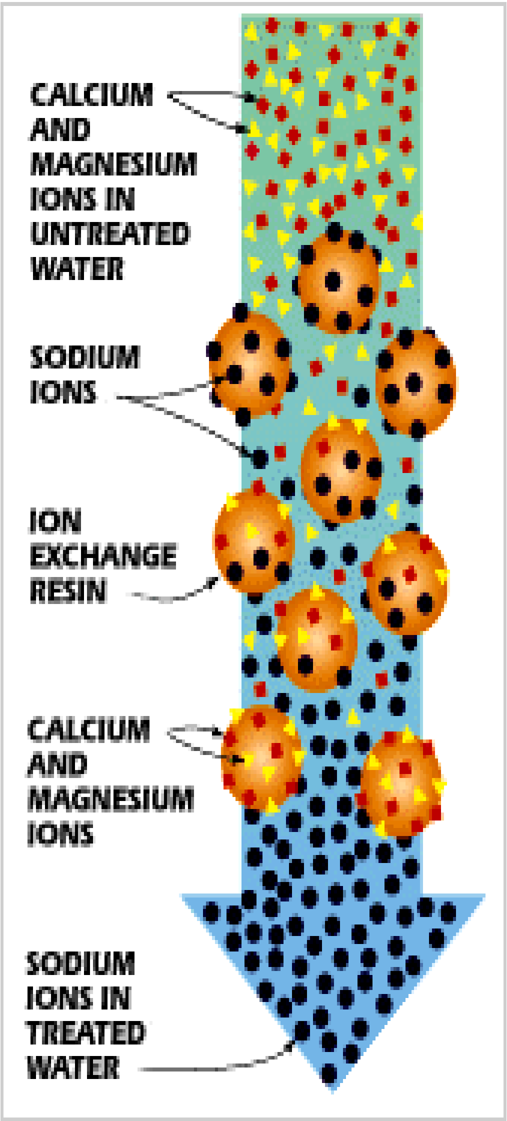
- Modern ion exchange resins are man-made materials which exchange or *'swap'* ions that cause hardness (Ca^{2+}, Mg^{2+}) with ions that do not cause hardness (Na^{+}).
- Ion exchange units used for water softening purpose, contain cation *(positive ion)* exchange resin.

ION EXCHANGE PROCESS

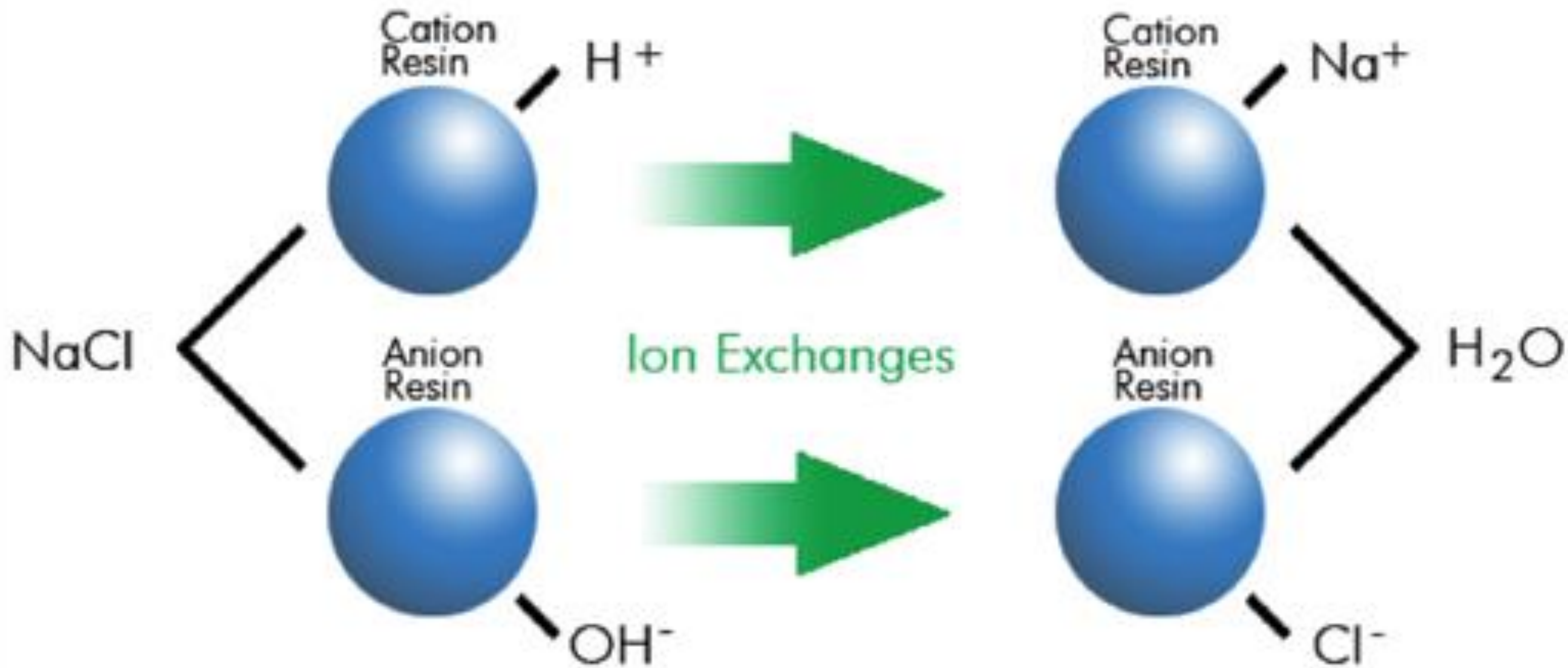
- The hard water is passed through a cation exchange resin.
- The resins used are complex sodium compounds and represented as RNa.
- The Ca^{2+} and Mg^{2+} ions in the hard water swap with the Na^{+} ions in the resin:
- $2RNa_{(s)} + Ca^{2+}{}_{(aq)} \rightarrow R_2Ca_{(s)} + 2Na^{+}{}_{(aq)}$
- Eventually the resin loses all of its Na^{+} ions and it needs to be regenerated by passing a concentrated solution of sodium chloride through it.

Ion Exchange Resin



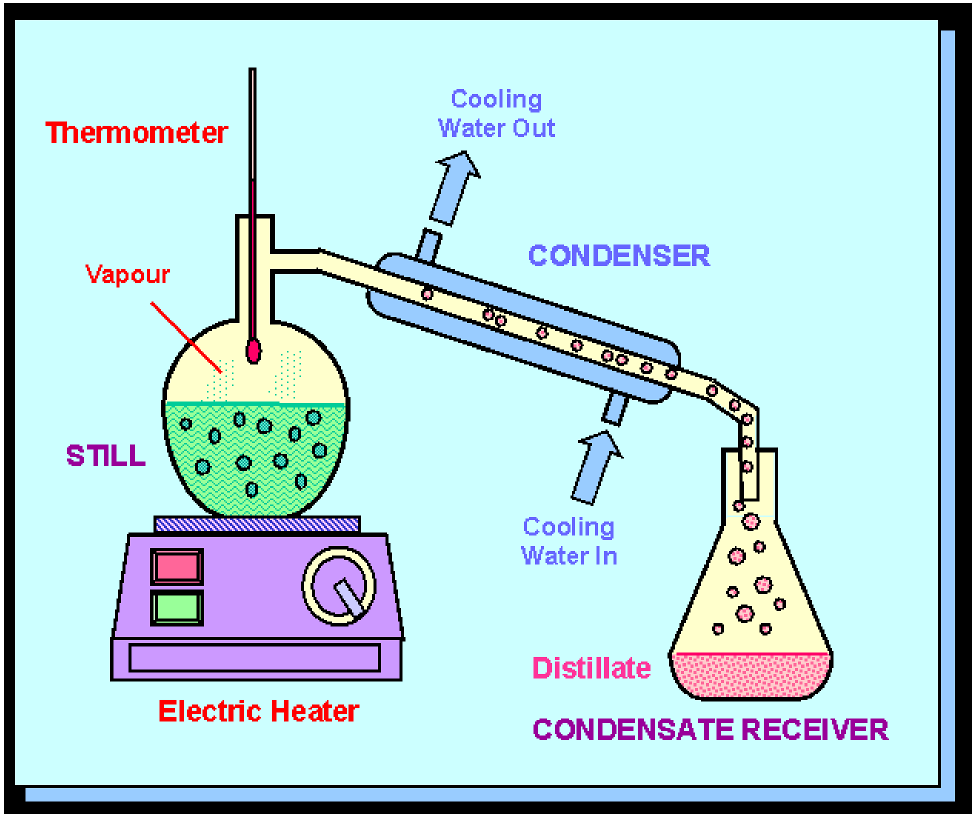


Deionisation



Distillation:

- Involves boiling the water and then cooling the vapour
- ALL dissolved and suspended solids and dissolved liquids are removed from the water
- not used on a large scale to soften water due to the expense involved in boiling the water



Internal Treatment

The methods used for internal treatment of water are:

1. Colloidal Conditioning
2. Carbonate Conditioning
3. Phosphate Conditioning
4. Calgon conditioning

Colloidal Conditioning

- Scale formation can be reduced by introducing colloidal substances like kerosene, tannin, glue, agar etc. to the boiler water.
- These substances act as protective coatings.
- They surround the minute particles of scale forming salts and prevent their coalescence and coagulation.
- Hence, the salts remain as loose, non-sticky deposits in the form of sludge, which can be removed by simple ‘blow down’ operation.
- This process is suitable for low pressure boilers.

Carbonate Conditioning

- This method is useful in low pressure boilers.
- Scale forming salts like $CaSO_4$ present in water are precipitated as insoluble $CaCO_3$ by the addition of sodium carbonate.

$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$$

- The lose and slimy precipitate (sludge) of $CaCO_3$ formed is removed by blow-down operation.

Phosphate Conditioning

- This technique is useful for high pressure boilers.

- Hardness causing salts are converted into non-adherent and easily removable soft sludge of their phosphates by treating them with sodium phosphates.

$$3MCl_2 + 2Na_3PO_4 \rightarrow M_3(PO_4)_2 + 6NaCl$$

$$3MSO_4 + 2Na_3PO_4 \rightarrow M_3(PO_4)_2 + 6NaSO_4$$

where M = Ca^{2+} and Mg^{2+}

- Calcium can be properly precipitated at a pH of 9.5 or above. Therefore, the choice of phosphate salt depends upon the alkalinity of boiler-feed water.

- The phosphate chosen should be adjusted to the pH 9.5 to 10.5.

- The three different phosphates are as follows.

(a) Mono sodium phosphate (NaH_2PO_4): It is highly acidic and used for highly alkaline water. In other words it reduces the pH of the highly alkaline water and brings it near the optimum pH.

(b) Disodium phosphate (Na_2HPO_4): Its acidity is moderate. It is used for moderate alkaline water.

(c) Trisoidum phosphate (Na_3PO_4): It is highly alkaline and used for low pH (acidic) water to increase the pH so that Ca^{2+} or Mg^{2+} may precipitate easily.

Calgon Conditioning

- Calgon is the commercial name of sodium hexametaphosphate.
- Ca^{2+} from the scale forming salts is trapped by the phosphate and forms complex, which is soluble in water and remains in the dissolved form without causing any harm to the boiler.

$$Na_2[Na_4(PO_3)_6] \rightarrow 2Na^+ + [Na_4(PO_3)_6]^{2-}$$

$$2CaSO_4 + [Na_4(PO_3)_6]^{2-} \rightarrow [Ca_2(PO_3)_6]^{2-} + 2Na_2SO_4$$

- However, this treatment is not capable of preventing the formation of iron oxide and copper depositions, which can be prevented by adding EDTA or its sodium salt to the boiler water. EDTA bind the cations of scale forming salts into soluble complexes.

Specification of Drinking Water

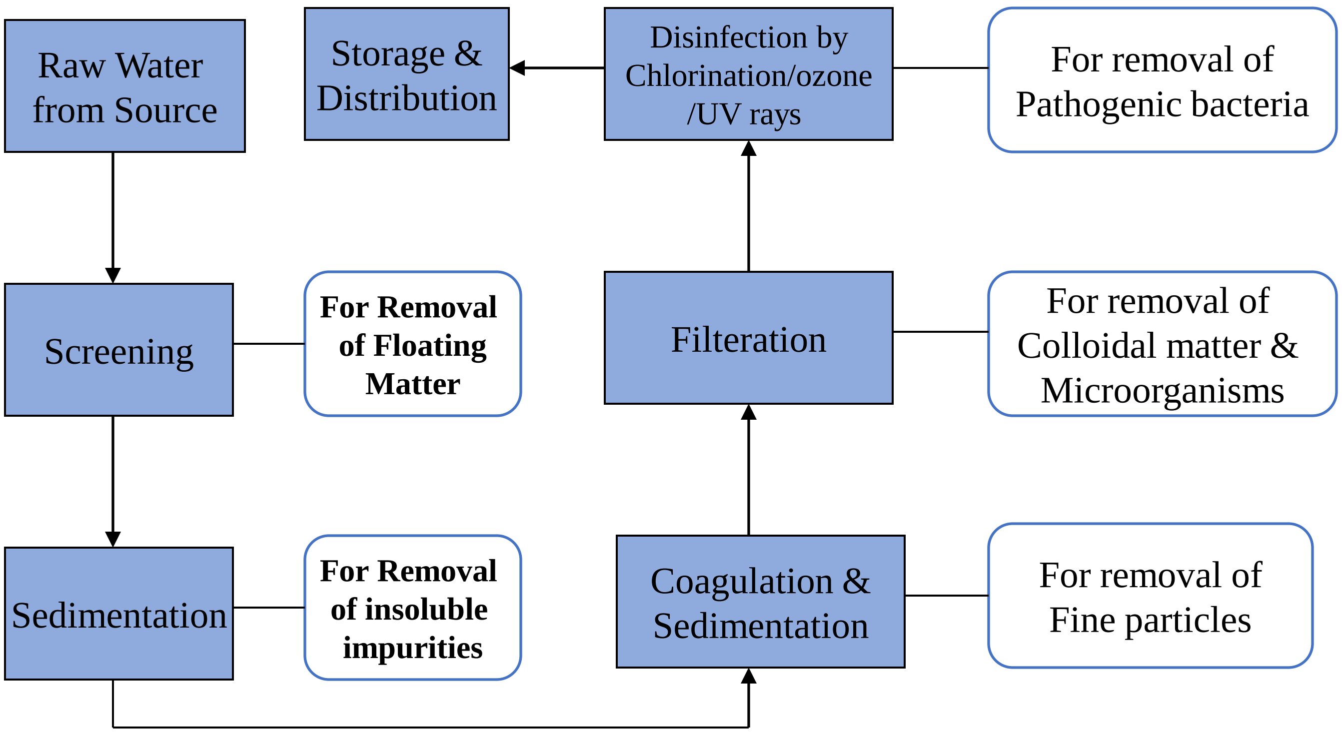
- Primary Standards: Primary standards specify the maximum contaminant levels of various dissolved minerals based on their effect on human health.

- Secondary Standards: vary from place to place depending upon the taste, odour, colour and hardness of water etc. and do not have any anticipated effect on the health.

Requisites of Drinking Water

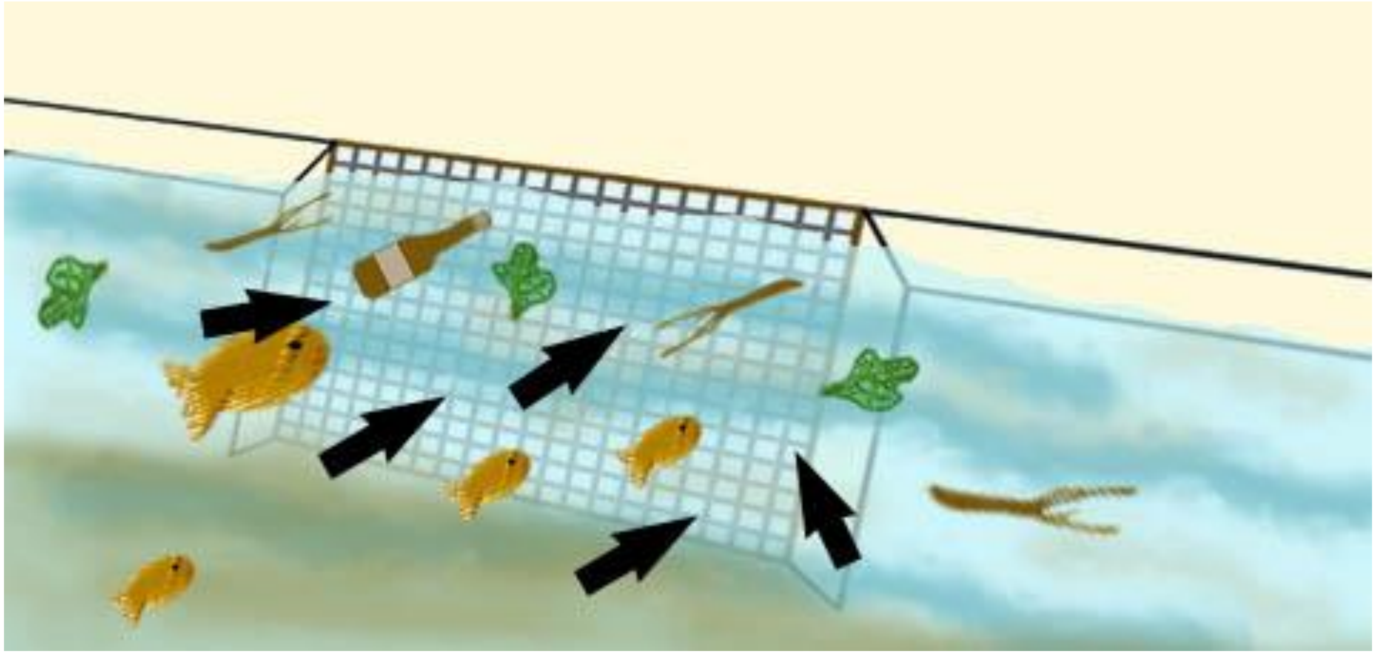
- Free from objectionable minerals.
- pH value ranging from 6.5 to 8.5.
- Total dissolved solids should be less than 500 ppm.
- Free from pathogenic microorganisms.
- Suspended matter should not exceed 10 ppm.
- Free of Fe & Mg, permissible limit being 0.3 mg/L and 0.05 mg/L resp.
- Free from objectionable dissolved gases like H_2S.
- Clear, odourless and should have pleasant taste.

Water Treatment for Domestic/Municipal Purpose



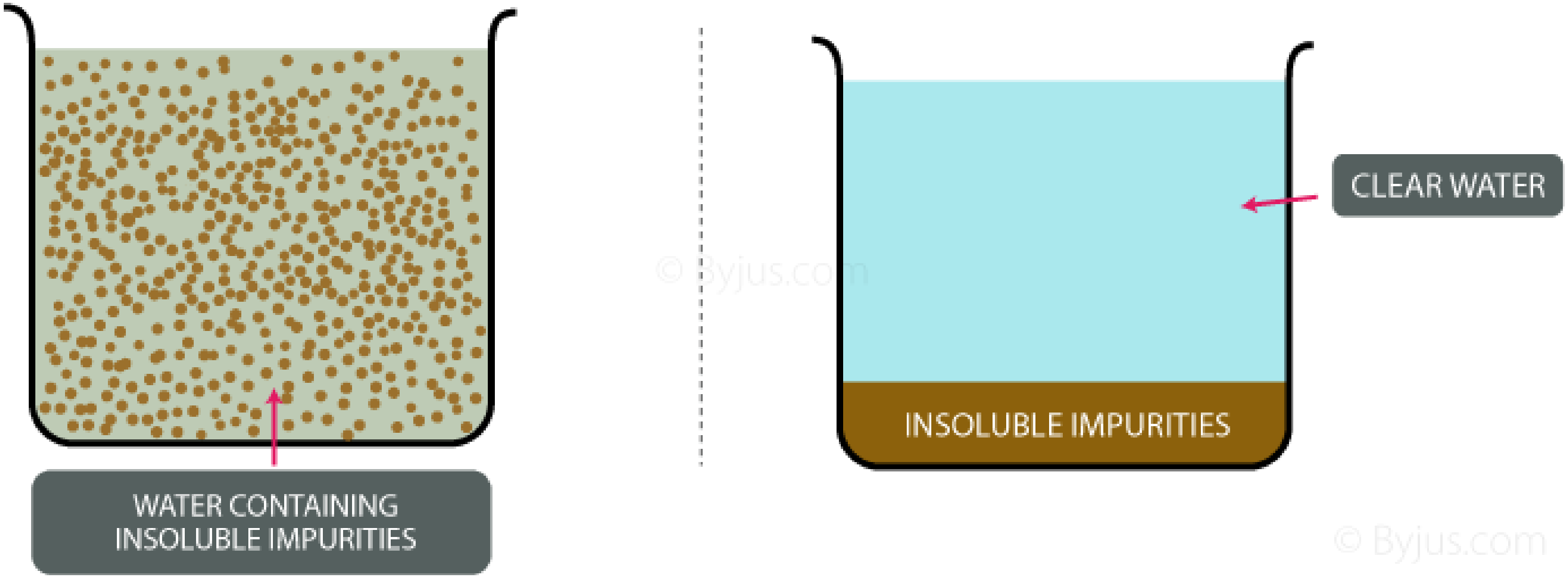
Screening:

Water is first passed through a wire mesh to remove any floating debris – twigs, plastic bags etc.



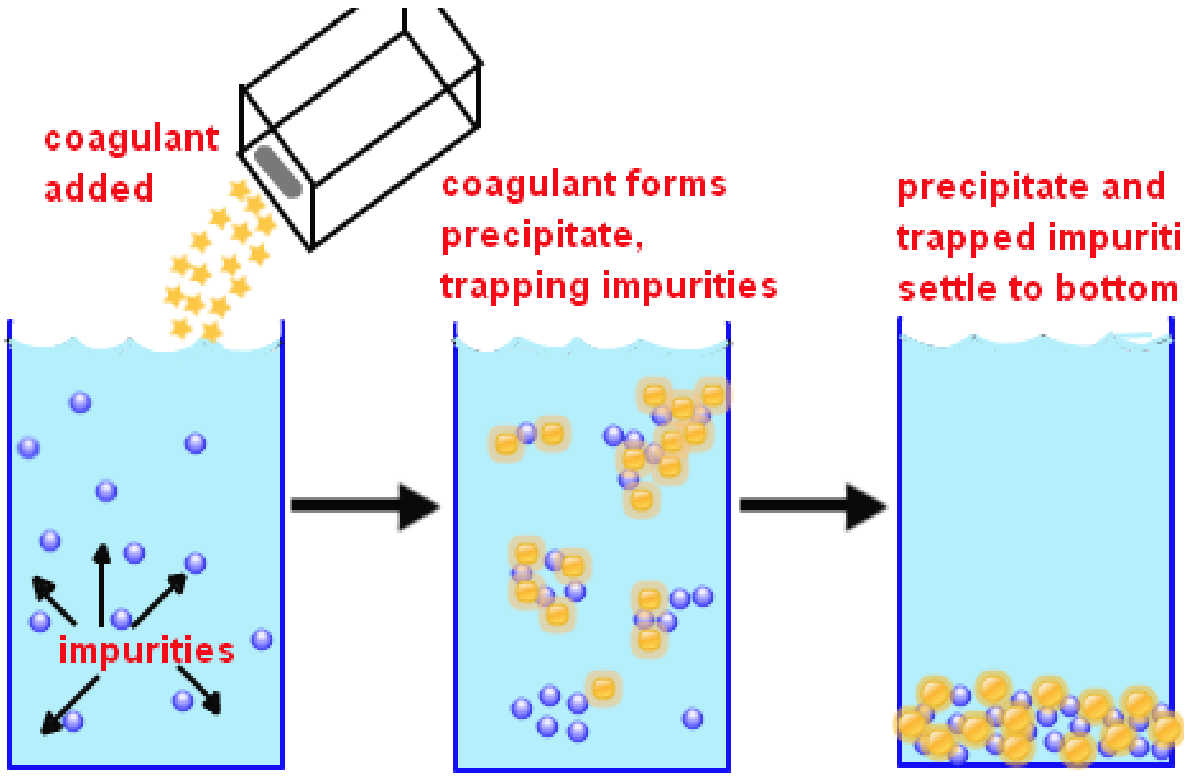
Sedimentation:

Process of allowing water to stand undisturbed in big tanks for 2-8 hours so that the suspended particles settle down at the bottom.



Coagulation:

- Fine particles of clay & silica doesn't settle down by sedimentation.
- A coagulant is added, which entraps the fine particles of clay & silica making bigger particles which settle down easily.
- Most commonly used coagulants: Alum [$K_2(SO_4)_3$. Al_2 $(SO_4)_3$. $24H_2O$], sodium aluminate [$NaAlO_2$] and ferrous sulphate [FeSO4. 7H2O].



Settlement (Sedimentation):

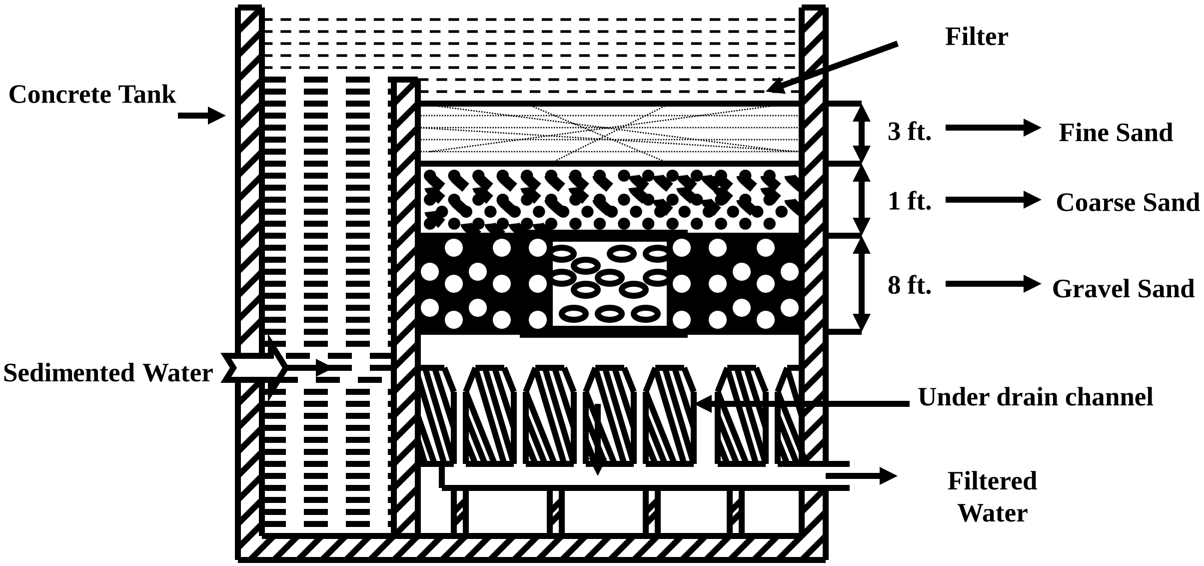
- The flocculated water is pumped into the bottom of large settlement tanks and rises up slowly (allows maximum settlement to take place atthe bottom of the tank) to the surface where clear water is collected in channels

- The suspended particles settle to the bottom.

- Approximately 90% of particles are removed in settlement stage.

Filtration:

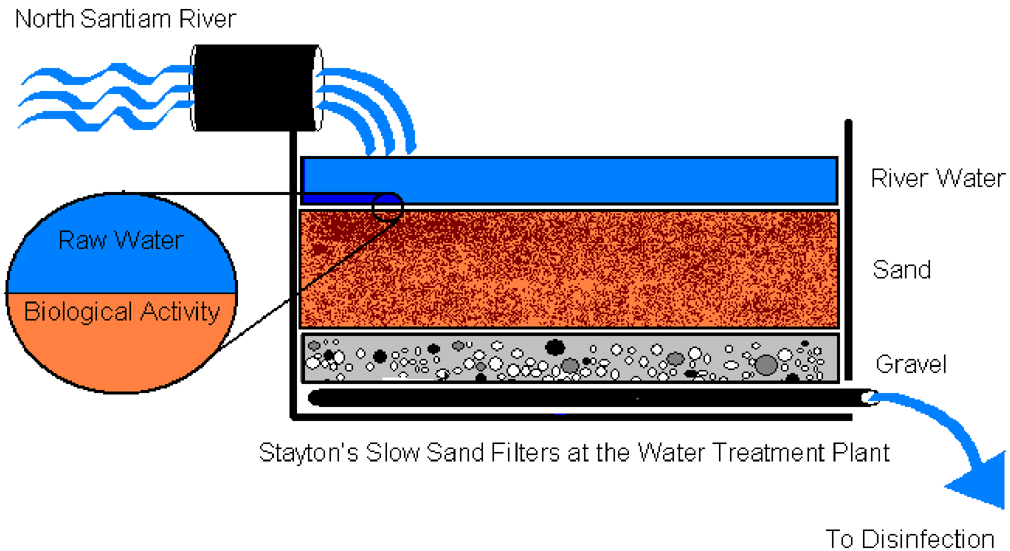
- The water, from top of settlement tanks, is allowed to fall through beds of graded sand and gravel.
- These filter beds remove any remaining suspended solids.
- The sand acts just like a sieve or filter paper in removing the suspended solids.

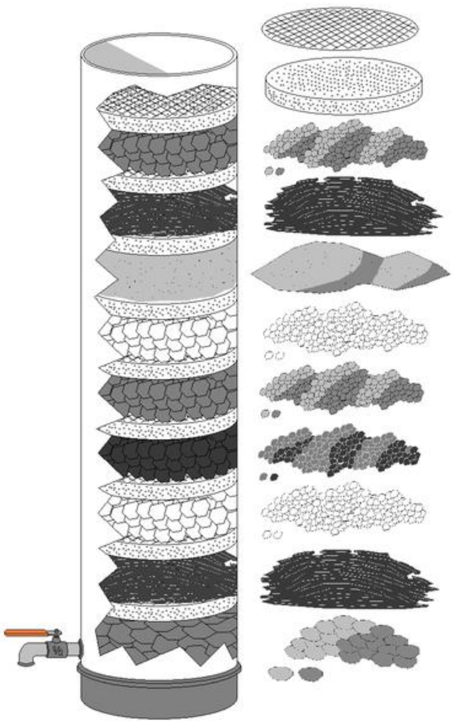


Rapid gravity filter

- Particles removed are in the range of 0.1 to 100 mm.

Filters


North Santiam River
Raw Water
Biological Activity
River Water
Sand
Gravel
Stayton's Slow Sand Filters at the Water Treatment Plant
To Disinfection



Disinfection:

- Process of destroying pathogenic bacteria and microorganisms is known as sterilization or disinfection.
- Physical disinfection techniques include boiling and irradiation with ultraviolet light.
- Chemical disinfection techniques include adding chlorine, bromine, iodine, and ozone to water.
- Chemicals used for disinfecting are known as disinfectants.

Sterilization (boiling):

- Boiling kills vegetative bacterial cells, but spores, viruses, and some protozoa may survive long periods of boiling.
- Boiling is an effective method for small batches of water during water emergencies.
- Boiling is prohibitively <u>expensive</u> for large quantities of water.

UV radiation:

- Ultraviolet radiation is an effective and relatively safe disinfection method, but is relatively expensive and not widely used.
- UV light disrupts DNA of microbial cells, preventing reproduction.
- Specific wavelengths, intensities, distances, flow rates, and retention times are required.

Chemical disinfection:

- Chemicals added to water for disinfection include chlorine, bromine, and iodine.
- Bromine is not recommended for drinking water disinfection, but may be used for pool water.
- Iodine is sometimes used for drinking water disinfection, but causes a bad aftertaste.

Chlorine disinfection:

- Chlorination is a cheap, effective, relatively harmless (and therefore most popular) disinfection method.
- Chlorine is added to water in following forms: Chlorine gas/liquid, bleaching powder ($CaOCl_2$)/hypochlorites ($NaOCl$), tablets, chloramines, ClO_2 gas.

Bleaching Powder

- $CaOCl_2 + H_2O \rightarrow Ca(OH)_2 + Cl_2$
- $Cl_2 + H_2O \rightarrow HCl + HOCl$ Hypochlorous Acid
- $HOCl \rightarrow HCl + [O]$

Chlorine Gas

- $Cl_2 + H_2O \rightarrow HCl + HOCl$
- $HOCl + H_2O \rightarrow H_3O^+ + OCl^-$ Hypochlorite Ion
- $OCl^- \rightarrow Cl^- + [O]$

- **Hypochlorous (HOCl) and hypochlorite ions are strong chemical oxidants, and kill microbes.**
- **Over chlorination (> 0.2 ppm) produces bad odour & taste in water. Dechlorination removes excess chlorine from water.**

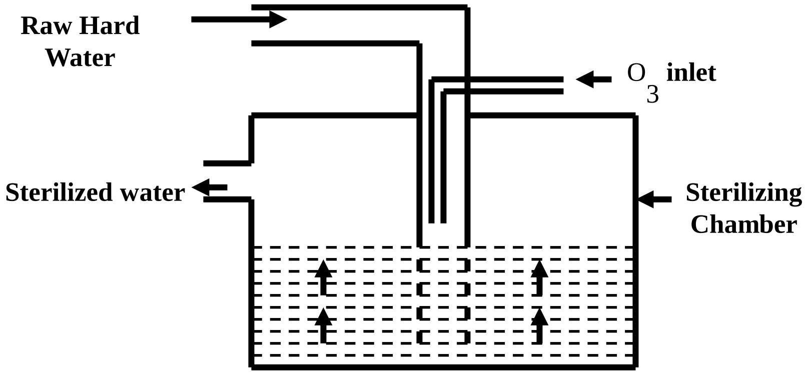
Ozonation

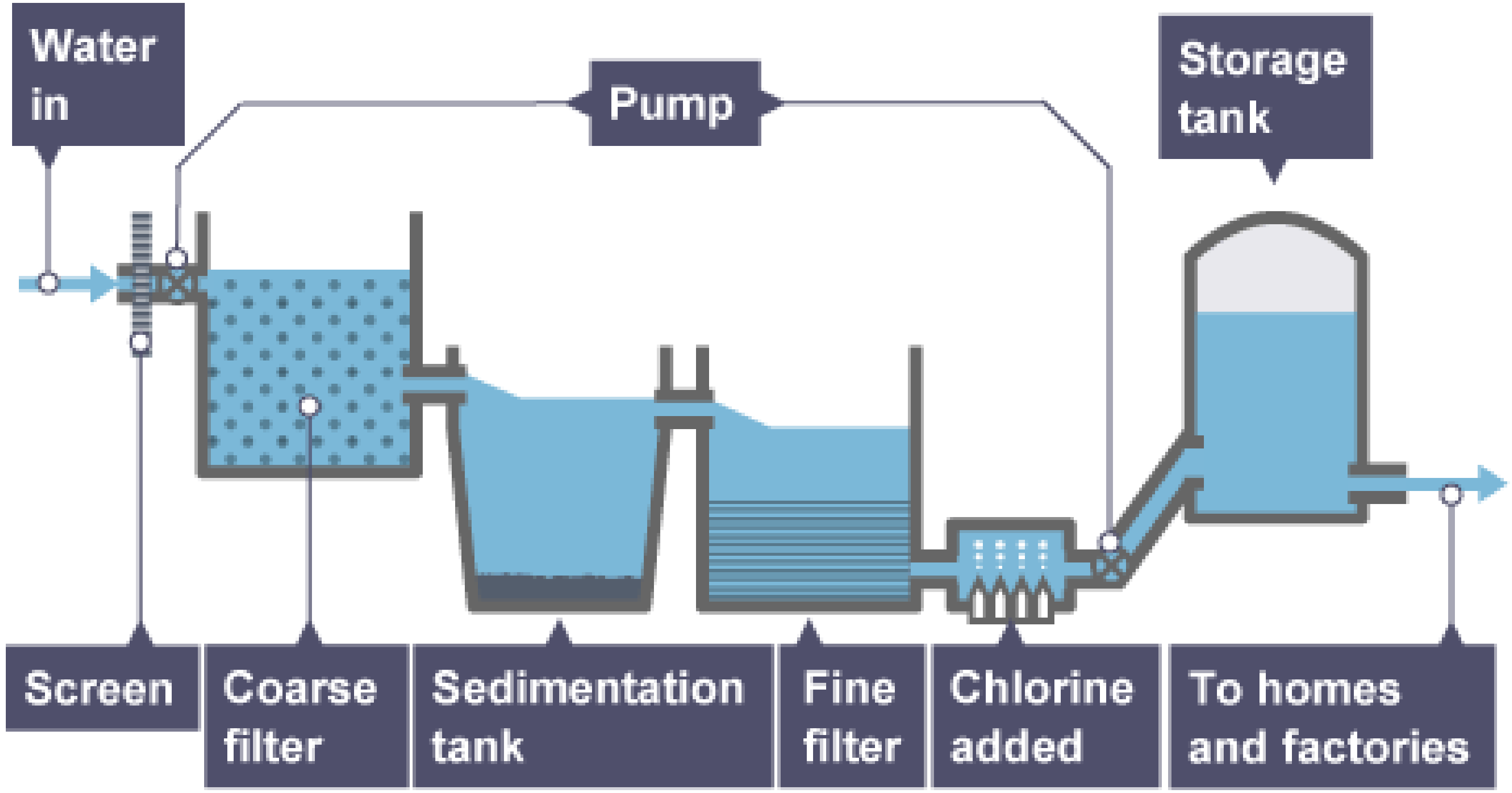
- Ozone can be produced by passing high voltage electric current through a stream of air in a closed chamber.

$$3O_2 \rightarrow 2O_3.$$

$$O_3 \rightarrow O_2 + [O]$$

- Nascent oxygen is a powerful oxidizing agent which removes the organic matter & kills the bacteria.
- Ozone removes colour, odour & taste from water.




Water in
Pump
Storage tank
Screen
Coarse filter
Sedimentation tank
Fine filter
Chlorine added
To homes and factories

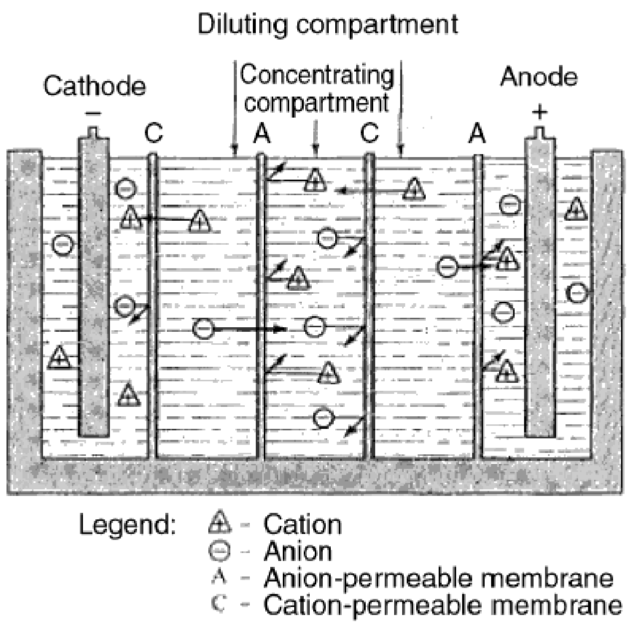
Q: Explain in terms of ions how washing soda softens water.

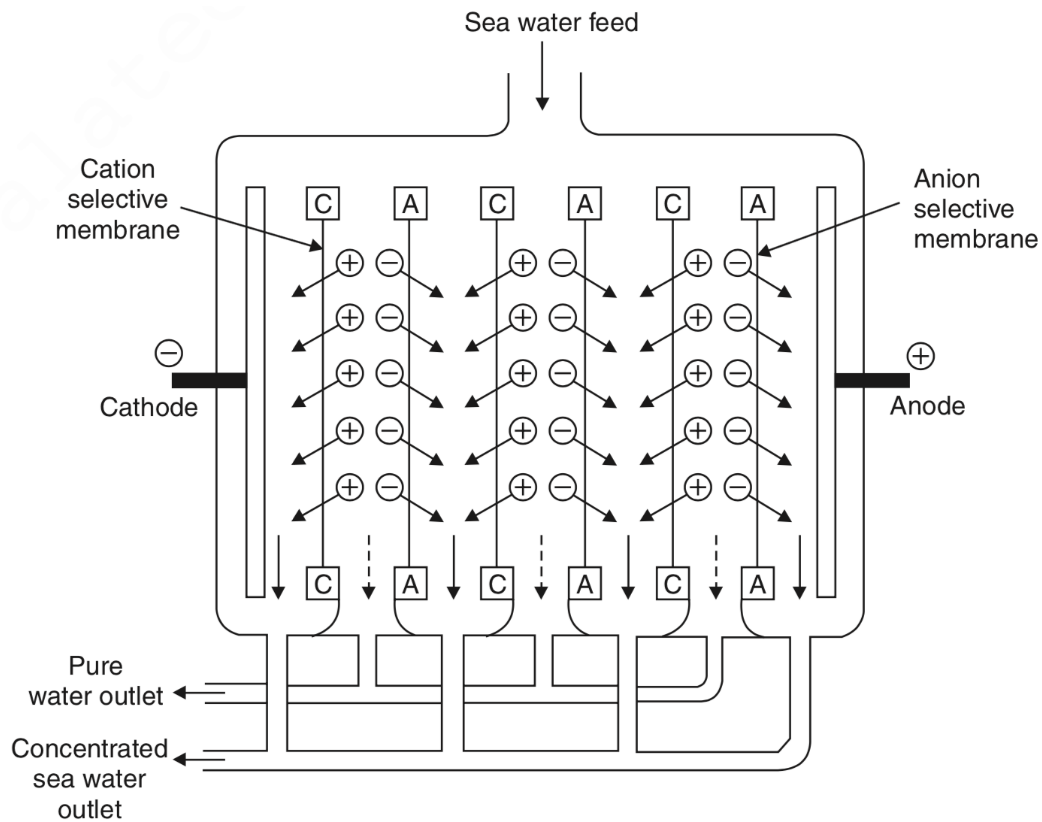
A: The calcium ions from the hard water reacts with the carbonate ions from the washing soda to form insoluble calcium carbonate.

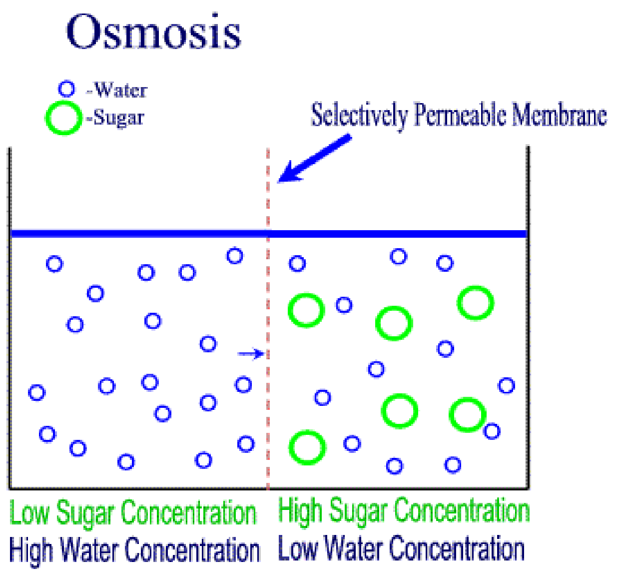
Q: Explain in terms of ions how an ion exchanger softens water.

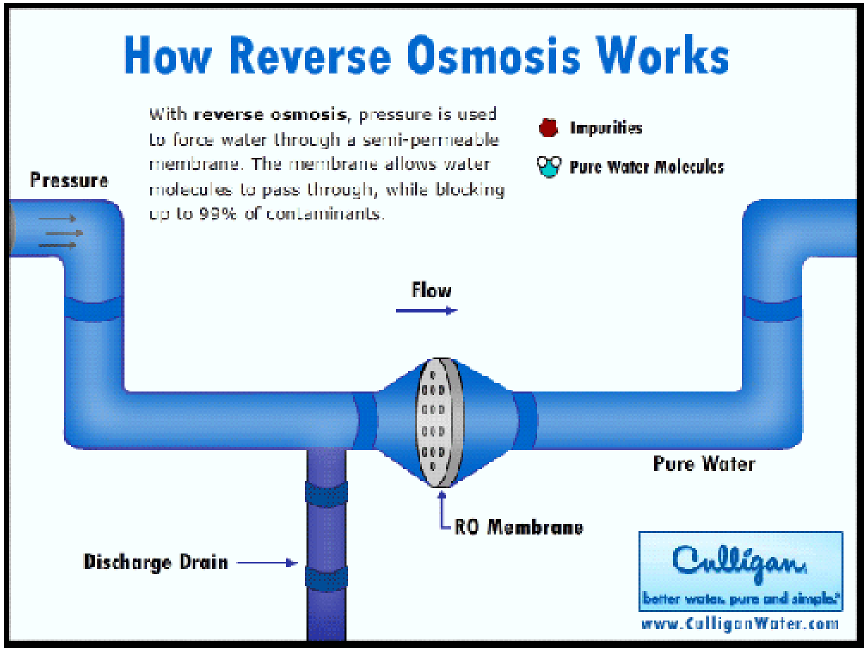
A: The calcium ions from the hard water are swapped for sodium ions from the exchanger. The water no longer contains calcium ions and therefore is no longer hard.

Electrodialysis for Desaliantion



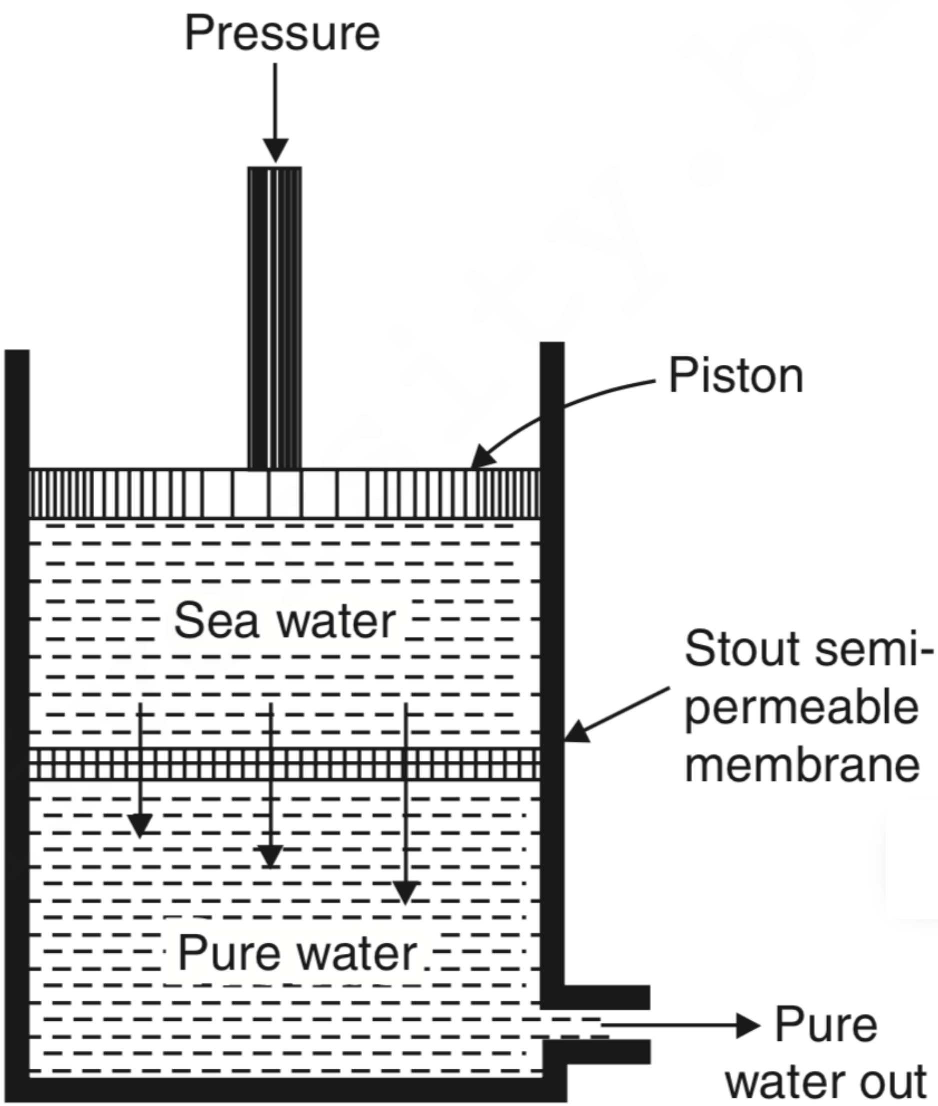


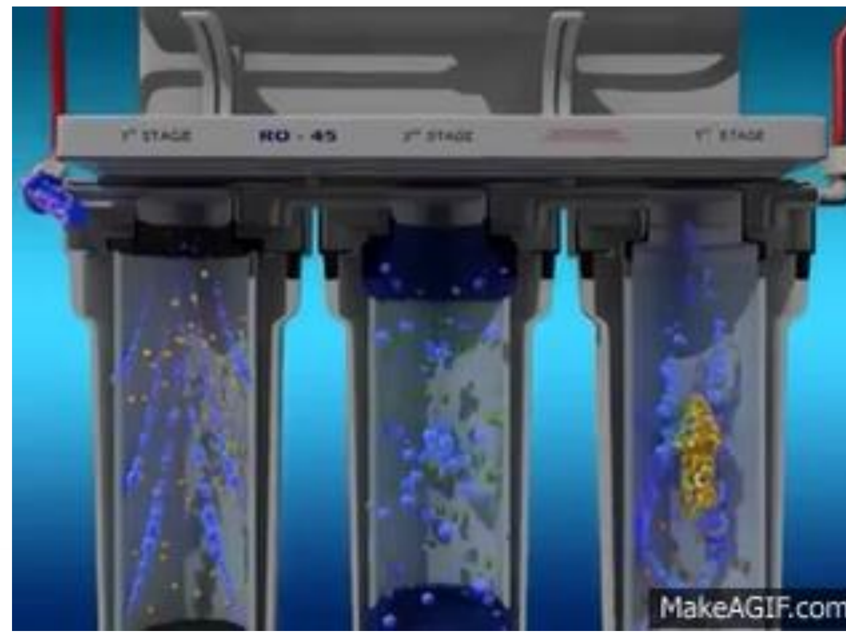


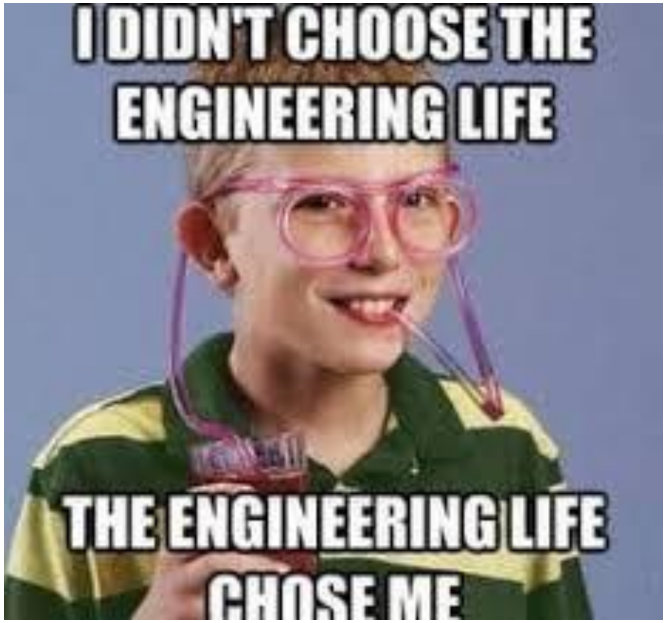


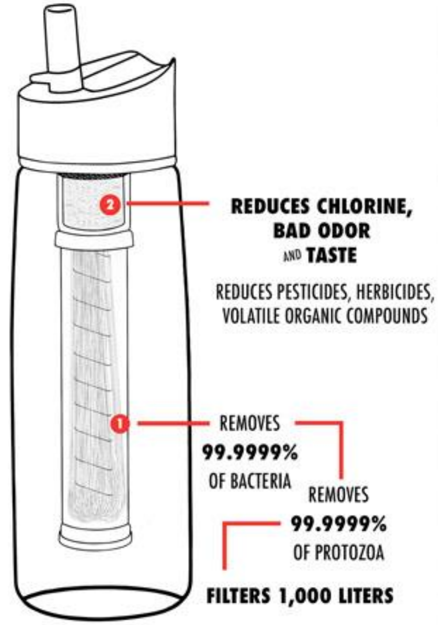
Reverse Osmosis

Reverse Osmosis

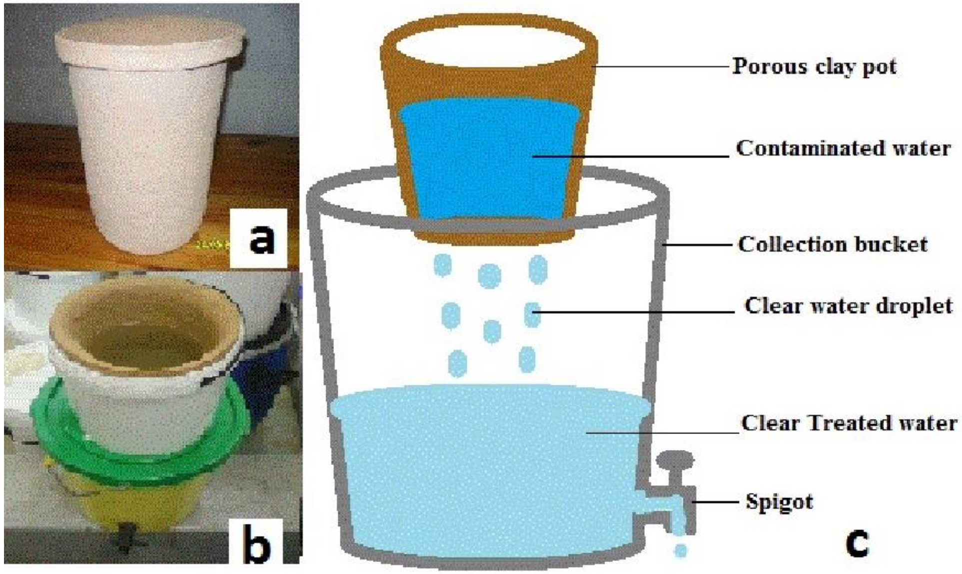








Design your own water filter.


Porous clay pot
Contaminated water
Collection bucket
Clear water droplet
Clear Treated water
Spigot
a
b
c