5. WATER TREATMENT

THEORY OF SEDIMENTATION

- Stokes Law

(a) $\boxed{V_S = \frac{g}{18}(G-1)\frac{d^2}{\nu}}$ for $d < 0.1$ mm.

where, V_S = Velocity of settlement of particle in m/s.

d = Diameter of the particle in meter.

G = SP gravity of the particle

$= \frac{\gamma_s}{\gamma_w}$ or $\frac{\delta_s}{\delta_w}$

ν = Kinematic viscosity of water in m^2/sec.

(b) $\boxed{V_S = \left[\frac{\frac{4}{3}gd(G-1)}{C_D}\right]^{1/2}}$

$\boxed{C_D = 0.4}$ → For $(R_e > 10^4)$ $\boxed{C_D = \frac{24}{R_e}}$ → For $(R_e < 0.5)$

$\boxed{C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34}$ For $\boxed{0.5 \le R_e \le 10,000}$

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

where, T = Temperature of water in °C

V_S is in mm/sec.

d is in mm.

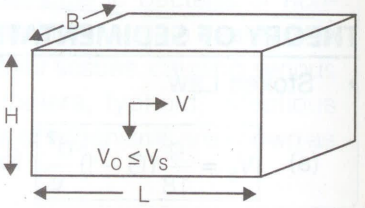
(d) $\boxed{V_S = 1.8\sqrt{gd(G-1)}}$ For $d > 0.1$ mm.

(e) $\boxed{V_S = 418(G-1)d\left(\frac{3T+70}{100}\right)}$ For $0.1 < d < 1$ mm.

SEDIMENTATION TANK

(a) $$\text{Over flow rate, } V_O = \frac{\text{Discharge}}{\text{Surface area}}$$

$$V_O = \frac{Q}{BL}$$



V_O = 12000 to 18000 lit/m²/day for plain sedimentation.

V_O = 24000 to 30,000 lit/m²/day for sedimentation with coagulation.

(b) Velocity of flow, $V_f = \frac{Q}{BH}$

(c) Time of horizontal flow, $T = \frac{L}{V_f} = \frac{L}{Q/BH} = \frac{LBH}{Q}$

(d) Time of falling through height 'H' $T = \frac{H}{V_S} = \frac{LBH}{Q}$

(e) Detention time, $t_d = \frac{L}{V_f} = \frac{H}{V_S}$

4 to 8 hr → For plain sedimentation

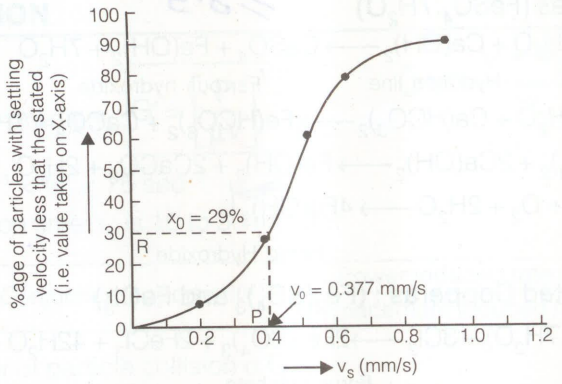
2 to 4 hr → For sedimentation with coagulation

(f) $P_p = \frac{V_S}{V_O} \times 100$ where, P_e = % of lighter particles (with settling velocity (V_S) less than V_O) which shall be removed in an ideal settling basin.

(g) % of particle removed

$$= (100 - x_0) + \int_{x=0}^{x=x_0} \left(\frac{V_S}{V_O} \times 100\right) \cdot dx$$

where, x_0 corresponds to V_0



(h) Detention time 't'

$t = \frac{BLH}{Q}$ for rectangular tank.

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

where, d = Dia of the tank

H = Vertical depth of wall or side water depth

(i) $$\text{Displacement efficiency} = \frac{\text{Flowing through period}}{\text{Detention period}}$$

(j) Scour velocity, V_d $V_d = \sqrt{\frac{8\beta}{f'} g(G-1)d}$

where, β = 0.04 for unigranular sand and 0.06 or more for non-uniform (interlocking) sticky material.

f' = Darcy weisback friction factor.

= 0.025 to 0.03 for settling tanks.

CHEMICALS USED FOR COAGULATION

- **Alum ($Al_2(SO_4)_3.18H_2O$)**

$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 \longrightarrow 3CaSO_4 + 2Al(OH)_3\downarrow + 6CO_2\uparrow$

$Al_2(SO_4)_3.18H_2O + 3Ca(OH)_2 \longrightarrow 3CaSO_4 + Al(OH)_3\downarrow + 18H_2O$

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

- **Copperas ($FeSO_4.7H_2O$)**

$$FeSO_4.7H_2O + Ca(OH)_2 \longrightarrow CaSO_4 + Fe(OH)_2 + 7H_2O$$

Copperas — Hydrated line — Ferrous hydroxide

$$FeSO_4.7H_2O + Ca(HCO_3)_2 \longrightarrow Fe(HCO_3)_2 + CaCO_3 + 7H_2O$$

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

$$Fe(OH)_2 + O_2 + 2H_2O \longrightarrow 4Fe(OH)_3\downarrow$$

Ferric Hydroxide

- **Chlorinated Copperas : ($Fe_2(SO_4)_3$ and $FeCl_3$)**

$$6(FeSO_4.7H_2O) + 3Cl_2 \longrightarrow 2Fe_2(SO_4)_3 + 2FeCl_3 + 42H_2O$$

Ferric sulphate

$$Fe_2(SO_4)_3 + 3Ca(OH)_2 \longrightarrow 3CaSO_4 + 2Fe(OH)_3\downarrow$$

Ferric Sulphate — Hydrated line — Ferric hydroxide ppt

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

Ferric Chloride — Hydrated line — Ferric hydroxide ppt

- **Sodium Aluminate ($Na_2Al_2O_4$)**

$$Na_2Al_2O_4 + Ca(HCO_3)_2 \longrightarrow CaAl_2O_4\downarrow + Na_2CO_3 + CO_2\uparrow + H_2O$$

$$Na_2Al_2O_4 + CaCl_2 \longrightarrow CaAl_2O_4\downarrow + 2NaCl$$

$$Na_2Al_2O_4 + CaSO_4 \longrightarrow CaAl_2O_4\downarrow + Na_2SO_4$$

MIXING BASIN

$$G' = \left[\frac{P}{\mu V}\right]^{1/2}$$

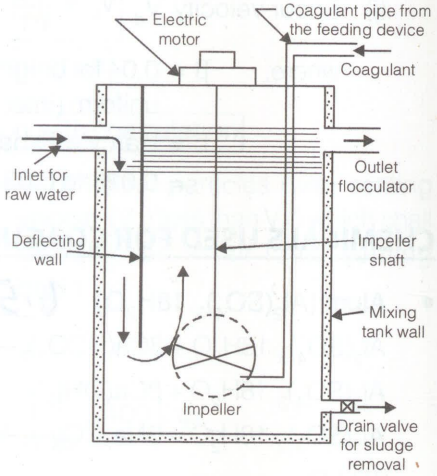
where,

G′ = Temporal mean Velocity gradient (per second).

P = Power dissipated in watts i.e., N-m/s.

V = Volume of raw water to which P is applied in m^3.

μ = Dynamic viscosity (N-s/m^2).



(Mixing basin with a flash mixer)

FLOCCULATION

- Velocity gradient, $G' = \left[\frac{P}{\mu V}\right]^{1/2}$.
- $20\ sec^{-1} < G' < 75\ sec^{-1}$.
- Detention time, t_d is 10 to 30 minute.
- $G' \cdot t_d\,(\text{Conjuction opportunity}) = \frac{\text{Power induced rate of flow}}{\text{Displacement induced rate of flow}}$
- Number of particle collision $\alpha\ G't_d$.
- $G'td = 2 \times 10^4$ to 6×10^4 for Alum.
  $= 1 \times 10^5$ to 1.5×10^5 for Iron salt.
- $\frac{G' \text{of influent end}}{G' \text{of effluent end}} = 2$

FILTRATION

A. Slow Sand Filter

- Depth of filter is 2.5 to 3.5 m.
- Plan area of filter is 100 to 200 m^2.
- $0.2 \le D_{10}$ of sand ≤ 0.3 mm.
- $\frac{D_{60}}{D_{10}} = 5$.
- Design period = 10 years.
- Depth of sand is 90 to 110 cm.
- Frequency of cleaning is 1 to 3 months
- Rate of filtration = 2400 to 4800 lit/m^2/day or 100 to 200 lit/m^2/hr.
- Efficiency of bacteria removal = 98 to 99%.
- It can not be used if turbidity > 50 ppm.
- It is designed for maximum daily demand.
- $\frac{\text{Discharge}}{\text{Rate of filteration}} = \text{Plan area}$.

B. Rapid Sand Filter

- $N = 1.22\sqrt{Q}$ where, N = Number of unit required
  Q = Plant capacity in million lit/day (MLD)

- $\frac{D_{60}}{D_{10}}$ = 1.2 to 1.8
- Sand layer depth is 60 to 90 cm.
- D_{10} of sand is 0.35 to 0.55 mm.
- Depth of tank = 2.5 m to 3.5 m.
- Area = 10 to 80 m^2 each unit.
- Rate of washing is 15 to 90 cm rise/minute.
- Rate of filtration 3000 to 6000 lit/m^2/hour (slow sand filter × 30)
- Cross-sectional area of manfold =2 × cross-sectional area of lateral.
- Cross-sectional area of each lateral = 2 to 4 times cross-sectional area of perforations in it.
- Total cross-sectional area of perforation = 0.2% of total area of 1 filter bed
- $\frac{\text{Length of each lateral}}{\text{Dia of lateral}} \neq 60$
- 4-5% of filtered water is used as back wash.
- 30 min. used for back wash.

Remember

Economical dia of rising main is given by Lea $\boxed{D = 1.22\sqrt{Q}}$

Q is in m^3/sec, D is in meter.

HYDRAULICS OF SAND GRAVITY FILTERS

$$\boxed{h_L = \frac{1.067V^2}{\phi \cdot g \cdot n^4} \in \frac{C_D \cdot f}{d}}$$

where, h_L = Frictional head loss through the filter in meter.
V = Approach velocity or filtration velocity in m/s.
D = Depth of filter in meter
ϕ = Shape factor (for non spherical particle)
d = Diameter of sand particles in meter.
g = Accelerations due to gravity in m/s^2.
n = Porosity
C_D = Newton's dray coefficient.
f = Mass friction of sand particle of dia d.

- **Rose Equation,** $\boxed{h_L = \left|\frac{1.067V^2D}{\phi g n^4} \cdot \frac{C_D}{d}\right|}$

HYDRAULIC HEAD LOSS AND EXPANSION OF THE FILTER DURING BACKWASH

- $\boxed{H_{L_e}\gamma_w = D\gamma_{sub}}$ where, H_{Le} = Head loss through the filter bed required to initiate expansion in meter.
  γ_w = Unit weight of mater in kN/m^3.
  D = Depth of filter bed in meter.
  γ_{sub} = Submerged unit weight of sand in bed of depth 'D' in kN/m^3.
- $\boxed{H_{L_e} = D(1-n)(G-1)}$ • $\boxed{H_{L_e} = D_e(1-n_e)(G-1)}$

  where, D_e = Depth of expanded/fluidized bed in meter.
  n_e = The porosity of the expanded fluidized bed.
- $\boxed{D_e = \frac{(1-n)D}{(1-n_e)}}$ • $\boxed{D_e = (1-n)D.\Sigma\frac{f}{1-n_e}}$

  where, f =mass fraction of sand of various sizes in the sand (as per sieve analysis)
- $\boxed{n_e = \left(\frac{V_b}{V_s}\right)^{0.22}}$ where, n_e = Porosity of expanded bed
  V_b = Backwash velocity in m/s
  V_s = Settling velocity in m/s.
- $\boxed{V_s = \left[\frac{4}{3}\frac{gd(G-1)}{C_D}\right]^{1/2}}$

Remember

- **Pressure Filters:** Pressure filters are just like small rapid gravity filters placed in closed vessels, and through which water to be treated is passed under pressure.
- Rate of Filtration—6,000 to 15,000 litre/hour/m^2 (Rapid Sand Filter × 2)
- The pressure filter are less efficient than the rapid gravity filters, in removing bacteria and turbidities.

DISINFECTION OR STERILIZATION

(i) Treatment with Ozone

$$\underset{\substack{\text{Oxygen}\\\text{Molecule}\\\text{3 Mole}}}{3O_2} \xrightarrow[\text{Arc voltage}]{\text{Under high electric}} \underset{\substack{\text{Ozone}\\\text{Molecule}\\\text{2 Mole}}}{2O_3}$$

$$\underset{\text{Ozone}}{O_3} \longrightarrow \underset{\text{Oxygen}}{O_2} + \underset{\text{Nascent oxygen}}{[O]}$$

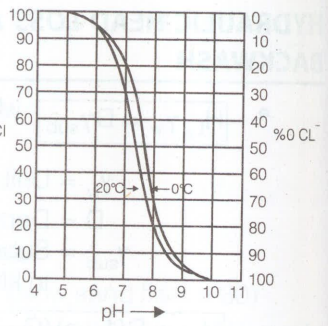
(ii) Disinfecting Action of Chlorine

$Cl_2 + H_2O \xrightarrow{PH>5} HOCl + HCl$

Hypochlorous acid.

$HOCl \underset{PH<7}{\overset{PH>8}{\rightleftharpoons}} H^+ + OCl^-$

Hydrogen ion Hypochlorite ion



$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$ PH > 7.5

Monochloro Amine

$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$ PH→5 to 6.5

Di-chloroamine

$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$ PH < 4.4

Nitrogen Trichloroamine

(iii) Doses of Chlorine

Type 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 dose varying from 21 to 138 mg/l.

(iv) Forms in which chlorine is applied

(a) Free chlorine
(b) Hypochlorites & Bleaching Powder
(c) Chloramines
(d) Chlorine dioxide (ClO_2)

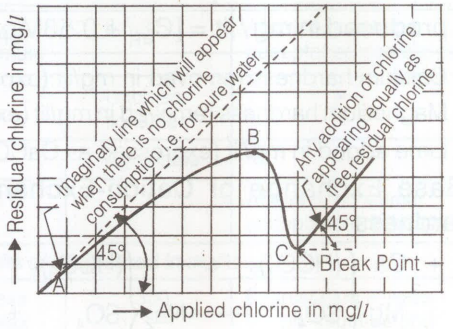
$Ca(OCl)_2 \xrightleftharpoons{H_2O} Ca^{2+} + 2OCl^-$

Calcium Hypochlorite Calcium ion Hypochlorite ion

$OCl^- + H^+ \underset{PH>8}{\overset{PH<7}{\rightleftharpoons}} HOCl$ (Hypochlorous acid)

TYPE OF CHLORINATION

(i) Plain chlorination
(ii) Pre-chlorination
(iii) Post-chlorination
(iv) Double chlorination
(v) Break point chlorination
(vi) Super chlorination
(viii) Dechlorination



STARCH IODIDE TEST

$$\begin{bmatrix}\text{Quantity of chlorine in mg/lit in the original sample of water}\end{bmatrix} = 0.355 \begin{bmatrix}\text{Number of ml of thiosulphate required to remove the blue colour}\end{bmatrix}$$

WATER SOFTENING

- **Methods of Removing Temporary Hardness**

(i) Boiling

$Ca(HCO_3)_2 + \text{Heat} \longrightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O$

Calcium bi Carbonate Calcium Carbonate

(ii) Addition of Lime

$MgCO_3 + Ca(OH)_2 \longrightarrow Mg(OH_2)\downarrow + CaCO_3\downarrow$

Magnesium carbonate Hydrated lime Magnesium Hydroxide Calcium Carbonate

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

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

- **Method of Removing Permanent Hardness**

(i) Lime-Soda Process

(a) $Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2CaCO_3\downarrow + 2H_2O$

(b) (i) $Mg(HCO_3)_2 + Ca(OH)_2 \longrightarrow Ca(HCO_3)_2 + Mg(OH)_2\downarrow$

(ii) $MgCO_3 + Ca(OH)_2 \longrightarrow Mg(OH)_2 + CaCO_3\downarrow$

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

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

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

(f) $CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + 2NaCl$

(g) $CaSO_4 + Na_2CO_3 \longrightarrow CaCO_3\downarrow + Na_2SO_4$

- Dry sludge produced in mg / lit = $[C_{aR} + 0.58M_{gR} + L_{iA}]$

where, C_{aR} = Calcium hardness removed in mg/lit (expressed as $CaCO_3$)

M_{gR} = Magnesium hardness removed in mg/lit (expressed as $CaCO_3$)

L_{iA} = Lime added in mg/lit (expressed as $CaCO_3$)

- **Zeolite or Base Exchange or Cation-Exchange Process for Removing Hardness**

$$Na_2z + Ca\begin{cases}(HCO_3)_2\\ SO_4\\ Cl_2\end{cases} \longrightarrow Na_2\begin{cases}(HCO_3)_2\\ SO_4\\ Cl_2\end{cases} + \begin{matrix}Ca\\ Mg\end{matrix}\Big\{ z$$

Sodium zeolite or active zeolite — Calcium or Magnesium Salt — Sodium slats which don't cause hardness — Calcium or Magnesium zeolite

$$\begin{matrix}Ca\\ Mg\end{matrix}\Big\} z + 2NaCl \longrightarrow Na_2z + \begin{matrix}Ca\\ Mg\end{matrix}\Big\} Cl_2$$

Used zeolite — Sodium chloride solution — Regenerated zeolite

- **Demineralization Process for Removing Hardness**

$$Ca(HCO_3)_2 + H_2R \longrightarrow CaR + 2H_2O + 2CO_2\uparrow$$

Fresh cation exchange resin — Exhausted rasin

$$CaCl_2 + H_2R \longrightarrow CaR + 2HCl$$
$$MgSO_4 + H_2R \longrightarrow MgR + H_2SO_4$$
$$2NaCl + H_2R \longrightarrow Na_2R + 2HCl$$
$$R\text{-}OH + HCl \longrightarrow RCl + H_2O$$

Fresh anion exchange resin — Exhausted resin — Water

$$2R\text{-}OH + H_2SO_4 \longrightarrow R_2SO_4 + 2H_2O$$

Fresh anion exchange resin — Exhausted resin — Water

Remember: Hardness for drinking water = 75 – 115 mg/lit. is recommended.

Drinking water specification: IS : 10500, 1992 (Reaffirmed 1993)
Tolerance Limit

S. No.	Parameter	IS: 10500 Requirement (desirable limit)	Undesirable effect outside the desirable limit	IS: 10500 Permissible limit in the absence of alternate source
	Essential Characteristics			
1.	pH	6.5-8.5	Beyond this range the water will effect the mucous membrane and/or water supply system	No relaxation
2.	Colour (hazen units), Maximum	6.5-8.5	Above 5, consumer acceptance decreases	25
3.	Odour	Unobjec-tionable	----	---
4.	Taste	Agreeable	----	---
5.	Turbidity, NTU, Max	5	Above 5, consumer acceptance decreases	10
	Following Results are expressed in mg/1:			
6.	Total hardness as $CaCO_3$ Max	300	Encrustation in water supply structure and adverse effects on domestic use	600
7.	Iron as Fe, Max	0.30	Beyond this limit taste/ appearance are affected, has adverse effect on domestic uses and water supply structures, and promotes iron bacteria.	1.0
8.	Chlorides as Cl, Max	250	Beyond this limit tast, corrosion and palatability are effected	1000
9.	Residual, Free Chlorine, Min	0.20	---	---
	Desirable Characteristics			
10.	Dissolved solids, Max	500	Beyond this palatability decreases and may cause gastro intentiona irritation	2000
11.	Calcium as Ca, Max	75	Encrustation in water supply structure and adverse effects on domestic use	200
12.	Magnesium as Mg, Max	30	---	100
13.	Nitrates as NO_3	45	Beyond this methane-moglobinemia takes place	100
14.	Fluoride, Max	1.0	Fluoride may be kept as low as possible. High fluoride may cause fluorosis	1.5
15.	Alkalinity, Max	200	Beyond this limit taste becomes unpleasant.	600

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