**Head loss caused by pipe friction can be found by using either of the following formula:**

**1. Darcy Weisbach's formula:**

$$H_L = \frac{f' LV^2}{2gd}$$

where $f'$ = Dimensionless friction factor (average value = 0.024) depends upon Reynold number $\left(Re = \frac{V_d}{V}\right)$ and relative roughness of the pipe ($f$).

The relative roughness $\left(f = \frac{2e}{d}\right)$ of a pipe depends upon the absolute roughness ($e$) of the inside surface and the diameter of the pipe $d$.

- The approximate values of '$f$' are given by the following empirical relations:

$$f = 0.04\left(1+\frac{1}{35d}\right) \text{ for old pipes}$$

$$= 0.02\left(1+\frac{1}{35d}\right) \text{ for new pipes}$$

- The accurate value of $f'$ depends upon R$e$ and $f$; and may be given by a formula, such as

(*i*) $f' = \frac{64}{Re}$ for laminar flow, *i.e.* upto Re = 2000

(*ii*) $\left.\begin{aligned} &(a)\ \frac{1}{\sqrt{f'}} = 2\log_{10} Re\sqrt{f'} - 0.8 \text{ for smooth pipes} \\ &(b)\ \frac{1}{\sqrt{f'}} = 2\log_{10}\frac{d}{2e} + 1.74 \text{ for rough pipes}\end{aligned}\right\}$ above Re = 400 turbulent flow is fully established

(*c*) $f' = 0.005 + \frac{0.396}{Re^{0.3}}$ for smooth pipes Re lies between $2 \times 10^4$ to $2 \times 10^6$

(*d*) $f' = 0.0032 + \frac{0.221}{Re^{0.237}}$ for smooth pipes Re lies between $2 \times 10^4$ to $3.24 \times 10^6$

(*iii*) $\frac{1}{\sqrt{f'}} = 1.74 - 2\log_{10}\left[\frac{2e}{d} + \frac{18.7}{Re\sqrt{f'}}\right]$

Re lies between 2000 to 4000

Value of 2$e$ cast iron = 300

Value of 2$e$ concrete = 300 – 3000

**2. Manning's formula:** (generally used for gravity conduit)

Also applicable to turbulent flow in pressure conduits and yields good results.

$$H_L = \frac{n^2V^2L}{R^{4/3}}, \text{ where, } R = \frac{d}{4}$$

We know, $V = \frac{1}{n}R^{2/3}S^{1/2}$

Squaring $V^2 = \frac{1}{n^2}R^{4/3}S$

Also, $S = \frac{H_L}{L} = \frac{V^2n^2}{R^{4/3}}$

$\therefore$ $H_L = \frac{V^2n^2L}{R^{4/3}}$

**3. Hazen-William's formula:** Widely used for pipe flow

Flow velocity, $V = 0.85C_H R^{0.63} S^{0.54}$

where, CH = Coefficient of hydraulic capacity

= 130 for concrete

= 130 for cast iron (new)

= 120 for cast iron (old)

R = Hydraulic mean depth = $\frac{d}{4}$

S = Slope of the energy line = $\frac{H_L}{L}$

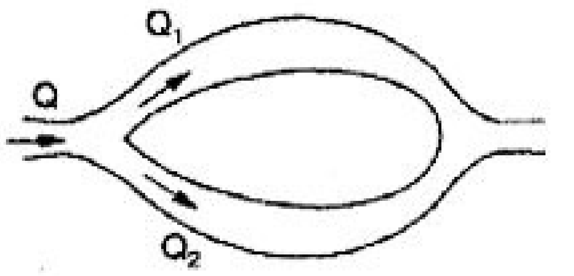
- The flow velocities are normally kept between 0.9 m/sec. to 1.5 m/sec. though velocities upto 3 m/sec. to 6 m/sec. can be resisted by the commonly available pipes or pipe materials.
- In smaller size pipes at equal velocities, the head loss is more. Hence the cost of pumping will be increased by using a smaller size pipe although the cost of the pipe itself will be reduced.
- Break horse power of pumps,

$$H.P. = \frac{WQH}{75\eta} = \frac{1000 \times Q \times H}{75 \times \eta}$$

where, $\eta$ = efficiency of pump set.

**FLOWS IN PIPE SYSTEMS**

- When the pipes are parallel; the head loss through each pipe will be different.




Applying continuity equation.

$$Q = Q_1 + Q_2$$

- When the pipes are in series, the total head loss is equal to the summation of the individual head losses in different pipes.
- The minor losses are represented as $k_1, \frac{V^2}{2g}$

## ANALYSIS OF COMPLEX PIPE NETWORKS

In any pipe network, the following two conditions must be satisfied:

(i) *The algebraic sum of the pressure drops around a closed loop must be zero, i.e.* there can be no discontinuity in pressure.

(ii) *The flow entering a junction must be equal to the flow leaving the same junction; i.e.* the law of continuity must be satisfied.

Based upon these two basic principles, the pipe networks are generally solved by the methods of successive approximation, because any direct analytical solution is not possible, as the same will involve various equations to be solved simultaneously and many of which are nonlinear.

**Important methods used for such solutions are:**

**1. Hardy-Cross Method**

The procedure suggested by Hardy and Cross requires that the flow in each pipe is assumed by the designer (in magnitude as well as direction) in such a way that the principle of continuity is satisfied at each junction (i.e. the inflow at any junction becomes equal to the outflow at that junction).

A correction to these assumed flows is then computed successively for each pipe loop in the network, until the correction is reduced to an acceptable magnitude.

If $Q_a$ is the assumed flow and Q is the actual flow in the pipe, then

Correction, $\Delta = Q - Q_a$

or $Q = Q_a + \Delta$

or $$\Delta = -\frac{\Sigma k.Q_a^x}{\Sigma x.kQ_a^{x-1}}$$

Since $\Delta$ is given the same sign (or direction) in all pipes of the loop, the denominator of the above equation is taken as the absolute same of the individual items in the summation.

$$\therefore \quad \Delta = -\frac{\Sigma k.Q_a^x}{\Sigma \,|\, x.kQ_a^{x-1} \,|}$$

or $$\Delta = \frac{-\Sigma H_L}{x.\Sigma\left|\frac{H_L}{Q_a}\right|}$$

where $H_L$ = head loss for the assumed flow $Q_a$

**2. Equivalent Pipe Method**

This method is sometimes used as an aid in solving large networks of pipes, in which it becomes convenient to, first of all, replace the different small loops by single *equivalent pipes* having the same discharging capacities and causing the same head loss.

In this method, pipe circuit can be reduced into a single equivalent pipe by using the following two principles of hydraulics :

(i) The loss of head caused by a given flow of water through the pipes connected in series is additive.

(ii) The quantity of discharge flowing through the different pipes connected in parallel will be such as to cause equal head loss through each pipe.

## FORCES ACTING ON PRESSURE CONDUITS

**Internal pressure of water:** The maximum internal pressure likely to come under worst circumstances is usually taken equal to the sum of full static pressure and the water hammer

pressure.

Total maximum internal pressure

= Static pressure + Water hammer pressure.

$$P = P_s + P_h$$

Due to this hoop stress developed, $\sigma = \frac{Pd}{2t}$

**1. Water hammer Pressure:**

It is the pulsation of pressures above and below the operating pressure, resulting from the pressure wave, caused by sudden closure of a discharge valve. The sudden acceleration/ develaration of the velocity of water caused by such a pressure wave, exerts a force, which is absorbed largely by the elastic properties of water, and partly by the elastic properties of the pipe material.

The maximum water hammer pressure is developed when the valve is quickly or instantaneously closed.

$$(P_h)\text{ maximum} = \rho_w U_p V \quad ...(i)$$

where, $U_p$ = velocity of the pressure wave generated.

V = velocity of water in the pipe (V to 0)

When the elasticity of pipe material is also considered, then velocity of pressure wave

When the elasticity of pipe is ignored, then velocity of the pressure wave

$$U_p = \sqrt{\frac{E_w}{\rho_w}}\frac{1}{\sqrt{1+\frac{E_w}{E_p}\times\frac{d}{t}}} \quad ...(ii)$$

where, $E_w$ = Modulus of elasticity of water or bulk modulus of compression of water

$E_p$ = Modulus of elasticity of pipe material

$d$ = Diameter of the Pipe

$t$ = Thickness of the pipe shell.

$\rho_w$ = Density of the water.

From equations (*i*) and (*ii*),

$$\rho_h \text{ maximum} = \rho_w \sqrt{\frac{E_w}{\rho_w}} \frac{1}{\sqrt{1+\frac{E_w}{E_p}\times\frac{d}{t}}}.V$$

where $\sqrt{\frac{E_w}{\rho_w}}$ = velocity of sound in water or sonic velocity = 1433 m/sec.

$$P_h \text{ (maximum)} = \frac{14.6\text{ V}}{\sqrt{1+\frac{k_d}{t}}} \text{ kg/cm}^2$$

where,

$$k = \frac{E_w}{E_p} = \frac{\text{Modulus of elasticity of water}}{\text{Modulus of elasticity of pipe material}}$$

- Value of E for water = 2100 MPa $\approx 0.02 \times 10^5$ MPa

  $E_p$ for steel = $2.1 \times 10^5$ MPa $\approx 2 \times 10^5$ MPa

  $E_p$ for cast iron = $1.05 \times 10^5$ MPa $\approx 1 \times 10^5$ MPa

  $E_p$ for concrete = $0.21 \times 10^5$ MPa $\approx 0.2 \times 10^5$ MPa

  Thickness of metal pipe for safe design against internal pressure of water.

$$t = \frac{1}{\eta}\frac{Pd}{\sigma_{st}}$$

where, P = internal pressure of water

$\eta$ = efficiency of joint

**Critical Time:** If the valve is closed gradually, the time taken by the wave in going to the reservoir and coming back to the valve, is called **critical time**.

$$T_c = \frac{2s}{U_p}$$

where $s$ is the distance of the valve from reservoir.

If the actual time of closure T is less than or equal to the critical time $T_c$, naturally full maximum water hammer will be developed.

If the actual closure time T is more than the critical time $T_c$ full pressure is not developed.

$$P_h = P_h\text{(maximum)}\left(\frac{T_c}{T}\right)$$

*i.e.* water hammer pressure can be considerably reduced by using slow closing valves.

**2. Pressure due to external load :**

External load transfered to the pipe are:

(*i*) weight of the backfill

(*ii*) super-imposed traffic load if any; and

(*iii*) self weight of pipe.

- For design consideration of pipe, internal pressure is considered zero. This is the worst condition.

- The stresses produced due to external loadings, at present, can be evaluated by using certain empirical formulas, as given below :

(*i*) For pipes resting on or projecting above the undisturbed ground in cohesionless soil and covered with fills the external load likely to come per unit length of pipe

$$W = C_p \gamma D^2$$

where, $C_p$ = a coefficient find from Table.

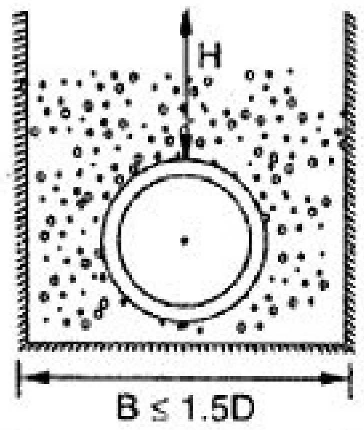
$\gamma$ = unit weight of the fill material.

D = external diameter of the pipe

$= d_i + 2t$

(*ii*) For flexible pipe (such as steel pipe) burried in narrow trench and throughly compaited side fills, the external load per unit length of pipe is given by

$$W = C\gamma BD$$




where, C = a coefficient find from Table.

D = external diameter of the pipe.

B = width of the french $\leq$ 1.5D

(*iii*) For rigid pipes (such as concrete, cast iron, vitrified clay, etc.) burried in narrow trenches and throughly compaited with cohesion-less fills, the external load per unit length of the pipe is given by

$$W = C\gamma B^2$$

where, C, $\gamma$, B have the same meaning as given above.

(*iv*) The amount of superimposed load (such as traffic load) which is transmitted to the pipe can be evaluated by using Boussineg's equation. Assuming fill surface to be horizontal

$$P_t = \frac{3Q}{2\pi}\frac{Z^3}{R^5}$$

where, $P_t$ = unit pressure developed at any point in the fill at a depth Z below the surface due to traffic load.

Q = superimposed load

R = slant height of the considered point from the load Q.

Z = distance of the top of pipe below the surface of the fill.

- The total traffic load developed on a unit length of conduit (w') can't found by integrating above equation over the projected area of the pipe.
- The effect of superimposed load increases rapidly as the depth of cover increases (because $Z^5$ increases much more than $H^3$)

  Total load per unit length of pipe

  = Load coming from backfill

  + load coming from traffic = W + W'
- Compressive stress produced, which should be checked when the pipe is empty will then be $= \dfrac{W + W'}{t}$ kg/m$^2$
- $\gamma$ for dry sand = lkN

3. **Temperature Stress:**

When pipes are laid above the ground, then due to change in temperature expansion and contraction takes place and longitudinal stresses are produced in the pipe materials.

$$\delta = L\alpha T$$

$$\varepsilon = \frac{\delta}{L} = \alpha T$$

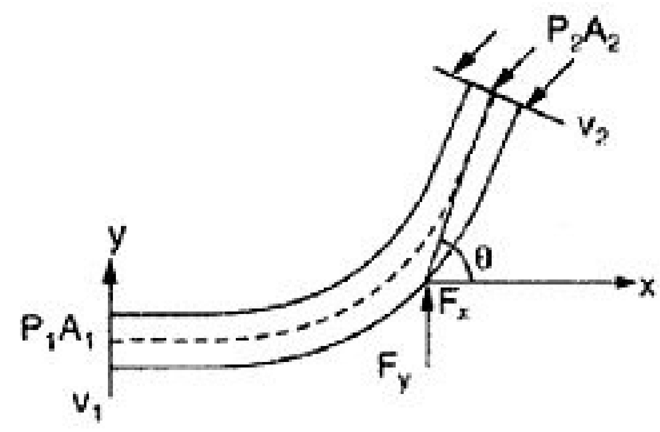
$$\sigma = E_p t = E_p \alpha T$$

where, $E_p$ = Modulus of elasticity of pipe material.

$\alpha$ = co-efficient of expansion of the pipe material = $11 \times 10^{-6}$/°C

T = change in temperature in °C.

4. **Stresses due to flow around bends and changes in cross-section:**




Free body diagram of water

Apply Newton's second law of motion

Net external force = Rate of change of momentum.

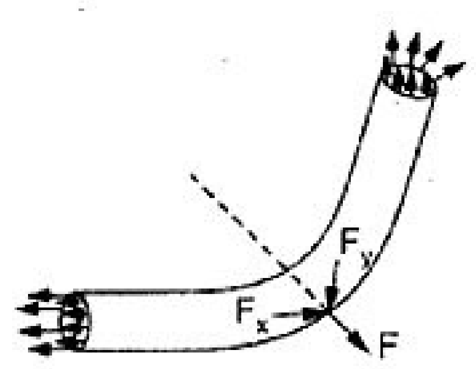
$$\Sigma F_x = \rho Q(V_2 \cos\theta - V_1)$$

$$\therefore \quad P_1A_1 - F_x - P_2A_2 \cos\theta = \rho Q(V_2 \cos\theta - V_1)$$

and $$\Sigma F_y = \rho Q(V_2 \sin\theta - 0)$$

$$\therefore \quad F_y - P_2A_2 \sin\theta = \rho Q(V_2 \sin\theta)$$

Resultant force, $F = \sqrt{F_x^2 + F_y^2}$




These force $F_x$ and $F_y$ and their resultant are the forces which are transmitted from the water to the pipe. An equal and opposite force must, therefore, be developed in the form of stresses in the pipe wall.

5. **Flexural stress:**

   (*i*) **Working Pressure** – Defined as actual maximum pressure.

   (*ii*) **Design Pressure** – Product of working pressure × Factor of safety.

   (*iii*) **Test Pressure**

## PUMPS FOR LIFTING WATER

**Types of pumps:**

1. Rotodynamic pumps
   - → Centrifugal pump
     - → Open impeller
     - → Closed impeller
   - → Axial flow pump
2. Displacement pumps
   - → Reciprocating pump
   - → Rotary type pump

} mostly user for hydraulic engineers.

3. Air lift pumps  4. Jet pumps  5. Hydraulic rams etc.

- Radial flow and mixed flow machines are commonly called **centrifugal pumps**, whereas the axial flow machines are called **axial flow pumps**.
- The efficiency of the "open impeller centrifugal pump" is generally much less than that of a **"closed impeller centrifugal pumps"**. But however, since the "open impeller" is less likely to be clogged by debris, etc. It is usually adopted for pumping raw water or sewage containing solids and other impurities.
- Impellers are placed in casing.
- In the case of bore hole pump, such as a deep well turbine pump, used for pumping ground water (sub-surface water), several impellers are installed on a vertical shaft, which is suspended and rotated from the prime mover motor placed at the ground surface.

**Priming and operation of centrifugal pump:**

A centrifugal pump may have to be primed before it is started. The priming consists in filling the pump casing with water, so that the air trapped in the pump does not hinder its operation to reduce its efficiency.

### Characteristics of centrifugal pumps:

A typical characteristic curves are the curves obtained by plotting at constant speed (N).

- These curves provide the following important conclusions and consideration which are helpful while selecting a particular pump for a particular use.
  (*i*) As the discharge increases, the head produced decreases.
  (*ii*) The maximum efficiency is obtained at a particular discharge or at a particular use.

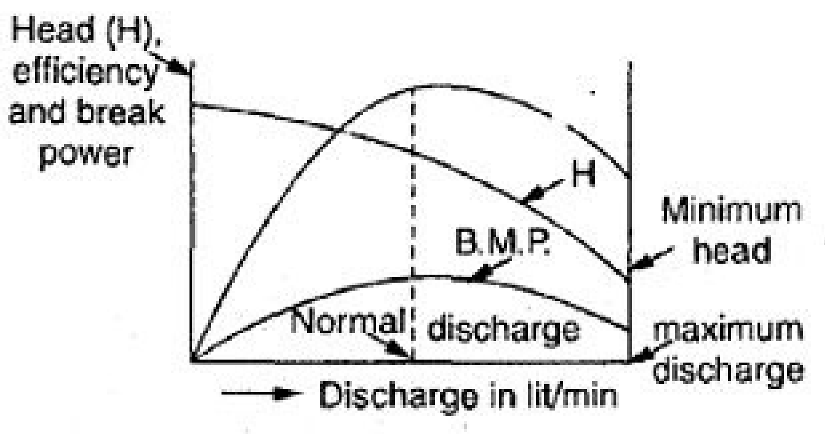



**Fig.** *variation of head, efficiency, and break horse power, against the corresponding rate of discharge.*

- In water supply schemes, where water demand is variable through out the day and year, several pumps of smaller capacities in parallel are used so that a variable number may be operated at capacity, depending on the flow requirements. With this arrangement, it is possible to operate all the pumps near the maximum efficiency or sometimes all the pumps are operated at full capacity, and the excess water during the period of less demand is stored in the "**service reservoir**" and utilised during high demand periods, (when demand rate exceeds the rate of pumping).

### Specific speed ($N_s$) :

Specific speed of a centrifugal pump is defined as the speed at which a pump will discharge a unit flow under a unit head at maximum efficiency.

$$N_s = 51.66\left[N.\frac{Q^{1/2}}{H^{3/4}}\right]$$

where, Q and H are at maximum efficiency for the given speed N.

Q is in cumecs.

H is in metres.

N and $N_s$ in rpm.

If $N_s$ = 1000 to 4000, radial flow centrifugal pump is used.

If $N_s$ = 4000 to 7000, mixed flow centrifugal pump is used.

If $N_s > 7000$, axial flow centrifugal pump is used.

### Air lift pump:

Air lift pumps are generally used for pumping water from deep wells.

- The effectiveness of an air lift pumps is generally measured by a factor called **percentage submergence**.

Percentage submergence

$$= \frac{\text{Depth of submergence } (D_s) \times 100}{\text{Depth of submergence } (D_s) + \text{Effective lift of pump } (H_e)}$$

- $(D_s + H_e)$ represents the effective length of suction pipe.

### Head, Power and Efficiency of Pump:

The total head (H) against which a pump has to work consists of

(*i*) suction lift ($H_s$);

(*ii*) delivery head ($H_d$); and

(*iii*) head lost due to friction, entrance and exit in the rising main ($H_L$).

$$H = H_s + H_d + H_L$$

- The work done by the pump in lifting Q cumecs of water by a head H = WQH kg. m/sec.
- The water horse power of the pump,

$$\text{W.H.P} = \frac{WQH}{75}$$

- If $\eta$ is the efficiency of the pump set, then the **Break horse power** of the pump (B.H.P) is given by

$$\text{B.H.P.} = \frac{WQH}{75\eta}$$

### Economical diameter of the pumping mains

Economical diameter in metres, D = 0.97 to 1.22 $\sqrt{Q}$

where, Q = discharge to be pumped in cumecs.

## QUALITY CONTROL OF MUNICIPAL AND INDUSTRIAL WATER SUPPLIES

### Characteristics of water

The raw or treated water can be checked and analysed by studying and testing their physical,

chemical and microscopical characteristics as explained below :

### Physical Characteristics:

This includes tests for determining

(*i*) Turbidity

(*ii*) Colour

(*iii*) Taste or odour

(*iv*) Temperature

(*v*) Specific conductivity, etc.

***(i)* Turbidity:**

The turbidity is measured by a turbidity rod or by a turbidimeter with optical observations, and is expressed as the amount of suspended matter in mg/lit or parts per million (ppm).

- For water, ppm and mg/lit are approximately equal.
- The standard unit is that which is produced by one milligram of finely divided silica (Fuller's earth) in one litre of distilled water.

**Turbidimeters :**

(*a*) **Turbidity rod:** The turbidity can be easily measured in the field with the help of a turbidity rod. It consists of an aluminium rod which is graduated, as to give the turbidity directly in **silica** units (mg/lit)

(*b*) **Turbidimeter:** The turbidity can be measured in the laboratory with the help of instruments called turbidimeter. In general, a turbidimeter works' on the principle of measuring the interference caused by the water sample to the passage of light rays.

(*c*) **Jackson's candle turbidimeter:** The height of water column will therefore, be more for less turbid water; and vice versa. Longer the light path lower the turbidity. Such a turbidimeter cannot measure turbidities lower than 25 JTU. It can be used for natural source only, and it cannot be used to measure the turbidities of treated supplies, for which **Baylis's turbidimeter** or **modern nephelometers are used**.

(*d*) **Baylis's turbidimeters :** One of the two glass tubes, is filled with water sample (whose turbidity is to be measured) and the other is filled with standard water solution of known **turbidity**. The electric bulb is lighted and the blue colour in both the tubes is observed from the top of the instrument.

(*e*) **Modern Nephelometer:** For low turbidity less than 1 unit

NTU - Nephelometric Turbidity Units

FTU - Formazin Turbidity Units

(*f*) **Ratio turbidimeter**

- River water has maximum amount of **Turbidity**.

(*ii*) **Colour:**

The presence of colour in water is not objectionable from health point of view; but may spoil the colour of the clothes being washed.

- The standard unit of colour is that which is produced by one milligram of platinum cobalt dissolved in one litre of distilled water.
- For public supplies, the colour number on cobalt scale should not' exceed 20, and should be preferably be less than 10.
- Colour determined by an instrument is known as tintometer.

(*iii*) **Taste and Odour:**

The extent of taste or odour present in a particular sample of water is measured by a term called **odour intensity**, which is related with the **threshold odour** or **threshold odour number**.

- Water to be tested is, therefore, gradually diluted with odour free water, and the mixture at which the detection of odour by human observation is just lost, is determined. The number of times the sample is diluted, represents the threshold odour number.
- For public supplies, the water should generally free from odour, i.e. the threshold number should be 1 and should never exceed 3.

(*iv*) **Temperature:**

For potable waters, temperature of about 10°C are highly desirable. It should not be more than 25°C.

(*v*) **Specific Conductivity :**

The total amount of dissolved salts present in water can be easily estimated by measuring the specific conductivity of water.

**CHEMICAL CHARACTERISTICS:**

This includes tests for determining.

(*i*) Total solids and suspended solids;
(*ii*) pH value of water
(*iii*) Hardness of water
(*iv*) Chloride content
(*v*) Nitrogen content.
(*vi*) Metals and other chemical substances; and
(*vii*) Dissolved gases.

***(i)* Total solids and Suspended solids:**

- Total solids (suspended solid + dissolved solid) can be obtained by evaporating a sample of water and weighing the dry residue left and weighing the residue left on the filter paper.
- The suspended solid can be found by filtering the water sample.

  Total permissible amount of solid in water is generally limited to 500 ppm.

***(ii)* pH value of water:**

$$pH = -\log [H^+] = \log \left[\frac{1}{H^+}\right]$$

If $H^+$ concentration increases, pH decreases and then it will be acidic.

If $H^+$ concentration decrease, pH increases and then it will be alkaline

- $[H^+][OH^-] = 10^{-14}$
- pH + pOH = 14
- If the pH of water is more than 7, it will be alkaline, and if it is less than 7, it will be acidic.
- Generally speaking the alkalinity is caused by the presence of bicarbonate of calcium and magnesium; or by the carbonates or hydroxides of sodium, potassium, calcium and magnesium.

  Some, but not all of the compounds that cause alkalinity also cause hardness.
- The pH value of water can be measured quickly and automatically with the help of a **Potentiometer**.
- The pH can also be measured by indicators.

| *Indicator* | *pH range* | *Original colour of indicator dye* | *Final colour produced water* |
|---|---|---|---|
| Methyl orange | 2.8 – 4.4 | Red | Yellow |
| Methyl red | 4.4 – 6.2 | Red | Yellow |
| Phenol red | 6.8 – 8.4 | Yellow | Red |
| Phenophathalein red | 8.6 –10.3 | Yellow | Red |

- Permissible pH value for public supplies may range between 6.6 to 8.4.
- The lower value of pH cause tuberculation and corrosion.
- The higher value of pH may cause incrustation, sediment deposits, difficulty in chlorination.

**(*iii*) Hardness of water:**

- Hard waters are undesirable because they may lead to greater soap consumption, scaling of boilers, causing corrosion and incrustation of pipes, making food tasteless etc.
- If bicarbonates and carbonates of calcium and magnesium are present in water, the water is render hard temporarily as this hardness can be removed to some extent by simple boiling or to full extent by adding lime to water. Such a hardness is known as **temporary hardness** or **carbonate hardness**.
- If sulphates, chlorides and nitrates of calcium or magnesium are present in water, they cannot be removed at all by simple boiling and therefore, such water require special treatment for softening. Such a hardness is known as permanent hardness or **non carbonate hardness**.

  It is caused by Sulphates, Chlorides, Nitrates of Ca and Mg.

  **Measurement of hardness; (EDTA method) :**

  Total hardness (T.H.) in mg/*l* as $CaCO_3$ is

$$= \left[ Ca^{+2} \text{ in mg}/l \times \frac{\text{Combine weight of } CaCO_3}{\text{Combine weight of } Ca^{+2}} \right.$$

$$\left. + [Mg^{+2} (mg/l) \times \frac{\text{Combine weight of } CaCO_3}{\text{Combine weight of } Mg^{+2}} \right]$$

Combine weight of $Ca^{+2} = 20$

$Mg^{+2} = 12$

and $CaCO_3 = 50$

Carbonate hardness

$$\left.\begin{array}{l} = \text{Total hardness} \\ = \text{Alkalinity} \end{array}\right] \rightarrow \text{whichever is less}$$

Non-carbonate hardness = Total hardness – Alkalinity.

- Carbonate hardness is equal to the total hardness or alkalinity, whichever is lesser.
- Non-carbonate hardness is the total hardness in excess of the alkalinity. If the alkalinity is equal to or greater than the total hardness, there is no non-carbonate hardness.
- One French degree of hardness is equal to 10 mg/*l* of $CaCO_3$.
- One British degree of hardness is equal to a hardness of 14.25 mg/*l*.
- Water with hardness upto 75 ppm are considered soft and above 200 ppm are considered hard. In between moderately hard.
- Underground waters are generally harder than the surface waters.
- The prescribed hardness limit for public supplies ranges between 75 to 115 ppm.

**(*iv*) Chloride content:**

- The chloride content of treated water to be supplied to the public should not exceed a value of about 250 ppm.
- The chloride content of water can be measured by filtrating the water with standard silver nitrate solution using potassium chromate as indicator.

**(*v*) Nitrogen content:**

- The presence of nitrogen in water may occur in one or more of the following forms:
  (*a*) **Free ammonia:** It indicates very first stage of decomposition of organic matter. It should not exceed 0.15 mg/*l*.
  (*b*) **Albuminous or Organic matter:** It indicates the quantity of nitrogen present in water before the decomposition of organic molten has stated. It should not exceed 0.3 mg/*l*.
  (*e*) **Nitrites:** Not fully oxidised organic matter in water.
  (*d*) Nitrates: It indicates fully oxidised organic matter in water (representing old pollution).

$$\underset{\text{(present polluted)}}{\text{Ammonia}} \longrightarrow \underset{\text{(old polluted)}}{\text{Nitrates (harmless)}}$$

- Nitrites is highly dangerous and therefore the permissible amount of nitrites present in potable water should be nil.
- Ammonia nitrogen + organic nitrogen = kjedhal nitrogen
- Nitrates in water is not harmful. However the presence of too much of nitrates in water may adversely affect the health of infants, causing a disease technically called **"mathemoglobinemia"** commonly called **"blue baby disease"**.
- The nitrate concentration in domestic water supplies is generally limited to 45 mg./l.
- In old days, nitrogen tests were considerable importance, as they were the only methods for detecting pollution caused by sewage or organic waste and thus indicating the presence or absence of bacteria and other such pollutants.

**(*vi*) Metals and other chemical substances:**

| | |
|---|---|
| Iron | – 0.3 ppm Excesses of these cause discolouration of clothes. |
| Maganese | – 0.05 |
| Copper | – 1.3 |
| Sulphate | – 250 |
| Fluoride | – 1.5 |

Excess affect human lungs and other respiratory organs.

- A fluoride concentration of less than 0.8-1.0 ppm cause dental cavity (tooth decay). If fluoride concentration is greater than 1.5 ppm, causing spotting and discolouration of teeth (a disease called **fluorosis**).

**(*vii*) Dissolved Gases:**

**Gases present are :**

$$N_2 \quad \underset{\text{explosive}}{CH_4}, \quad \underset{\text{bad taste odour}}{H_2S}, \quad \underset{\text{corrosion biological activity}}{CO_2} \quad \text{and} \quad \underset{\text{useful and necessary (D.O.)}}{O_2}$$

Oxygen gas is generally absorbed by water from the atmosphere, but it being consumed by unstable organic matter for their oxidation. Hence, if the oxygen present in water is found to be less than its saturation level, it indicate presence of organic' matter and consequently making the waters suspicious.

- The extent of organic matter present in water sample can be estimated by supplying oxygen to this sample and finding the oxygen consumed by the organic matter present in water. This oxygen demand is known as **Biological oxygen demand (BOD)**.
- It is not practically possible to determine ultimate oxygen demand. Hence, BOD of water during the first five days at 20°C is generally taken as the standard demand.

$$BOD_5 = \text{BOD of 5 days} = \text{Loss of oxygen in mg}/l \times \text{Dilution factor.}$$

- The BOD of safe drinking water must be nil.

**BACTERIAL and MICROSCOPICAL CHARACTERISTICS:**

Five types of parasitic organisms (viz. bacteria, protozoa, viruses, worms and fungi) are generally known to be infective to man and are found in water.

- **Bacteria:** These are the minute single cell organisms possessing no defined nucleus and having no green material to help them manufacture their own food. They are reproduced by binary fission and may be of various shapes, and sizes are 1 to 4 microns, examined by microscope.
- **Non-disease** causing bacteria - Non pathogenic bacteria.
- Disease causing bacteria known as - Pathogenic bacteria.
- **Protozoa:** These are single cell animals and are the lowest and the simplest form of animal life. They are bacteria eaters and thus destroy Pathogens. They are directly counted by microscope.
- **Worms** are the larva of flies
- **Fungi** are those plants which grow without sunlight and live on other plants or animals, dead or alive.

**Classification Based on the oxygen requirements of the bacteria:**

(*i*) Aerobic bacteria : Those which require oxygen for their survival

(*ii*) Anaerobic bacteria : Those which flourish in the absence of free oxygen.

(*iii*) Faculative bacteria : Those which can survive with or without free oxygen.

Pathogenic bacteria can be tested and counted in the laboratories but with great difficulty. These tests are therefore, generally not performed in routine to check up of the water quality. The usual routine tests are generally conducted to detect and count the presence of **coliforms** which in themselves are **harmless organisms**, but their presence or absence indicates the presence or absence of pathogenic bacteria.

**Methods to measure the presence of coliform bacteria:**

(*i*) Membrane filter technique (Modern Technique).

(*ii*) Mixing different dilution of a sample of water with lactose froth and incubating them in test- tubes for 48 hours at 37°C. The presence of acid or carbon dioxide gas in tubes will indicates the presence of coliform bacteria.

- Most probable number (MPN) represent the bacterial density.

(*iii*) **Coliform index:**

It may be defined as the reciprocal of the smallest quantity of a sample which would give a positive portion. Coliform sometimes, called bacteria coli (B-coli) or Escherichia coli (Ecoli) are harmless aerobic micro-organisms.

- If not more than 1 coliform colony is present per 100 ml. of water, then water is said to be safe for drinking.

- $$\text{MPN/100 ml.} = \frac{100 \times \text{Number of Positive Portion}}{\sqrt{(\text{ml. in all negative portion}) \times (\text{ml. in all positive portion})}}$$

**Water Borne Diseases and their control**

Water borne diseases are those diseases which spread primarily through contaminated water.

**Important water borne diseases:**

**1. Disease caused by bacterial infections:**

(*i*) Typhoid fever and paratyphoid fever ( caused by salmonella typhi bacteria)

(*ii*) Cholera (caused by vibrio-cholera bacteria)

(*iii*) Bacillary dysentery (caused by shiga bacillus or flexner bacillus.

**2. Disease caused by viral infections:**

(*i*) Infectious hepatitis or infectious jaundice (caused by hepatitis virus).

(*ii*) Poliomyelitis (caused by polio virus).

(*iii*) Gastroentritis.

**3. Disease caused by protozoal infections:**

Amoebic dysentery (caused by entamoeba hystolytic germ).

**WATER QUALITY STANDARDS FOR DRINKING WATER**

| *S. No.* | *Type of Characteristic* | *Type of imputrity* | *Permissible limit* | *Absolute maximum limit* | *Remark* |
|---|---|---|---|---|---|
| 1. | Physical | Turbidity | 5 | 25 | On silica scale |
| | | Colour | 5 | 50 | Colour number on cobalt scale |
| | | Taste & odour | 1 | 3 | Threshold odour number |
| 2. | Chemical | pH value | 7-8.5 | 6.5-9.2 | |
| | | Hardness | 75 mg/l | 110 mg/l | Hardness expenssed as CaCO. |
| | | Total solids | 500 mg/l | 1500 mg/l | As Der WHO standards |
| | | Magnesiun & Sodium | 500 | 1000 mg/l | As perWHO standards |
| | | Chlorides | 200 | 600 mg/l | As Der WHO standards |
| | | Sulphates | 200 | 400 mg/l | As per WHO standards |
| | | Calcium | 75 | 200 mg/l | As perWHO standards |
| | | Zinc | 5 | 15 mg/l | As per WHO standards |
| | | Copper | 1 | 1.5 mg/l | As per WHO standards |
| | | Iron | 0.3 | 1.0 | As Der WHO standards |
| | | Maganese | 0.1 | 0.5 | As Der WHO standards |
| | | Arsenic | Nil | 0.2 | As Der WHO standards |
| | | Lead | Nil | 0.1 | As per WHO standards |
| | | Selenium | Nil | 0.05 | As perWHO standards |
| | | Chromium | Nil | 0.05 | As per WHO standards |
| | | Phenolic compounds | | | |

| S. No. | Type of Characteristic | Type of imputrity | Permissible limit | Absolute maximum limit | Remark |
|---|---|---|---|---|---|
| | | as phenol | 0.001 | 0.002 | As per WHO standards |
| | | Cynide | Nil | 0.01 | As per WHO standards |
| | | Fluoride | 0.5 mg/l | 1.5 mg/l | As per WHO standards |
| | | Cadmium | – | 0.05 mg/l | As per WHO standards |
| 3. | Biological and Micro-organic | | Coliform bacteria | Nil colony per 100 ml. or MPN of B coli is limited to 1 per 100 ml. | 1 coliform |
| 4. | Radiological<br>β-emitters | α-emitters | Nil<br>Nil | 1 μμc/litre<br>10 μμc/litres. | W.H.O. standard<br>W.H.O. standard |

- Water used in pulp or paper industries, must be free from iron, maganese, and hardness.
- Water required for breweries, distilleries, and bakeries should preferably be hard.
- For steel rolling mills, the chloride content of water must be less than 150 mg/l
- The Water (prevention and control of pollution) Act enacted by the Indian Parliament in 1974.

## BIOCHEMICAL OXYGEN DEMAND :

If sufficient oxygen is present in the water, the useful aerobic bacteria production will flourish and cause the biological decomposition of waste and organic matter thereby reducing the carbonaceous material from the water. The amount of oxygen required in the process untill oxidation gets completed is known as BOD.

## PURIFICATION OF WATER SUPPLIES

### Methods of Purification of Water

(*i*) Screening (Intake)

(*ii*) Plain sedimentation

(*iii*) Sedimentation with coagulation;

(*iv*) Filtration

(*v*) Disinfection

(*vi*) Aeration

(*vii*) Softening; and

(*viii*) Miscellaneous treatments, such as fluoritation, recarbonation, liming, desalination. etc.

## PLAIN SEDIMENTATION

- Principle behind sedimentation is to reduce the flow velocity by providing tank called **settling tank**, or **clarifier** or **sedimentation basin**.
- Theoretical average time for which the water is detained in the tank is called the detention period.
- The settling velocity of spherical particle,

$$V_s = \frac{g}{18}(G-1)\frac{d^2}{v} \text{ for } d < 0.1 \text{ mm. [Re} < 0.5]$$

where, $V_s$ = velocity of settlement of particle.

$d$ = diameter of the particle.

G = specific gravity of the particle.

$v$ = kinematic viscosity of water.

$$R_e = \text{Reynold number} = \frac{V_s d}{\nu}$$

Since, the viscosity depend upon temperature, the above equation can be modified as

$$V_s = 418(G-1)d^2\left(\frac{3T+70}{100}\right) \text{ for } d < 0.1 \text{ mm.}$$

where, T = temperature of water in degree centigrades.

$V_s$ = velocity of settlement in mm/sec

$d$ = diameter of the particle in mm.

$$V_s = 1.8\sqrt{gd(G-1)}$$

for $d > 1.0$ mm (turbulent settling)

- In transition zone, settling velocity is given by Hazen as :

$$V_s = 418(G-1)d\left(\frac{3T+70}{100}\right) \text{ when } d \text{ lies between 0.1 mm. and 1 mm.}$$

The above formula represent the theoretical settling velocities of discrete spherical particles.

The actual settling velocities in the sedimentation basins, will be much less than that calculated by these formulae, because of:

(*i*) the non-sphericity of the particles,

(*ii*) the upward displacement of the fluid caused by the settling of other particles, and

(*iii*) convection currents.

- A plain sedimentation tank under normal conditions may remove as much as 70% of the suspended impurities present in water.

**Types of sedimentation tank:**

(*i*) Intermittently function sedimentation tank - not preferred these day.

(*ii*) Continuously function sedimentation tank.

- The velocity is so adjusted that the time taken by the particle to travel from one end to another is slightly more than the time required for settling of that particle.

## DESIGN OF CONTINUOUS FLOW TYPE OF SEDIMENTATION TANK

- Flow velocity, $V = \dfrac{Q}{BH}$

where, Q = Discharge entering the basin,
B = Width of the basin, and
H = Depth of water in the tank.

- $$\frac{V}{V_s} = \frac{L}{H}$$

$$\Rightarrow \quad V_s = \frac{VH}{L} = \frac{Q}{BH} \times \frac{H}{L} = \frac{Q}{BL}$$

$$\Rightarrow \quad V_s = \frac{Q}{BL} = \text{Permissible velocity}$$

- It shows that all those particles having a settling velocity equal to or greater than $\dfrac{Q}{BL}$ will settle down and be removed.
- $\dfrac{Q}{BL}$, *i.e.* the discharge per unit of plan area (surface area) is a very important term for the design of continuous flow type settling tanks; and is known as the **overflow rate** or the **surface loading** or the **overflow velocity**.

  Overflow velocity = 500 – 700 litres/hr./m$^2$ of plan area for plain sedimentation tanks and overflow velocity = 1000 – 1250 litres/hr./m$^2$ of plan area for plain sedimentation tanks using coagulants as aids.
- Smaller particles will also settle down, if the overflow rate is reduced.
- Usual values of depth ranges between 3.0 to 4.5 m.

**Detention period or Retention period (*t*):**

It is the average time for which the water is detained in the tank.

- Detention time for rectangular tank,

$$t = \frac{\text{Volume of the tank}}{\text{Rate of flow}}$$

*i.e* $$t = \frac{BLH}{Q}$$

Detention time for a circular tank,

$$t = \frac{d^2(0.011d + 0.785H)}{Q}$$

where, $d$ = Diameter of the tank.
H = Side water depth.

- Detention time = 4 to 8 hr. for plain sedimentation; and

  Detention time = 2 to 4 hr. when the coagulants are used.
- B ≈ 10 to 12 m.
- Length of the tank is not generally allowed to exceed four times the width.
- Normally kept flow velocity at about 0.3 m./min.
- In actual practice, certain amount of short circuiting always exist and therefore, the actual average time which a batch of water takes is passing through a settling tank, is called the **flowing through period**.
- Displacement efficiency

$$= \frac{\text{Flowing through period}}{\text{Detention period}} \approx 0.25 \text{ to } 0.5$$

- For tanks without mechanical sludge removal equipment, an additional minimum depth of about 0.8 to 1.2 m. should be provides for storage of sediment, and is called the **sludge zone**.

## SEDIMENTATION AIDED WITH COAGULATION

Certain chemical compounds called **coagulants** are added to the water, which on through mixing from a gelatenous precipitate called **'floc'**. The very fine mud particles and the colloidal matter present in water get attracted and absorbed in these flocs, forming the bigger sized floculated particles. The process of addition and mixing of the chemicals (i.e, the coagulants) is called the **coagulation**. The coagulated water is then made to pass through the sedimentation tank, where the floculated particles settle down and, are, thus removed.