UNIT – I WATER TECHNOLOGY

PART – A

1. **What are ion-exchange resins? (May 2008); (May 2011)**

Ion-Exchange Resins are long chain, insoluble, cross linked, organic polymers which are capable of exchanging its ions with water. They are of 2 types.

1)Cation exchange resins – RH^+ (e.g) Sulphonated coals , RSO_3H

2)Anion exchange resins – $R'OH^-$ (e.g) Ureaformaldehyde, Amines $R\text{-}NH_2$

2. **Distinguish between soft water and demineralized water. (June 2011)**

Soft water	Demineralized water
It does not contain hardness producing calcium and magnesium ions, but it may contain other ions like K^+, Na^+, Cl^- etc.	Demineralized water does not contain any ions including hardness producing ions.
Softening involves removal of only hardness causing ions.	Demineralization involves removal of all the ions present in water.

3. **What is meant by 'internal conditioning of water'. Name any two boiler compounds used in internal conditioning of boiler feed water. (Apr. 1994)(Oct. 1996)**

The residual salts which are not removed by external methods can be removed by adding some chemicals directly into the boiler water. These chemicals are known as 'Boiler compounds'. This method is known as internal conditioning of water'

Eg : Carbonate conditioning – Sodium carbonate, Phosphate conditioning – Sodium phosphate

4. **What do you understand by demineralization of water ?What are the advantages and disadvantages of demineralization process? ?(Oct. 1996)**

During this process cations and anions of water are completely removed. It uses two columns of cation -exchange column and anion- exchange column filled with resins

Advantages:

i) The process can be used to soften highly acidic or alkaline waters.

ii) It produces water of very low hardness (2ppm).

iii) It is very good for treating water for use in high-pressure boilers.

Disadvantages:

i)The equipment is costly and more expensive.

ii)The turbidity must be below 10 ppm.

5. **What is Desalination? Name the different methods of desalination. (May 2011)**

Removal of common salt (NaCl) from water is called 'Desalination'. Various methods of desalination: Reverse Osmosis, Distillation, Electro- dialysis, Freezing, Solar distillation.

6. **What are the requirements(or) requisites of boiler feed water?**

Water used in boilers known as boiler feed water must be free from

(i) Hardness producing salts (Ca^{2+}, Mg^{2+} ions)

(ii) Suspended impurities like silica, oil,etc.

(iii)Dissolved gases like O_2, CO_2, etc.

7**. Give the chemical formula of zeolite. What are the merits and demerits of zeolite process?**

Zeolite is hydrated sodium alumino silicate. Chemical formula of sodium zeolite is

$Na_2O.\ Al_2O_3.xSiO_2.\ YH_2O.$ where X= 2-10, Y = 2-6.

Zeolites are capable of exchanging reversibly their sodium ions for hardness producing ions in water.

Merits: (i) The softened water has hardness between 15-50ppm. (ii) Requires less time for

softening(iii) No sludge is formed during this process.

Demerits:(i)The treated water contains more sodium salts which cannot be used as boiler feed water.(ii) Highly turbid water cannot be treated by this method.(iii) Zeolite Plant occupies more space.

8.Distinguish between Zeolite process and demineralization process.

S.No.	Zeolite process	Demineralization process
1.	Exchange only cations	Exchange cations as well as anions.
2.	Acidic water cannot be treated since acid decomposes the zeolite	Acidic water can be treated.
3.	Zero hardness cannot be achieved	Zero hardness can be achieved
4.	The treated water contains large amount of dissolved salts which leads to caustic embritttlement in boilers.	The treated water does not contain any ions and therefore it can be safely used in boilers.

9. What is blow down operation?

It is a process in which a portion of concentrated water containing large amount of dissolved salts are replaced by fresh water frequently during steam production.

10.What are the differences between sludges and scales.

S.No.	Sludges	Scales
1.	It is a soft, loose precipitate formed inside the boiler walls during steam production	It is hard, adherent coating formed on the inner walls of the boiler during steam production
2.	Sludges are produced due to the presence of temporary hardness causing compounds like $Ca(HCO_3)_2$, $Mg(HCO_3)_2$	Scales are produced due to the presence of permanent hardness causing substances like $CaCl_2$,$CaSO_4$,$MgCl_2$,$MgSO_4$
3.	It is also produced due to the presence of suspended and colloidal impurities.	It is produced due to the presence of dissolved salts.

PART –B

1. **Explain the demineralization of water by Ion-exchange process. How are the exhausted Cation and anion exchange resins regenerated?**

A.Ion exchange method (Demineralisation)

Working:

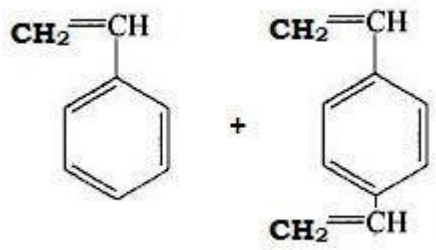
1. Here all the cations and anions are completely removed. It uses two column of cation exchange column and anion exchange column filled with resins.
2. Resins are long chain, insoluble, cross linked, organic polymers. There are 2 types.

i) Cation exchange resins – RH^+ (e.g) Sulphonated coals , RSO_3H

ii) Anion exchange resins . $R'OH^-$ (e.g) Ureaformaldehyde, Amines $R\text{-}NH_2$

iii)

The resins are prepared by copolymerization of styrene and di vinyl benzene.



3. The water is fed into cylinder –I where all the cations are replaced by RH_2 Resins.

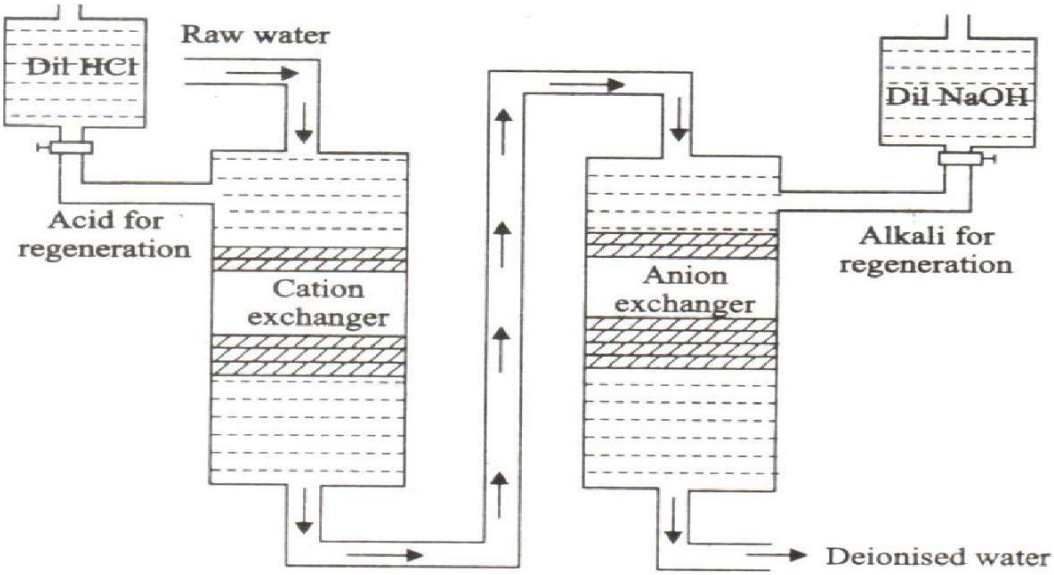
$$2RH^+ + Ca^{2+} \rightarrow R_2\,Ca^{2+} + 2\,H^+$$

4. The cation free water is fed to cylinder II, where all the anions are replaced.

$$2R'OH^- + SO_4^{2-} \rightarrow R_2'\,SO_4^{2-} + 2\,OH^-$$

5. So, the resultant water is free from all types of ions.

Diagram:



Regeneration:

On prolonged use, as all the resins are exhausted, there will be no H^+ or OH^- ions to exchange the unwanted ions. So, they have to be regenerated.
Cation resins are regenerated by HCl and anion resins by NaOH.

$$R_2\,Ca^{2+} + 2\,H^+ \rightarrow 2RH^+ + Ca^{2+}$$

$$R_2'\,SO_4^{2-} + 2\,OH^- \rightarrow 2R'OH^- + SO_4^{2-}$$

Advantages of Ion exchange method:

i) Can be used for high pressure boilers also.
ii) It can treat highly acidic or alkaline water.
iii) We can get pure water as hardness as low of 2 ppm.

Drawbacks of Ion exchange method:

i) Expensive
ii) Fe, Mn cannot be removed as they form complexes with resins
iii) Cannot be used for turbid water as they clog the resins.

2. What is meant by reverse osmosis? Explain the desalination of brackish water by reverse osmosis.

Reverse Osmosis Method: (Desalination): Hyperfiltration/ Super filtration/ brakish water treatment

1. Removal of common salt (NaCl) from water is called ' Desalination'.

2. Various methods:
Reverse Osmosis, Distillation, Electro dialysis, Freezing, Solar distillation, etc.,

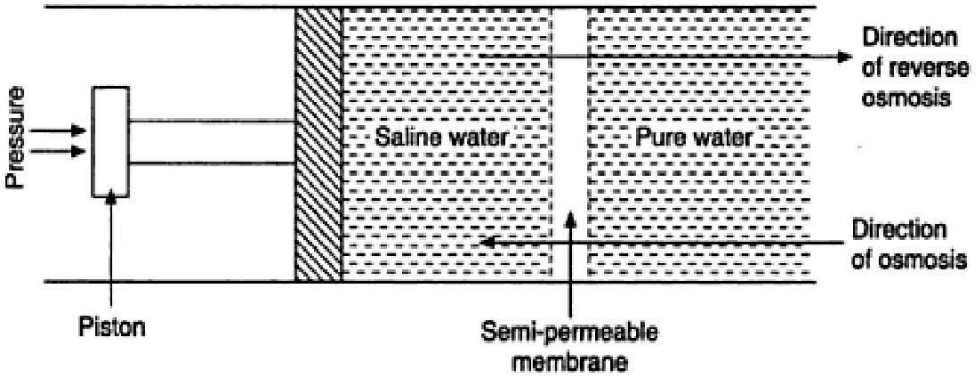
3. Brakish water: Water containing dissolved salts with a peculiar salty taste.

4. Osmosis: When two different concentrated solutions are separated by a semi permeable membrane, due to osmotic pressure, low concentrated solvent flows to higher one. This is known as osmosis.
5. But when we apply an excess and opposite Hydrostatic pressure(15-40kg/cm^2) to overcome the osmotic pressure, then higher concentrated solvent will flow to the lower one. This is known as reverse osmosis.
6. During this RO process , only the water flows across the membrane and it prevents the salt migration. So, this method is also called as ' Super filtration'.

7. The membrane is madeup of cellulose acetate,cellulose butyrate,polymethacrylate

Advantages of Reverse Osmosis:
1.High life time
2.Removes ionic, non-ionic and colloidal silica impurities , which can not be removed by demineralization method.
3. Low capital cost.
4. Simple operational procedure.
5. The membrane can be replaced within a few minutes, thereby providing uninterrupted water supply.

Diagram:



3. What are zeolites? Explain the softening of water by zeolite process mentioning its Advantages, disadvantages and regeneration methods. (Jan 2009)

ZEOLITE (PERMUTIT) SOFTENING PROCESS

Setup

i)Hydrated sodium alumino silicates available in nature are known as zeolite.

ii) These natural zeolites are green sand . They are non porous in nature.

iii) Zeolites are having the general formula Na_2O . Al_2O_3. $xSiO_2$. yH_2O (x = 2 to 10; y = 2 to 6)

iv) The porous and gel structured synthetic zeolites are known as permutit.

v) These zeolites and permutits are used for water softening.

vi) Synthetic zeolite is represented as Na_2Ze.

Principle

i) The sodium ions are loosely held in these zeolites. They are easily replaced by Calcium and magnesium ions present in the water.

ii) When hard water is passed through a bed of sodium zeolite kept in a cylinder, it exchanges its sodium ion with Ca^{2+} and Mg^{2+} ions present in the water to from Calcium and Magnesium zeolites.

iii) Zeolite softeners may be of pressure type or gravity type.

Reactions:

$$CaSO_4 + Na_2Ze \rightarrow CaZe + Na_2SO_4$$

$$MgSO_4 + Na_2Ze \rightarrow MgZe + Na_2SO_4$$

$$CaCl_2 + Na_2Ze \rightarrow CaZe + 2\ NaCl$$

$$MgCl_2 + Na_2Ze \rightarrow MgZe + 2\ NaCl$$

The outcoming water is enriched with large amount of sodium salts which do not cause any hardness. But in cannot be used in boiler.

Regeneration:

i) On prolonged use, all the zeolite sodium ions are exhausted.

ii) There will be no sodium ions to exchange the Calcium and magnesium ions. So, they have to be regenerated.

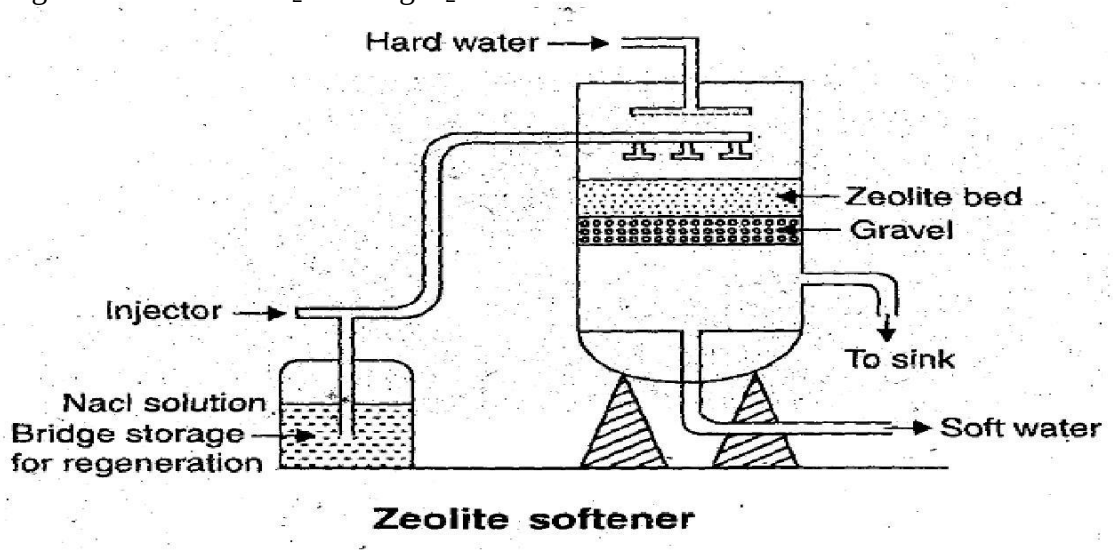
iii) The exhausted zeolite is regenerated by treating with 10% solution of NaCl.

Regeneration reaction:

The regeneration step comprises of a) backwashing b) salting c) rinsing before reuse

$CaZe + 2\ NaCl \rightarrow Na_2Ze + CaCl_2$

$MgZe + 2\ NaCl \rightarrow Na_2Ze + MgCl_2$



Zeolite softener

Advantages of zeolite process:

1. The outlet water will have least hardness around 1 – 2 ppm only.

2. As the zeolite can be regenerated, the method is cheap.

3. Operation is easy.

4. The space requirement for this setup is minimum .

5. No sludge is formed during this process.

Disadvantages of zeolite process:

1. Turbid water cannot be treated as it blocks the pores of the zeolite bed.

2. Acidic water cannot be treated as it decomposes the structure of zeolite.

3. Water containing Fe, Mn cannot be treated as the regeneration is difficult.

4. Brackish water cannot be treated because it contains Na+ ions. So, the ion exchange reaction will not occur.

5. When the softened water contains more dissolved sodium salts, it may result in boiler corrosion and caustic embrittlement.

4. What are boiler compounds? Describe briefly the various methods of internal conditioning of Boiler feed water (June 2009)

INTERNAL TREATMENT BY BOILER COMPOUNDS:

The residual salts that are not removed by external methods can be removed by adding some chemicals directly into the boiler water. These chemicals are known as 'Boiler compounds'. This method is known as 'Internal treatment'.

E.g) Carbonate conditioning, Phosphate conditioning , Calgon conditioning, etc.,

a) Carbonate conditioning:

Used for low pressure boilers. Here the salts like $CaSO_4$ are converted to easlity removable $CaCO_3$. But some times it produces NaOH, CO_2 and hence Carbonic acid. So it is less preferred.

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

b)Phosphate conditioning:

Used for high pressure boiler. No risk of CO_2 liberation.

$$3CaSO_4 + 2\ Na_3PO_4 \rightarrow Ca_3(PO_4)_2 + 3\ Na_2SO_4$$

Three types of Phosphate salts are used:

S.No	Salt	Name	Used for treating
1	Na_3PO_4	Tri sodium Phosphate	highly acidic water
2	Na_2HPO_4	Di sodium hydrogen Phosphate	slightly acidic water
3	NaH_2PO_4	Sodium di hydrogen phosphate	highly alkaline water

c) Calgon conditioning:

Calgon is the trade name of sodium hexa meta phosphate- $Na_2[\ Na_4\ (PO_3)_6]$.
With calcium ions it forms a soluble complex and prevents scale and sludge formation. It is used for high and low pressure boilers.

$$2CaSO_4 + Na_2[\ Na_4\ (PO_3)_6] \rightarrow Na_2\ [Ca_2(PO_3)_6] + 2\ Na_2SO_4$$

d) Colloidal conditioning

Formation of scale in boilers can be avoided by adding organic substances like kerosene, tannin, agar-agar, etc. these substances get coated over the scale forming precipitates thereby yielding non-sticky deposits which can be removed.

5. What are boiler troubles? How are they caused? Suggest steps to minimize the boiler troubles.

Definition:

The water fed into the boiler for the production of steam is called "Boiler feed water".

Requirements for boiler water

S.No	Requirements for boiler water	If not, it will cause
1	Free from hardness causing salts	Sludge and scale
2	Free from oil and greases	Foaming
3	Free from dissolved salts, suspended impurities	Caustic embrittlement
4	Free from dissolved gases, suspended salts	Boiler corrosion

3. Boiler troubles (OR) Disadvantages of using hard water in boiler

1. Scale and Sludge formation
2. priming and foaming (Carry over)
3. caustic embrittlement (Inter crystalline cracking)
4. boiler corrosion are collectively known as boiler troubles.

Caustic Embrittlement: (Inter crystalline cracking of boiler metal)

It is the intercrystalline cracking of boiler due to Na_2CO_3. In high pressure, Na_2CO_3 undergoes hydrolysis to produce NaOH. This makes water caustic. The NaOH contenting water flows into the minute hair-cracks.

$$Na_2CO_3 + H_2O \rightarrow 2\,NaOH + CO_2$$

This NaOH occupies the hair line cracks of boiler metal and converts the insoluble Fe into soluble Sodium Ferroate. Thus it makes the cracks bigger in bents, joints and crevices.

$$Fe + 2\,NaOH \rightarrow Na_2FeO_2 + H_2\uparrow$$

(Insoluble) (Soluble)

Prevention of caustic embrittlement:

1. As softening agent, we can use sodium phosphate instead of sodium carbonate.
2. The hair line cracks can be sealed by waxy materials like Tannin and Lignin.

Sludge and scale:

Definition: If the water contains hardness causing salts like $MgSO_4$, $MgCl_2$,$CaSO_4$, $Ca(HCO_3)_2$. on evaporation, the salts are precipitated .

If they form *loose, slim , non-adherent* precipitate, It is known as sludge. If they form *hard, thick , adherent* precipitate, it is known as scale.

Reasons for sludge and scale:

Sludge: $MgCl_2$, $MgSO_4$, $CaCl_2$

Scale: $CaCO_3$, $MgCO_3$. $Ca(HCO_3)_2$

Disadvantages of scales and sludges:

a) Wastage of fuel:

Scales have low thermal conductivity. So, the heat transfer from boiler to inside water may not be sufficient. In order to provide steady supply of heat to water, over heating is to be done which causes wastage of fuel. The wastage of fuel depends on the thickness and nature of the scale which is shown in the table.

Thickness of scale (mm)	0.325	0.625	1.25	2.5	12
Wastage of fuel (%)	10	15	50	80	150

b) Decrease in efficiency:

Scales sometimes deposit in the valves and condensers of the boilers and heat exchangers and cause choking. This results in decrease in efficiency of the boiler and heat exchangers.

c) Boiler explosion:

Sometimes due to overheating the thick scales may crack which causes the sudden contact of high heated boiler material with water. This causes formation of a large amount of steam and it develops high pressure. This leads to explosion.

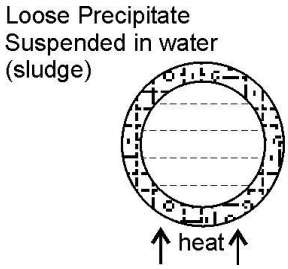
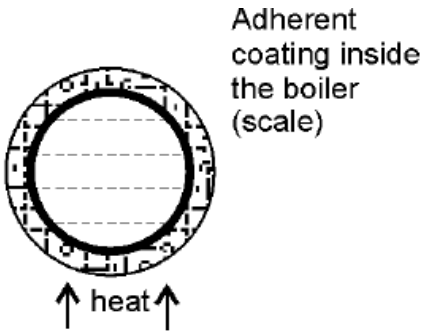
Examples of Scale deposits:

S.No	Name of the deposit	Properties
1	$CaCO_3$ Deposit	It is formed due to decomposition of calcium bicarbonate. It has lower solubility and forms tenacious scale. The liberated CO_2 produces carbonic acid and produces boiler corrosion.
2	$CaSO_4$ deposit	At high temperature and high pressure boilers, It forms harder and denser deposit.
3	$Mg(OH)_2$ deposit	It is formed due to decomposition of magnesium bicarbonate. It reacts with water and liberates corrosive HCl.
4	SiO_2 deposit	It formsa hard, porcelain coating on the boiler surface.
5	Fe deposit	It cause dark coloured, magnetic deposits.

Prevention of Scales:

1. At earlier stage, scraper, wire brush, mechanical scrubber can be used to remove scales.
2. Thermal shocks are used to remove brittle scales.
3. By external treatment methods (eg) Ion exchange demineralization, zeolite softening
4. By using boiler compounds in internal treatment (eg) Carbonate, phosphate, calgon, EDTA
5. By acid treatment

Differences between sludge and scale:

No	Sludge	Scale
1	Loose, slim , non-adherent deposit on the inner walls of boiler.	Hard, thick , adherent precipitate
2	Due to salts like $MgSO_4$, $MgCl_2$	Due to salts like $CaSO_4$, $Ca(HCO_3)_2$
3	Due to poor conductance, they decrease the boiler efficiency to lesser extent and causing chocking in the pipelines.	Due to poor conductance, they decrease the boiler efficiency to maximum extent, cause reduced fuel economy , improper boiling, boiler explosion etc.,
4	It can be prevented by periodical replacement of concentrated hard water by fresh water. This process is known as "blow down" method.	It can be prevented by special methods like i)external treatment of ion exchange , ii)Internal carbonate, phosphate, Calgon conditioning iii)Mechanical hard scrubbing methods. iv) Thermal shocks
5	Diagram: 	

Priming and Foaming: (Carry Over)

1) Due to rapid boiling, the steam may carry some water droplets along with it. This is called wet steam .The process of wet steam production is called Priming. It can reduce the heat of the steam and cause corrosion in the pipelines.

Priming is due to:

a) Improper design of boiler
b) High water level
c) High velocity of steam
d) Uneven boiling

Priming can be controlled by

i)Proper boiler design
ii)Maintaining proper water level

iii)Proper boiling

2) If oils and greases are present, they produce stable bubbles on the water surface. This will increase the wet steam production. This is known as "Foaming".

Foaming is prevented by adding

i) Anti foaming agents (e.g.) synthetic poly amides , castor oil

ii) Coagulants (e.g.) Aluminium hydroxide

3) Foaming and priming are collectively known as ' Carry over".

Boiler Corrosion

It may be due to three major reasons:

i) Dissolved oxygen

ii) Dissolved CO_2

iii) Dissolved salts like $MgCl_2$

Corrosion Due to dissolved oxygen:

Dissolved oxygen in presence of water, causes corrosion. The dissolved oxygen in water attacks the boiler material at higher temperature.

$4Fe + 6\ H_2O + 3O_2 \rightarrow 4\ Fe\ (OH)_3$

(Rust)

Prevention from oxygen:

a) Chemical method -

i)Adding Sodium Sulphite: $2\ Na_2SO_3 + O_2 \rightarrow 2\ Na_2SO_4$

This method results in other precipitates which can have some side effects. So this method is less preferred.

ii)Adding Hydrazine: $N_2H_4 + O_2 \rightarrow N_2 + 2\ H_2O$

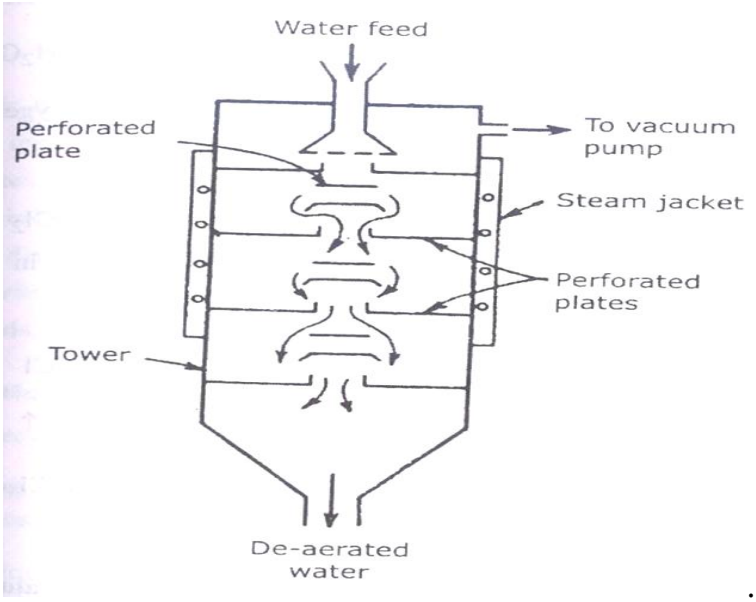
This method results in inert gas and pure water, and has no side effects. So it is preferred.

b) Mechanical deaeration method:

1. This is based on the principle that at high temperature , low pressure and high exposed area, the solubility of gases in water is decreased. So, the gases can be expelled easily.

2. Here, the water is fed into the mechanical deaerator which is provided with vacuum pump, heaters and perforated plates.

3. The out coming water will be free from dissolved gases.



Corrosion due to CO_2

Salts like Calcium bicarbonate on heating produces CO_2 . CO_2 dissolves in water to form carbonic acid which corrodes the boiler metal.

$$Ca(HCO_3)_2 \xrightarrow{\Delta} CaCO_3 + H_2O + CO_2$$
$$H_2O + CO_2 \rightarrow H_2CO_3$$

Prevention from CO_2

1. Chemical method: By adding calculated amount of ammonium hydroxide
   $$2NH_4OH + CO_2 \rightarrow (NH_4)_2CO_3 + H_2O$$
2. Mechanical deaeration method (similar to oxygen method)

Corrosion due to Dissolved salts like $MgCl_2$

Dissolved salts like $MgCl_2$ cause acid formation. This will be prevented by alkali neutralisation.

$$MgCl_2 + 2\,H_2O \rightarrow Mg(OH)_2 + 2\,HCl \text{ (Corrosive acid)}$$

Neutralisation:
Excess acidic nature is neutralized by adding alkalis and vice versa.

$$HCl + NaOH \rightarrow NaCl + H_2O$$