The coagulation before sedimentation is almost universally adopted in all the major water treatment plants, and is followed by rapid sand filtration.

Chemicals used for coagulation:

- Aluminium sulphate, iron salts like ferrous sulphate, ferric chloride, ferric sulphate. These chemicals are most effective when water is slightly alkaline.

1. Aluminium sulphate

$$Al_2(SO_4)\cdot 18H_2O + 3\,Ca\,\underset{\text{Bicarbonate alkalinity present in raw water}}{(HCO_3)_2} \rightarrow 3CaSO_4 + 2\underset{\text{(floc)}}{Al\,(OH)_3} \downarrow + 6CO_2 \uparrow + 18H_2O$$

- Average normal does is about 17 mg/l (5 mg/l – 55 mg/l)
- If raw water supplies are not sufficiently alkaline, then the external alkalies like lime *i.e.* $Ca(OH)_2$ or soda ash (Na_2CO_3) are generally added.

(*i*) $Al_2(SO_4)_3\,.\,18H_2O + 3Ca\,(OH)_2 \rightarrow 3\,CaSO_4 + Al(OH)_3 \downarrow + 18\,H_2O$

(*ii*) $Al_2(SO_4)_3\,.\,18H_2O + 3Na_2CO_3 \rightarrow 3\,Na_2SO_4 + 2Al\,(OH)_3 \downarrow + 3CO_2 \uparrow + 15\,H_2O$

- Aluminium sulphate is very effective coagulant, and is now extensively used throughout the world.

2. Ferrous sulphate (copperas) ($FeSO_4\,.\,7H_2O$)

When copper as is added earlier to lime :

(*i*) $FeSO_4\cdot 7H_2O + Ca(HCO_3)_2 \rightarrow Fe\,(HCO_3)_2 + CaSO_4 + 7H_2O$

$Fe\,(HCO_3)_2 + 2Ca(OH)_2 \rightarrow Fe\,(OH)_2 + 2CaCO_3 + 2H_2O$

$4\,Fe\,(OH)_2 + O_2 + 2H_2O \rightarrow 4\,Fe\,(OH)_3$

$\downarrow$ (Ferric hydroxide precipitate)

(*ii*) When lime is added first:

$FeSO_4\cdot 7H_2O + Ca(OH)_2 \rightarrow CaSO_4 + Fe\,(OH)_2 + 7H_2O$

$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow \underset{\text{(floc)}}{4Fe\,(OH)_3} \downarrow$

- Copperas are used when the raw waters are not coloured and high pH (8 to 10).

3. Chlorinated copperas

$$6(FeSO_4\,7H_2O) + 3Cl_2 \rightarrow \underset{\text{Ferric sulphate known as chlorinated copperas}}{2Fe_2(SO_4)_3} + \underset{\text{Ferric chloride}}{2FeCl_3} + 42H_2O$$

$Fe\,(SO_4)_3 + 3Ca(OH)_2 \rightarrow 3CaSO_4 + 2Fe\,(OH)_3 \downarrow$

$2FeCl_3 + 3Ca(OH)_2 \rightarrow 3CaCl_2 + 2Fe\,(OH)_3 \downarrow$

- It remove colour and effective in low & high pH range.

4. Sodium Aluminate ($Na_2H_2O_4$)

$$Na\,Al_2O_4 + Ca\,(HCO_3)_2 \rightarrow \underset{\text{Cal. aluminate}}{CaAl_2\,O_4} \downarrow + Na_2CO_3 + CO_2 \uparrow + H_2O$$

$Na_2\,Al_2O_4 + CaCl_2 \rightarrow CaAl_2O_4 \downarrow + 2NaCI$

$Na_2\,A1_2\,O_4 + CaSO_4 \rightarrow CaAl_2\,O_4 \downarrow + Na_2SO_4$

Iron salts are used as coagulants more frequently for treating sewage, and alum is used more frequently for treating raw water.

Parts of a Coagulation Sedimentation Plant

The coagulation sedimentation plant clariflocculator contains the following four units:

1. Feeding device;
2. Mixing device or mixing basin;
3. Flocculation tank or Flocculator; and
4. Settling or sedimentation tank.

- The complete process of coagulation sedimentation may help in removing turbidities upto as low values as 10-20 mg/l. It may also help in reducing the bacteria from the water, and thus to reduce the B-coli index by as much as 70%.
- Large plant uses wet feeding while smaller plants uses dry feeding.

1. Feeding Device:

These are of two types:

(*i*) Dry feeding

(*ii*) Wet feeding.

Feeding depends on following factors

(*i*) Characteristics of coagulant and convenience.

(*ii*) Amount of coagulant

(*iii*) Cost of coagulant and size of plan

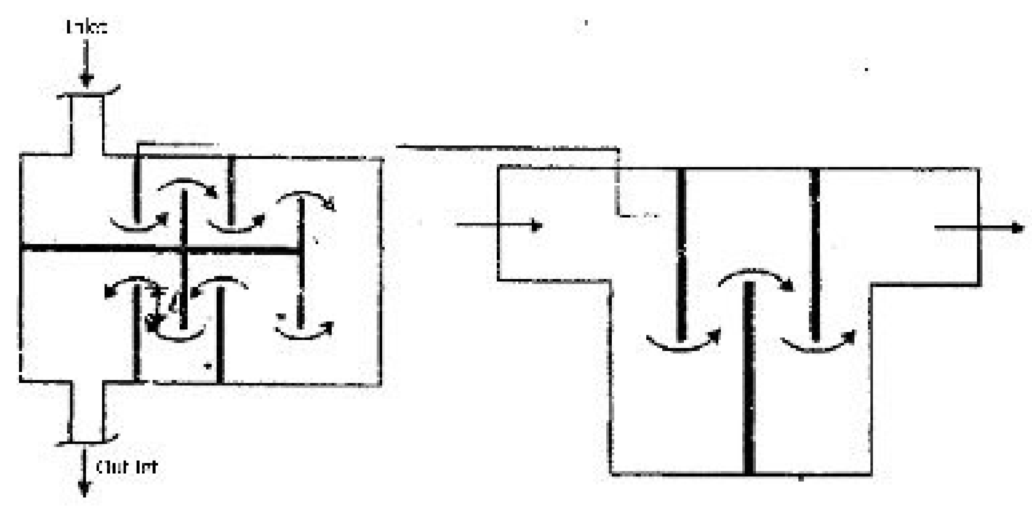
Note. Large plants use wet feeding and smaller plants use dry feeding, unless objected to by characteristics of coagulant.

2. Mixing Devices.

As Centrifugal pumps, compressed air, mixing basins etc.

MIXING BASINS

(*a*) With Baffle Walls



Design Criteria

Velocity of flow in channels = 1.15 to 0.045 m/sec.

Detention period = 20-50 min.

Hence length of flow is known.

The clear opening between end of each baffle and the tank wall should be kept about 1.5 × distance between baffles.

minimum value = 60 cm

Note:

(1) Around the end baffles should not be used when the computed depth < 1m.

(2) In over and under baffles; depth is normally kept (2 to 3) × distance between baffles.

(3) In basins, loss of head ≈ 3.2 × velocity head in channel

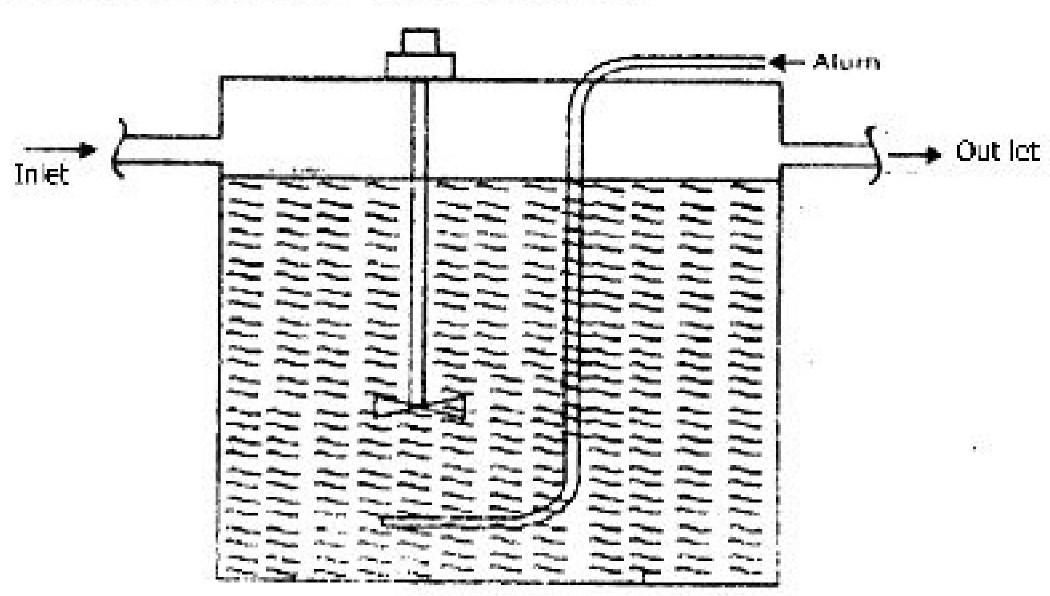
(4) Baffle type mixing basins are not used in modern day or on large plants.

With Mechanical devices.

These use Flash Mixer

Impeller's speed = 100 - 120 rpm.

Detention period = 2-3 minutes.



Flocculator

Paddles rotated at speed of 2-3 rpm.

Detention period = 30 to 60 minutes (ave. 40 min.)

Clear distance between paddles and wall is about 15 to 30 cm.

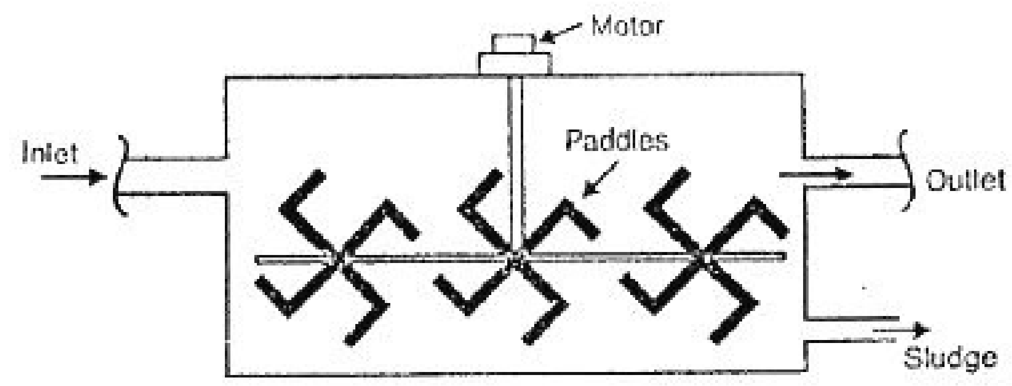


Fig. Flocculator

Sedimentation Tank

Detention period = 2 – 4 hrs.

Overflow rate = 1000 – 1250 lit/hr./m^2

Combined Co-agulation-cum-Sedimentation Tank

Detention period = 15 – 40 in. floc-chamber, and

2-4 hrs. in settling tank

Optimum Coagulant Quantities Determination.

Jar test is made. Large number of jars are used for good results.

The amount of coagulant in jar which produces a good floc with the least amount of coagulant, indicates optimum dosage.

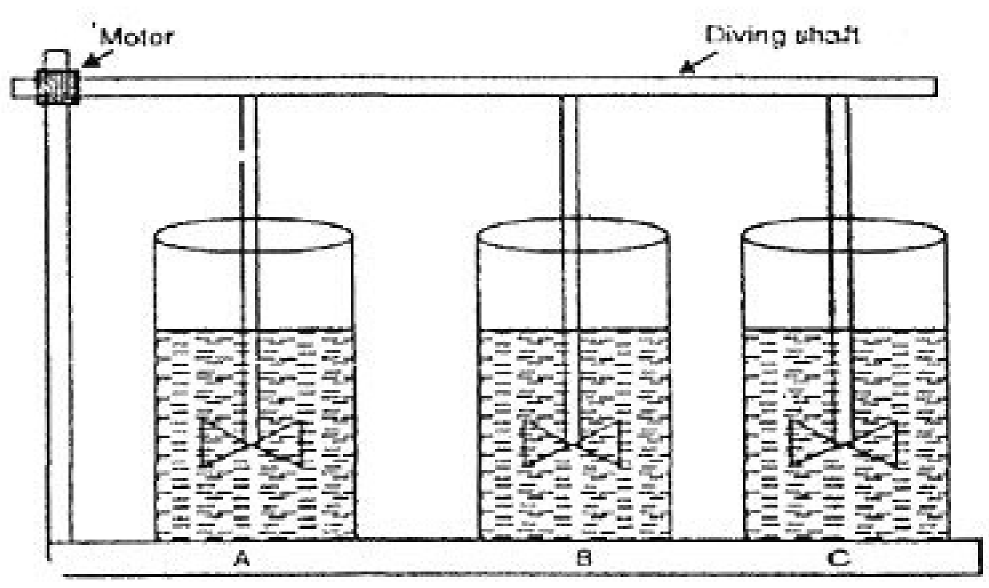


Fig. Jar Test

Production of Sludge

Alum, which is chiefly used has been found to be generating sludge equal to 0.24 times of its

own weight.

Dry Sludge produced in mg/day = Q in lit/day [suspended solids removed in mg/l + 0.24 × Alum does in mg/l + misc. chemicals added like carbon, clay, polymer in mg/l]

Dewatering and Disposal of Sludge from Water Treatment Plants

Wet or watery sludge is produced in a water treatment plant in its following units :

(*i*) Sedimentation flocculation tank or clariflocculator; and

(*ii*) Filters

Methods for disposing of wastes obtained from above plants:

(*i*) Ponding in artificial or natural lagoons

(*ii*) Sand drying bed

(*iii*) Gravity thickeners

(*iv*) High speed centrifuges

- The dewatered sludge is finally disposed off either by incineration or by burial in trenches.

FILTRATION

The process of passing the water through the beds of granular materials is known as **Filtration**. Filtration may help in removing colour, odour, turbidity and pathogenic bacteria from the water.

Types of filters:

1. Slow sand gravity filters
2. Rapid sand gravity filters
   - Pressure filters are used for small plants such as for individual industrial supplies, not adopted for treating large scale municipal supplies.
   - Slow sand filters remove larger percentage of impurities and bacteria as compare to rapid sand filters but slow sand filters are obsolete these days due to slow rate of filtration.
   - In the modern treatment plants, rapid sand gravity filters are nowadays almost universally adopted. The water from the coagulation sedimentation plant is directly fed into the rapid sand gravity filters, and the resultant supplies are disinfected for complete killing of germs and colour removal.

SLOW SAND FILTERS

Construction of slow sand filters:

Parts of slow sand filter are:

1. **Enclosure tank or basin:** Depth of tank = 2.5 to 3.5 m.

   Plan area of the tank = 100 to 2000 m^2
2. **Filter media:** Sand layers go to 110 cm. in depth.
3. **Base material:** 30 to 75 cm. thick gravels of different sizes placed in layers.
4. Under drainage system.
5. Inlet and outlet arrangements.
6. Other appurtenances.

Rapid Sand Filters or Mechanical Sand Filters

These filters employ coarse sand, with effective size as 0.5 mm or so. On an average, these filters may yield as high as 30 times the yield given by the slow sand filters. Water from the clariflocculator are used in these filters, and filtered water is treated with disinfectants, so as to obtain potable supplies.

Construction of Rapid Gravity Filters

Parts of rapid sand filter are

1. **Enclosure tank or basin:** Depth of tank = 2.5 to 3.5 m.

   Plan area of tank = 10 to 50 m2 for each unit.
   - Number of units at a filter plant

   $$N = 1.22\sqrt{Q}$$

   where, Q = Plant capacity in million litres per day.
2. **Filter media :** Sand layer 60 to 90 cm. in depth.
3. **Base material :** Gravel layer 60 to 90 cm. thick gravels of different sizes placed in layers.
4. Under drainage system
5. Other appurtenances.

Working and Cleaning of Rapid Gravity Filters:

- The amount of water required for washing a rapid gravity filter may vary from 21.5% of the total amount of water filtered. The rapid gravity filers get clogged very frequently and have to be washed every 24 to 48 hours.
- The rapid gravity filters are conventionally cleaned by back washing.

Rate of Filtration or Rate or Loading for Rapid Gravity Filters

3000 to 6000 litres/hr/m^2 of filter area.

Rate of filtration of pressure filter: 6000 to 15000 l/h/m^2 of filter media.

3000 to 6000 litres/hr/m^2 of filter area.

- The pressure filter are less efficient than the rapid gravity filter.
- Pressure filters are generally not used for treating municipal surface supplies.

Comparison of slow sand and Rapid sand filters:

S.No.	Item	Slow sand filters	Rapid gravity filters
1.	Pre treatment requirements	Effluents either from plain sedimentation tanks or raw waters without any treatment are generally fed into them; and coagulation is not at all required.	Coagulation, flocculation, and sedimentation is a must.
2.	Base material	The gravel base supports the sand. It varies from 3 to 65 mm in size and 30 to 75 cm. in depth.	The gravel base supports the sand and also distributes the wash water uniformly on the surface of sand. It varies from 3 to 40 mm. in size and its depth is slightly more, *i.e.* about 60 to 90 cm.
3.	Filter sand	The effective size (D_{10}) of filter sand ranges between 0.2 to 0.4 mm. and uniformity coefficient between 1.8 to 2.5 or 3.0. The grain size distribution is generally uniform throughout the depth of filter media, except that top 10 to 15 cm. may be laid of finer variety.	The effective filter sand ranges between 0.35 to as and uniformity coefficient between 1.2 to 1.8. The sand is laid in layers with smallest grain size at top and coarsest grain size at the bottom.
4.	Underdrainage system	Laid in order to receive filtered water.	Laid harder to receive filtered water and also to pass water for back washing at a very high rate.
5.	Size of each unit	Large such as (30 m to 60 m). The area varying from 100 to 2000 sq. m. or more.	Small, such as 5m × 8m. The area varying from 10 to 80 sq. m.
6.	Rate of filtration	Small such as 100 to 200 lit./hr./m^2 of filter area.	Large such as 3000 to 6000 lit./hr./m^2 of filter area.
7.	Economy	High initial cost of both land and material but low cost of operation and maintenance.	Low initial cost, but higher cost of operation and maintenance overall, it is cheaper & economical.
8.	Depreciation cost	Relatively low.	Relatively high.
9.	Efficiency	Very efficient in removing bacteria (98 to 99%) but less efficient in removing colour. Overall turbidity removal in these filters using plain sedimentation is also low. They cannot handle turbid water containing turbidities more than 50 mg/l.	Less efficient in removing bacteria (80 to 90%) but very efficient in removing colour. The overall turbidity removal in these fill using coagulation sedimentation, is also high. They can therefore, handle very turbid waters.
10.	Flexibility	Not flexible for meeting variations in demand.	Quite flexible for meeting reasonable variations in demand.
11.	Suitability and adaptability	May be adopted for treating smaller village supplies or for individual industrial supplies. They are absolute these day.	They are widely and almost universe adopted for treating public supplse especially at all major cities & town.
12.	Post treatment requirement, if any	Almost pure water is obtained. However; it may be disinfected slightly to make it completely safe. Other miscellaneous may or may not be required.	Disinfection is must and some other miscellaneous treatment may be given, if needed.
13.	Ease in construction	Simple	Complicated, as under drainage is properly designed.
14.	Skilled supervision, if required	Not required.	Essential.
15.	Method of cleaning	(a) Scrapping and removing the top 1.5 to 3 cm. thick layer and washing down by hoses. (b) Laborious method.	(a) Agitating the sand grains and back washing with or without compressed air. (b) Short and easy method.
16.	Period of cleaning	Cleaned at intervals of 1 to 3 months.	Cleaned frequently at intervals of 1 to 3 days.
17.	Loss of head	Approximately 10 cm is the initial loss, and 0.8 to 1.2 m is the final limit when cleaning is required	Approximately 0.3 m is the initial loss, and 2.5 to 3.5 m. is the final limit when cleaning is required.
18.	Quantity of wash water required	0.2 to 0.6% of the total water filtered	1 to 5% of the total water filters

DISINFECTION OR STERILISATION

- Chlorine has been found to be the best and the most ideal disinfectant and is now invariably used throughout the world.
- Disinfection means killing of only the disease producing bacteria, whereas sterilisation means killing of the bacteria of all types.
- Disinfection, chlorination and sterilization are used as synonymous to each other.

Some Minor Methods of Disinfection.

1. Boiling of water
2. Treatment with excess lime
3. Treatment with ozone
4. Treatment with iodine and bromine
5. Treatment with ultraviolet rays - suitable for swimming pool water
6. Treatment with potassium permaganete; and
7. Treatment with silver, called Eleipa-katadyn Process.

1. **Boiling of water:** It can only kill the existing germs but cannot take care of the future possible contaminations, hence it is not used for disinfecting public supplies. However, during water borne epidemics, public is advised to drink water only after boiling.
2. **Treatment with excess lime:** Lime is generally used as a water purification plant for softening (i.e. reducing hardness), but excess lime may kill the bacteria also.
   - The excess lime when added to water, in fact, raises the pH value of water.
   - This method is quite practical for complete removal of bacteria, yet needs the removal of excess lime from the water before it can be supplied to the general public (called recarbonation). Moreover, it cannot protect the water from the possible dangers of recontamination, and hence not used these days.
3. **Treatment with Ozone:**

$$3O_2 \xrightarrow[\text{arc voltage}]{\text{under high electric}} 2O_3$$

$$O_3 \rightarrow O_2 + O_{\text{nascent oxygen}}$$

   - The nascent oxygen, so produced, is a powerful oxidising agent and removes the organic matter as well as the bacteria from the water.
   - Ozone being unstable, nothing remain in water, by the time it reaches the distribution system.
   - Ozone remove colour, taste and odour from water, in addition to removing the bacteria from it.
   - The Ozonised water becomes tasty and pleasant unlike the chlorinated water which becomes bitter to tongue.
4. **Treatment with Pottasium permanganate ($KMnO_4$):**

   It is used for disinfecting well water supplies in village; which are generaly contaminated with lesser amount of bacteria. It also produce taste.

   - If the pink colour disappears, it shows that organic matter is present in water.

CHLORINATION:

The treatment of water by called water is casud **chlorination**.

$$Cl_2 + H_2O \xrightarrow{pH > 5} \underset{\text{Hypochlorous acid}}{HOCl} + HCl$$

$$HOCl \underset{pH < 7}{\overset{pH > 8}{\rightleftharpoons}} H^+ + OCl^- \text{ (Hypochlorite ions)}$$

- The sum of hypochlorous acid, hypochlorite ions, and molecular chlorine existing in a sample of water is termed as **free available chlorine**.
- Out of these form of free available chlorine, the hypochlorous acid is the most destructive, being about 80 times more effective than OCl. For this reason, the pH value of water during chlorination is generally maintained slightly less than 7, so as to keep the dissociation of HOCI to minimum and thereby keeping more HOCI in solution compared to OCL ions.
- Moreover, the chlorine will immediately react with ammonia present in water to form various chloramines, as given below:

$$\left.\begin{array}{l} NH_3 + HOCl \xrightarrow{pH > 7.5} \underset{\text{Monochloramine}}{NH_2Cl + H_2O} \\ NH_2Cl + HOCl \xrightarrow{pH\ 5\ \text{to}\ 6.5} \underset{\text{Di-chloramine}}{NHCl_2 + H_2O} \\ NHCl_2 + HOCl \xrightarrow{pH < 4} \underset{\text{Nitrogen. Trichloramine}}{NCl_3 + H_2O} \end{array}\right\} \begin{array}{c}\text{all posses disinfecting} \\ \text{property and also} \\ \text{stable compound}\end{array}$$

  In usual chlorine treatment, when pH is kept slightly less than 7, $NHCl_2$ is the most predominant.
- If all NH_3 is consumed by added Cl_2, then it would persist as free **chlorine**.
- Chloramine is less effective than free chlorine.
- Correct sequence of formation of residual chlorine compound is NH_2Cl, $NHCl_2$, HOCl, OCl

Dose of Chlorine:

The amount of Cl_2 used in reducing organic and inorganic impurities is called the chlorine **demand of water**. After the Cl_2 demand is fulfilled, Cl_2 will appear as free chlorine residual (hypochlorites). This residue Cl_2 will serve as disinfectant to kill pathogens.

Chlorine does required for killing isolated virus:

Types of virus to be killed	*Quantity of free chlorine required in mg/l with about 30 minutes contact period for water of pH lower than 7 or so.*
Poliomyelitis Virus	0.1
Hepatitis Virus	0.4
Cysts of E. histolytica, *i.e.* the organism causing ameobic dysentery.	3.0 or even lower.
Tuberculosis organisms	3.0
Coxsaickie Virus	Very huge does varying from 21 to 138 mg/l

Various forms in which chlorine can be applied:

As free chlorine

In the form of liquid chlorine or as chlorine gas. ($HOCl$, OCl^-)

As combined chlorine

1. In the form of hypochlorites or bleaching power $(Ca\,(OCl.)_2]$
2. In the form of chloramines, i.e. a mixture of ammonia and chlorine.
3. In the form of chlorine dioxide: Disinfecting power is 2½ times stronger than chlorine but is very useful.

1. **Use of Hypochlorites or Bleaching powder** (not used these days)

$$Ca(OCl)_2 \xrightleftharpoons{H_2O} \underset{\text{Hypochlorite ions}}{Ca^{++} + 2OCl^-}$$

$$OCl^- + H^+ \underset{pH > 8}{\overset{pH < 7}{\rightleftharpoons}} \underset{\text{Hypochlorans acid}}{HOCl}$$

This process is known as *hypochlorination*. The hypochlorite ions as well as hypochlorous acid both causing disinfection of water.

2. **Use of chloramines or use of chlorine with ammonia:**

Types of chlorination and certain important definitions:

(*i*) Plain chlorination

(*ii*) Prechlorination

(*iii*) Postchlorination

(*iv*) Double chlorination

(*v*) Breakpoint chlorination

(*vi*) Super chlorination

(*vii*) Dechlorination

(*i*) **Plain chlorination:** It indicates that only chlorine treatment and no other treatment has been given to the raw water.

The used quantity of chlorine required is about 0.5 mg/l or more

(*ii*) **Pre-chlorination:** Pre-chlorination is the process of applying chlorine to the water before filtration or rather before sedimentation.

The normal doses are as 5 to 10 mg/l so that 0.1 to 0.5 mg/l of residual chlorine comes to the filter plant.

(*iii*) **Post-chlorination:** It is the process of applying chlorine after filtration and before enter the distribution system. The dosage of chlorine should be such as to leave a residual chlorine of start 0.1 to 0.2 mg/l after a contact period of about 20 minutes. This residual will ensure the disinfection of water, if at all any future recontamination occurs in the distribution system.

(*iv*) **Double chlorination :** It indicates that water has been chlorinated twice. The prechlorination and post-chlorination are generally used in double chlorination. Post chlorination, however, is generally always used, while the pre-chlorination is also used when the waters are highly turbid and contaminated.

(*v*) **Break-point chlorination:**

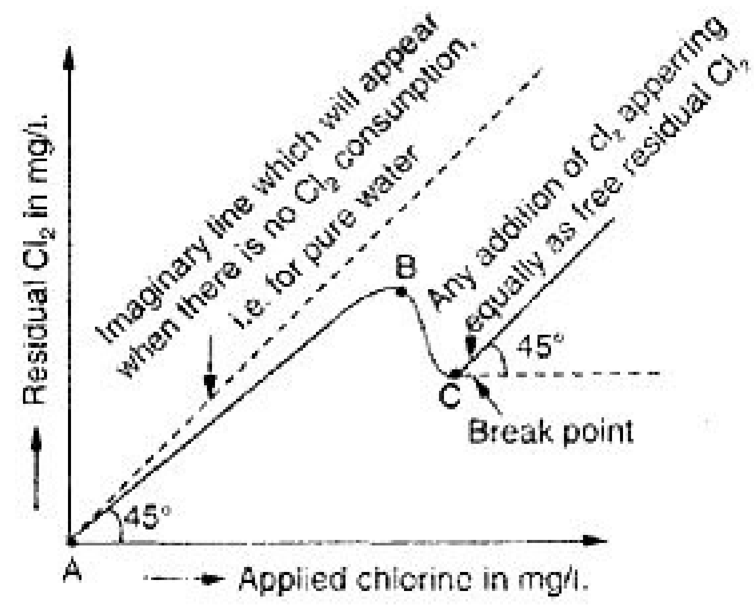


Fig:- Break point Chlorination

- Some Cl_2 is consumed for killing bacteria and thus the amount of residual Cl_2 shall be slightly less than that added as shown by the curve AB.
- If the addition of Cl_2 is continued beyond the point B, the organic matter present in water gets oxidised and therefore, the residual Cl_2 content suddenly falls down as shown by curve BC.
- Break point chlorination is a term which gives us an idea of the extent of chlorine added to water beyond which any further addition of chlorine will appear as free residual chlorine.
- The D.P.D. test will indicate the quantum of total residual chlorine **"combined"** as well as **"free"**.
- The point C is the point beyond which any further addition of Cl_2 will appear equally as free chlorine. This point **"C"** is called the **break point**. The addition of Cl_2 beyond break point is called **break point chlorination**.
- It is a general practice to add Cl_2 beyond break point, and thus to ensure a residual of 0.2 to 0.3 mg/l of free chlorine.

(*vi*) Super chlorination: It indicates the addition of excessive amount of chlorine (*i.e.*, 5 to 15 mg/l) to the water. This may be required in some special cases of highly polluted water, or during epidemics of water borne diseases.

- The huge quantity of Cl_2 is added in super chlorination is such as to give about 1 to 2 mg/l of residual beyond the break point in the treated water.
- Sometimes, even higher doses may be used and the resultant water is dechlorinated after the end of the desired contact period, by using dechlorinating agent. This ensures the removal of bad tastes and odour caused by the presence of excess chlorine. Since residual Cl_2 is zero, so again chlorinate the water by a dose of about 0.1 to 0.2 mg/l.

(*vii*) Dechlorination: It means removing of chlorine from water. The dechlorination may be carried out by adding certain chemicals to water or by **simple aerating the water**. These chemicals are called **dechlorinating agents**.

Some common dechlorinating agents are:

(*i*) Sulphur dioxide gas (SO_2);

(*ii*) Activated carbon;

(*iii*) Sodium thiosulphate (Na_2, S_2, O_3), cheapest dechlorinating agent

(*iv*) Sodium metabisulphate ($Na_2S_2O_5$);

(*v*) Sodium sulphite (Na_2SO_3);

(*vi*) Sodium bisulphite ($NaH\ SO_3$); and

(*vii*) Ammonia (NH_4OH).

Testing of chlorine residuals:

(*i*) Orthotolidine test;

(*ii*) D.P.D. test;

(*iii*) Chlorotex test; and

(*iv*) Starch iodine test.

WATER SOFTENING

- The reduction or removal of hardness from water is known as water softening.

Methods of removing Temporary hardness:

Removed either by boiling or by adding lime to the water.

1. **Boiling:** When water is boiled, it leads to the precipitation of ($CaCO_3$), which can be sedimented out in settling tank. But boiling cannot remove hardness caused by magnesium as $MgCO_3$ is fairly soluble in water

$$Ca(HCO_3)_2 \xrightarrow[+CO_2, H_2O]{\text{Heat}} CaCO_3 \downarrow \text{insoluble}$$

2. **Addition of lime:**

$$MgCO_3 + Ca(OH)_2 \rightarrow \underset{\text{(insoluble)}}{Mg(OH)_2 \downarrow} + \underset{\text{(insoluble)}}{CaCO_3 \downarrow}$$

$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow Ca(HCO_3) + Mg(OH)_2 \downarrow$$

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

The calcium carbonate and magnesium hydroxide are precipitated, and can be removed in the sedimentation tank.

METHOD OF REMOVING PERMANENT HARDNESS

The three methods, which are commonly adopted for softening waters containing either permanent hardness or permanent as well as temporary hardness both, are

1. Lime soda process;
2. Base exchange process, generally called zeolite process; and
3. Demineralisation process.

1. Lime-Soda Process:

In this process lime [$Ca(OH)_2$] and soda ash [Na_2CO_3] are added to the hard water, which react with the Ca and Mg salts, to form insoluble precipitates of $CaCO_3$ and $Mg(OH)_2$. These precipitates can be sedimented out in sedimentation tank.

(*i*) $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$

(*ii*) (*a*) $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow Ca(HCO_3)_2 + Mg(OH)_2 \downarrow$

(*b*) $MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCO_3 \downarrow$

(*iii*) $MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaCl_2$

(*iv*) $MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaSO_4$

(*v*) $\underset{\text{(free dissolved } CO_2)}{CO_2} + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O$

(*vi*) $CaCl_2 + Na_2CO_3 \text{ (Soda)} \rightarrow CaCO_3 \downarrow + 2NaCl$

(*vii*) $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4 \downarrow$

- After sedimentation of $CaCO_3$ and $Mg(OH)_2$, a little quantity may remain as finely divided particles and may cause trouble by getting deposited on the filter or in the pipes of the distribution system. To present this, water be recarbonated by passing CO_2 gas through it if leaves the sedimentation tank.

(*i*) $CaCO_3 \downarrow + CO_2 + H_2O \rightarrow \underset{\text{soluble cal. bicarbonate}}{Ca(HCO_3)_2}$

(*ii*) $Mg(OH)_2 + CO_2 \rightarrow MgCO_3 + H_2O$
$MgCO_3 + CO_2 + H_2O \rightarrow Mg(HCO_3)_2$

- Many of the hard water contain the carbonate hardness and very low amounts of non carbonate hardness.
- For treating all such waters, lime is often the only chemical required.
- The equipment required for lime soda treatment is similar to that required for chemical coagulation.
- The effluents from the recarbonation plant are finally passed through a rapid gravity filter.

Dry sludge produced in mg/l = [Ca_R + 0.58 Mg_R + Li_A]

where, Ca_R = Calcium hardness removed in mg./l. (expressed as ($CaCO_3$)

Mg_R = Magnesium hardness removed in mg./l. (expressed as $CaCO_3$)

Li_A = Lime added in mg./l. (expressed as $CaCO_3$)

ALKALINITY

It may be defined as the quantity of ions in water that will react to neutralise the hydrogen ion (H^+).

Alkalinity = $[HCO_3] + [2CO_3^{--} + [OH^-] - [H^+]$

where, [ ] refers the concentration in moles/L.

- The carbonate hardness can be considered to be equal to the alkalinity provided, there is no sodium alkalinity in water.
- It follows that if non-carbonate hardness is present in water, then its carbonate hardness will be equal to its alkalinity, since sodium alkalinity will be zero.
- When pH > 11.5, the entire alkalinity is in the form of CO_3^{--} and OH^-.

  When 7.5 < pH < 8.3 the entire alkalinity is in the form of HCO_3^-.

  When pH < 4.5 the entire alkalinity is in the form Carbonic acid H_2CO_3.

Zeolite Process or Base-Exchange or Cation-Exchange process for Removing Hardness:

- General formula of Zeolites are $Na_2O\,Al_2O_3\,x\,SiO_2\,y\,H_2O$. The usual value of x is 2 or more and that of y of ranging amounts.
- During softening operation, the sodium ions of the zeolite get replaced by the calcium and magnesium ions present in hard waters. The Co and Mg zeolite can be regenerated into active sodium zeolite by titrating it with 5 – 10% solution of sodium chloride.
- Zeolite softeners may be either gravity or pressure filters; pressure filter type zeolite softeners being more common. The rate of filteration through a zeolite softener is about 300 l/minute/m^2 *i.e.* 18000 l./h./m^2.
- The zeolite process will result in a water of zero hardness, which generally is not suitable for public supplies. Therefore, only a portion of the water passing through the treatment plant is to be soften and then mixed with unsoftened water to obtain the desired water quality.

Comparison of Lime-Soda and Zeolite Processes of softening water supplies.

S.No.	Item	Lime Soda Process	Zeolite Process
1.	Size of plant	Bulky and Large	Compact and small.
2.	Skilled super-vision if required.	Careful and skilled supervision is necessary for obtaining results.	Automatic and easy to operate.
3.	Sludge troubles, if any	Large quantity of sludge is formed.	No sludge is formed.
4.	Post treatment if needed.	Recarbonation is a must after sedimentation and filtration.	No such post treatment is required.
5.	Results obtained	It can produce water of hardness not less than about 50 mg./l. Therefore, useful for public supplies only.	Water of zero hardness can be obtained.
6.	Removal of colour due to iron and manganese.	Can remove thc colour due to iron and manganese, but only to a very small extcnt.	Can remove the colour due to Fe & Mn, although very costly for treating such waters, because the exhausted Mn and Fe zeolite cannot be regenerated.
7.	Effects on bacteria	The increased causticity may help in killing pathgenic bacteria.	No such advantage is offfered by this process.
8.	pH of thc treated water	Increases the pH value of water, which reduces the corrosion of distribution pipes.	pH value of the water is not affected.
9.	Economy	Process is economical and can be easily combined with usual water treatment methods at slight extra cost.	Process is costlier.
10.	Hardness which can be treated	Excessively hard waters can be treated.	Raw waters with hardness greater than 800 mg./l. cannot be easily and economically treated.
11.	Allowable turbidity in raw waters.	Highly turbid and acidic water can be treated.	Highly turbid waters are difficult to be treated.

Demineralisation Process for Removing Hardness:

- It means removing the minerals from the water. This demineralised water, sometimes called *de-ionised water*, is as pure as distilled water, and is very suitable for industrial purposes.
- This complete removal of minerals present in water can be carried out by first passing the water through a bed of cation exchange resins, and then through a bed of anion exchange resins.

MISCELLANEOUS TREATMENTS

The fluoride content of the water should neither be less as to cause dental caries (early tooth decay) in children, during the calcination of their permanent teeth, nor it should be too high as to cause fluorisis (discolouration of teeth) and even deformation of bones (in extreme cases).

REMOVAL OF COLOURS, ODOURS AND TASTES FROM WATER

1. **Aeration:** Under the process of aeration, water is brought in intimate contact with air, so as to absorb oxygen and to remove CO_2 gas. It may also help in killing bacteria, removing H_2S gas, iron and manganese to a certain extent, from the treated water.

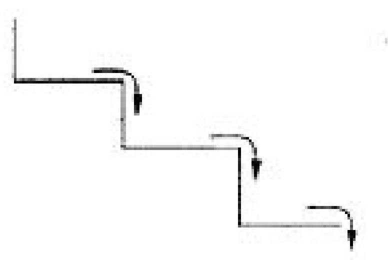
   The aeration of water can be carried out in one of the following ways :

   (*i*) By using spray nozzles

   (*ii*) By permitting water to trickle over cascades;

   (*iii*) By air diffusion;

   (*iv*) By using trickling beds: More efficient than casades.



2. **Treatment with activated carbon:** It posses the property of absorbing and attracting impurities, such as gases, liquids and finely divided solids. It is widely used for removing tastes and odours from public supplies. It is very useful for removing phenol type impurities.
   - The activated carbon is available under various potential trade names, such as **Darco**, Nuchar etc. It is available in granular as well as powder forms.
   - The activated carbon is mostly used in the powdered form and may be added to the water either before or after the coagulation, but before filtration.
   - Activated carbon may also be used in the granular form as a filter media.

   Advantage of activated carbon:

   (*i*) It reduces the chlorine demand of treated water.

   (*ii*) It removes the organic matter present in water.

   (*iii*) It removes the tastes, odours and colours caused by the presence of Fe, Mn, phenols, excess chlorine, H_2S etc.

   (*iv*) It's overdose is not harmful.
3. **Treatment with copper sulphate ($CuSO_4.7H_2O$):** Algae control compound.

   The solution of $CuSO_4$ may be prepared and added just at the entry of water into the distribution system.
4. **Treatment with oxidising agents:**

   The oxidising agents commonly used are $KMnO_4$, Cl_2, O_3 etc.

REMOVAL OF IRON AND MAGANESE FROM WATER

- When present without combination with organic matter, they can be easily removed by aeration. On the other hand, when iron and maganese are present in combination with organic matter, it becomes difficult to break the bond between them and removal.
- Maganese can be removed by activated alumina.

FLUORIDATION AND DEFLUORIDATION OF WATER

- The process of adding fluoride compounds is called **fluoridation**.

  Compounds used are:

  Sodium fluoride (NaF) (mostly used), sodium silica fluoride ($Na_2\,Si\,F_2$), hydrofluosilic acid ($H_2Si\,F_6$) etc.
- The process of removal of fluorine is called **defluoridation** process. Process used are:

  Lime soda process, cation exchange etc.
- Fluorides is removed by maganese zeolite.

REMOVAL OF RADIOACTIVITY FROM WATER

Certain promising methods which are studied for removing radioactivity from water are:

(*i*) By phosphate coagulation method;

(*ii*) By electrolysis method;

(*iii*) By adding of clay materials to water; and

(*iv*) By adding of metallic dusts of water.

DESALINATION OF BRACKISH WATER

The process of removing salts such as NaCl from water is known as **desalination**.

- Scarcity of water – Hongkong (import from other country)
- Desalination is a very costly process.
- National Chemical Laboratory (Poona), and Central Arid zones Research Institute (Jodhpur) are busy on this subject.

Methods of desalination:

Various methods which are generally adopted for the conversion of salt water into fresh waters are:

(*i*) Desalination by evaporation and distillation;

(*ii*) Electrodialysis method;

(*iii*) Reverse osmosis method;

(*iv*) Freezing process;

(*v*) Solar distillation method; and

(*vi*) Other methods.

DISTRIBUTION SYSTEM

The distribution pipe system consists of supply **mains, submains, branches** and laterals.

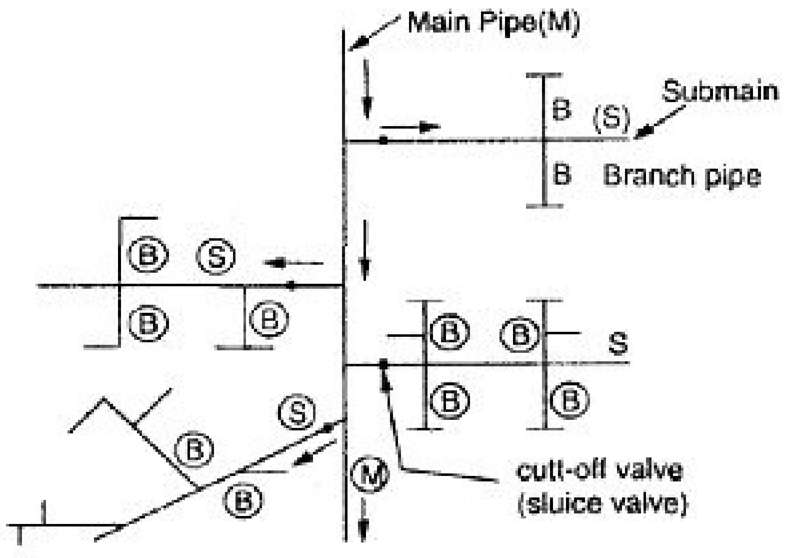
LAYOUTS OF DISTRIBUTION NETWORK

In general, four different types of pipe network; any one of which either singly or in combinations, can be used for a particular place.

1. Dead-end system or Tree system;
2. Grid iron system or Interlaced system or Recirculation system;
3. Ring system or circular system; and
4. Radial system.

1. **Dead-end system:**

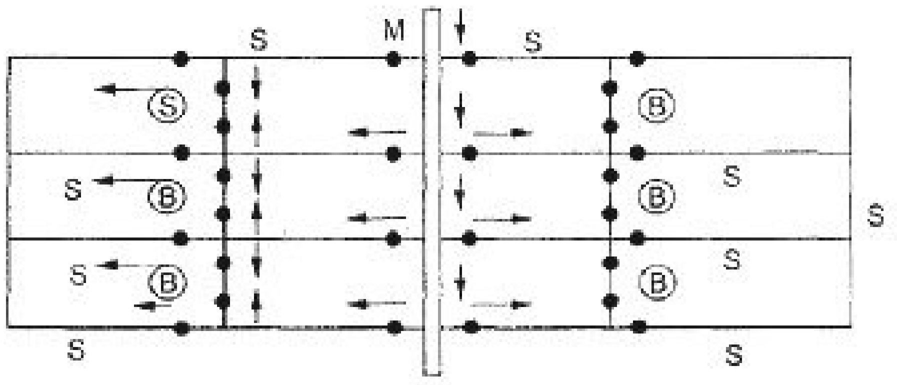
This type of layout may have to be adopted for older towns which have developed in a haphazard manner. So formation of number of dead-ends.



This system is suitable for countries which expand irregularly.

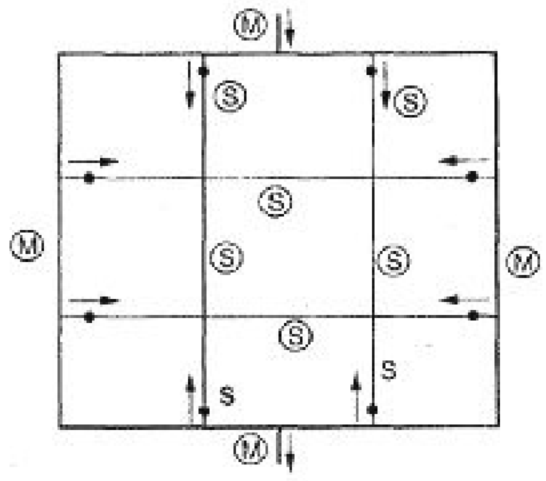
- **Dead-end:** The termination or end point of the pipe is known as a **dead-end**.
- Economy and simplicity.

2. **Grid-iron system:**



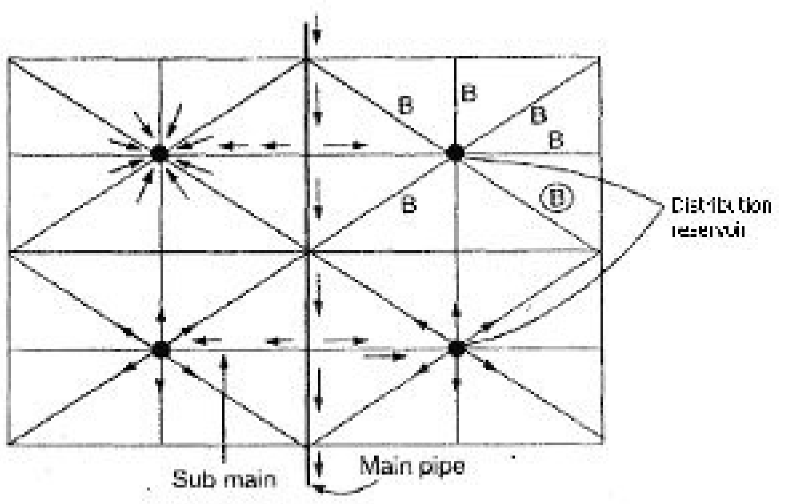
- Suitable for well planed towns and cities.
- Require larger number of sluice valves.
- Both economy and reasonably equal pressures.

3. **Ring system:**



- Equal pressure and multiple flow paths.

4. **Radial system:**



- Zonal distribution

METHODS OF DISTRIBUTION

The water may be forced into the distribution system in the following three ways:

1. By gravitational system;
2. By pumping system or Pumping without storage system;
3. By combined gravity and pumping system called Pumping with storage system. (Adopted these days).

PRESSURE IN THE DISTRIBUTION SYSTEM

- The greater the design pressure, the costlier it will be, but will cause more convenience to the consumers.

Sluice value or cut-off value: To control flow of water through pipe lines.

Air valve: To release the accumulated air in pipe.

Score valve: To remove silt in a pipe line.

Check valve: To prevent entry of pollution into the pure water.

DISTRIBUTION RESERVOIR OR SERVICE RESERVOIR

Type of distribution reservoirs:

1. Surface reservoir or ground reservoir.
2. Elevated reservoir.

} Made of R.C.C, steal or masonry.

STAND PIPES

Stand pipes are a kind of elevated tanks without any erected towers for resting the tank body. They are thus tall cylindrical shells resting directly on the ground, acts like elevated reservoir.

STORAGE CAPACITY OF DISTRIBUTION RESERVOIRS

The total storage capacity of a distribution reservoir is the summation of:

1. Balancing storage (or equalising or operating storage);
2. Breakdown storage; and
3. Fire storage.

Balancing storage or Equalising storage: The main and primary function of a distribution reservoir is to meet the fluctuating demand with a constant rate of supply from the treatment plant. The quality of water required to be stored in the reservoir for equalising or balancing this variable demand against the constant supply is known as the balancing reservoir or balancing storage or the storage capacity of a balancing reservoir.

- This balancing storage can be worked out by **mass curve method** or by using an **analytical solution**.