

TREATMENT OF WATER-MODULE-III

Process of treatment

- Screening
- Plain sedimentation
- Sedimentation with coagulation
- Filtration
- Disinfection
- Aeration
- Softening

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Miscellaneous methods such as → Fluoridation, Re carbonation, Liming, Desalination

Screening

Coarse screen

screens



Vertical rods/pipes, dia. 2-10cm
less than 1cm

Placed 45°-60° inclined

Limiting the velocity, 0.8-1m/sec
should be removed

Fine



Small wires of dia.

perforated metals

Material collected U/S

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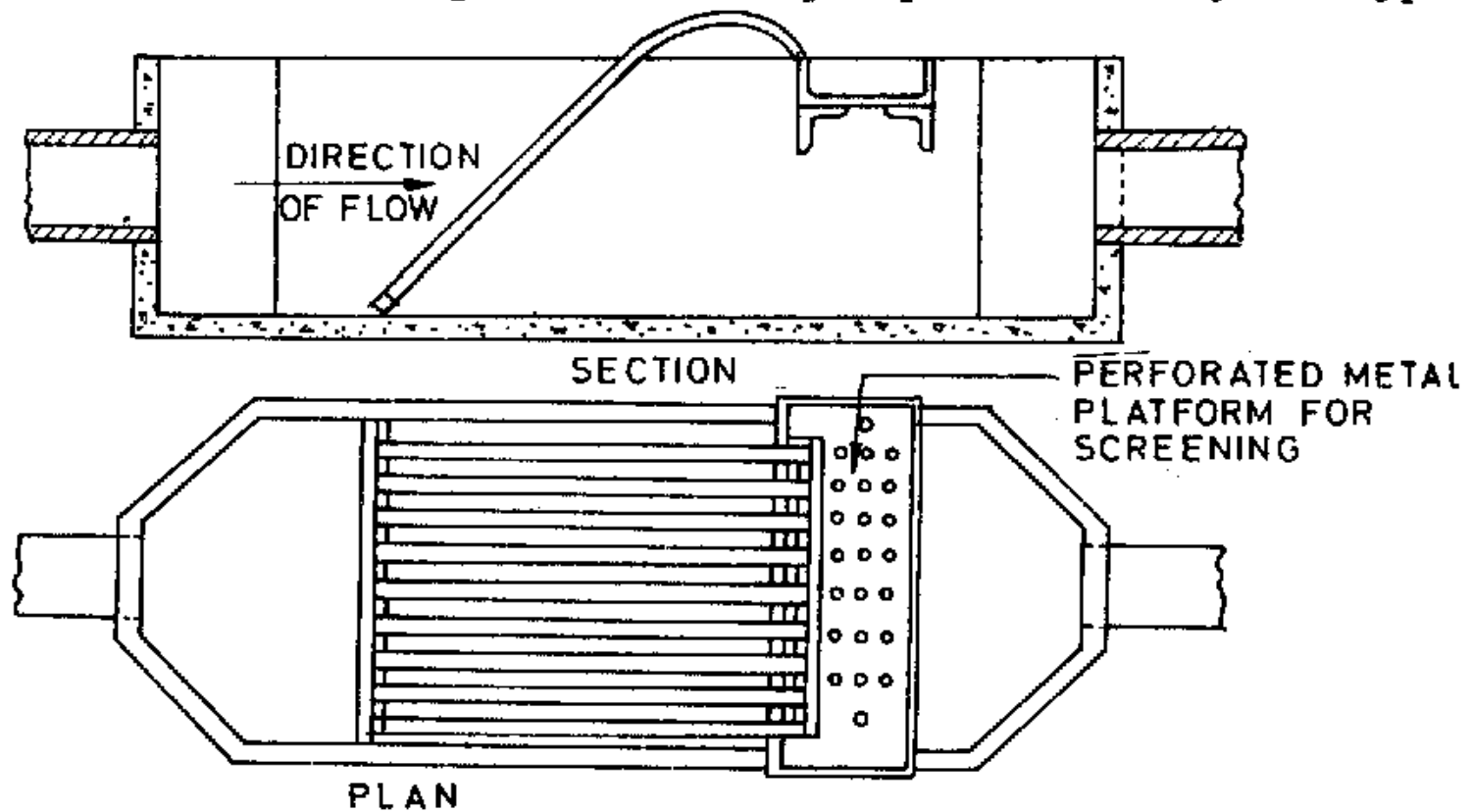


Fig. 9.1. Fixed bar type screen.

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Theory of sedimentation

- The settlement of the particles depends on the following
- Velocity of flow
- Viscosity of the water
- The size and shape
- Sp. Gravity
- Stokes's law

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Sedimentation-Principles→

- Most of the particles are higher sp. gravity than water, 1.02-2.65
- Particles of sp. gravity greater than 1.2, may settle down in still water
- A chamber/ a tank is provided to reduce the turbulence/ entry velocity, called sedimentation tank
- The average time for which the water detained in the sedimentation tank is called the detention period

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$V_s = (g/18)*(G-1)*d^2/v$ for, $d=0.1\text{mm}$ → Used for spherical particles

V_s → Settling velocity in m/sec.

G → sp.gravity

d → diameter of the particle in metres

v → kinematic viscosity of water in m^2/sec .

$V_s = 418(G-1)*d^2 [(3*T+70)/100]$, for $d=0.1\text{mm}$ → stream line settling

T → Temp. in $^{\circ}\text{C}$

V_s → mm/ sec.

d → diameter in mm

$V_s = 1.8gd*\sqrt{(g-1)}$ for $d>0.1\text{mm}$ → Turbulent settling

Note: Grit particles are normally in between, 0.1mm and 1mm and settling velocity is given by

$$V_s = 418(G-1)*d [(3T+70)/100]$$

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Type of sedimentation tank

Sedimentation tank



Horizontal flow type ← → Vertical flow type



Rectangular with horizontal flow

Circular with radial flow

Concepts in plain sedimentation tank (Type-I Settling)

Consider a fluid particle entering in the bottom of the tank, which moves upwards with a velocity of flow, say v_0 and settling velocity of v_s . Then the particle does not move up if the settling velocity is more than the liquid rise velocity.

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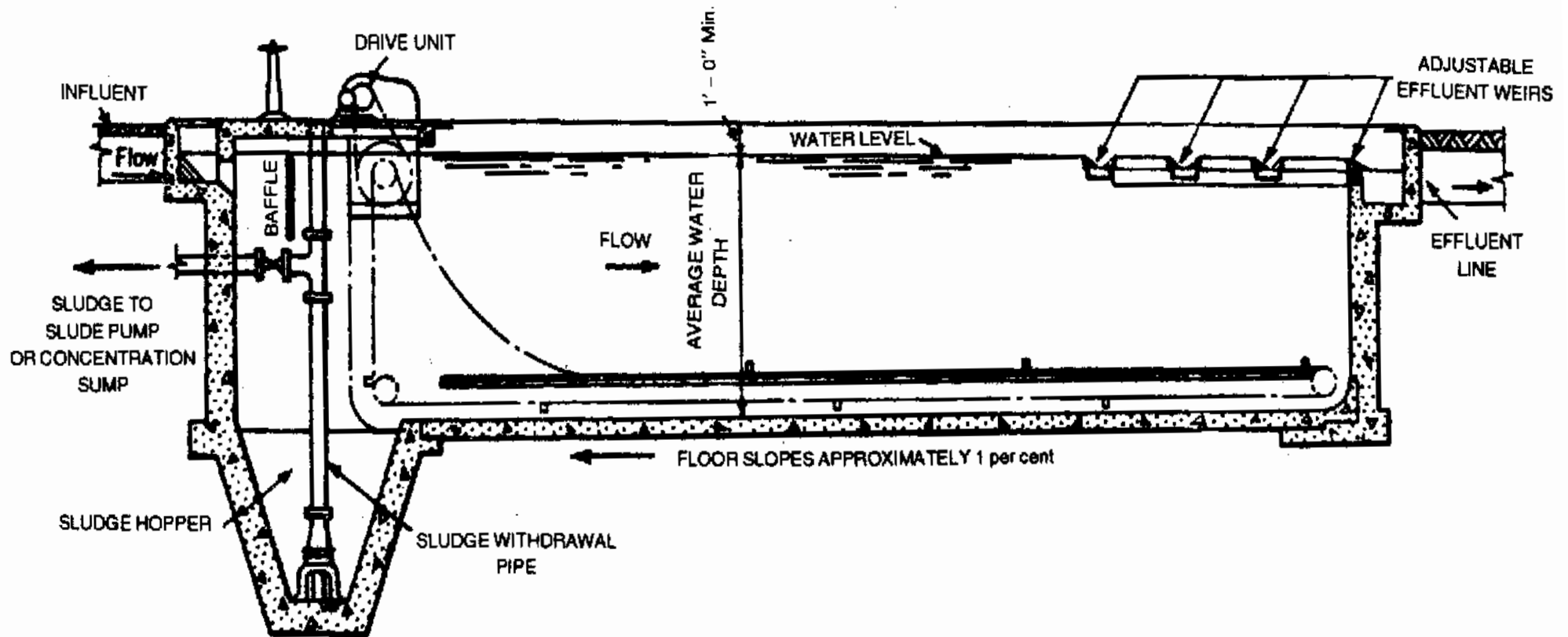


Fig. 9.3. Rectangular sedimentation tank (ideal horizontal flow tank).

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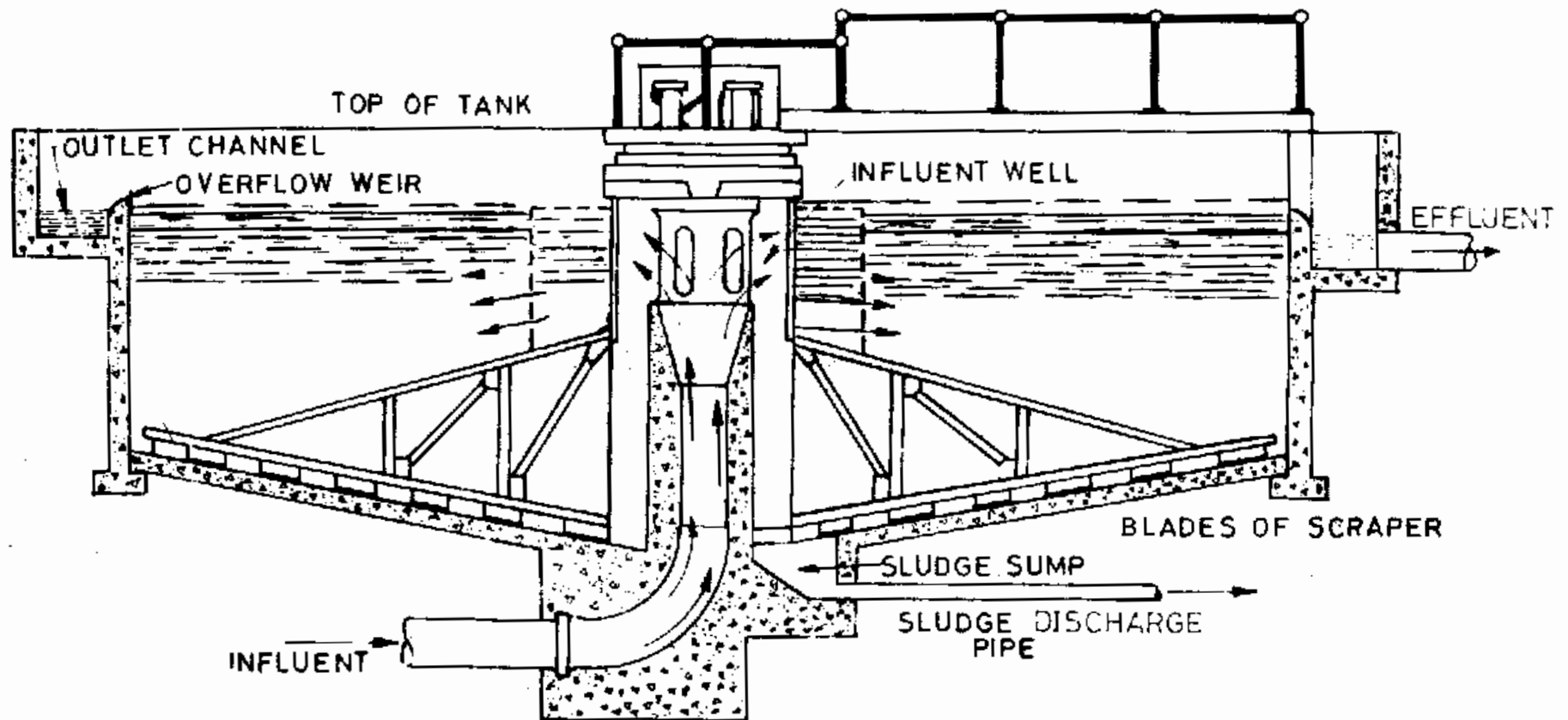


Fig. 9.4. Circular sedimentation tank (central feed) with radial flow.

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$V_0 \rightarrow \text{Discharge} / \text{Surface area} \rightarrow \text{volume} / \text{time}$

Surface area

$$\frac{(\text{Surface area} \times \text{depth}) / \text{time}}{\text{Surface area}} \rightarrow \frac{\text{depth}}{\text{time}}$$

That is liquid velocity

Note: This is also called the overflow rate/ overflow velocity/
surface overflow rate/surface loading

- As long as the settling velocity is greater than the overflow rate, particles settle down and can be removed.

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Assumptions made in the horizontal settling tank

- Particles and their velocity vectors are evenly distributed across the tank cross section and is a function of the inlet zone
- The liquid moves as an ideal slug, down the length of the tank
- Any particle hitting the tank bottom can be removed
- Let us consider the water containing the uniformly distributed particles enters the tank cross section, with a uniform velocity, v as given by

$$v \rightarrow Q/B \cdot H$$

$B \rightarrow$ width of the tank

$H \rightarrow$ height of the tank

$Q \rightarrow$ discharge entering the basin

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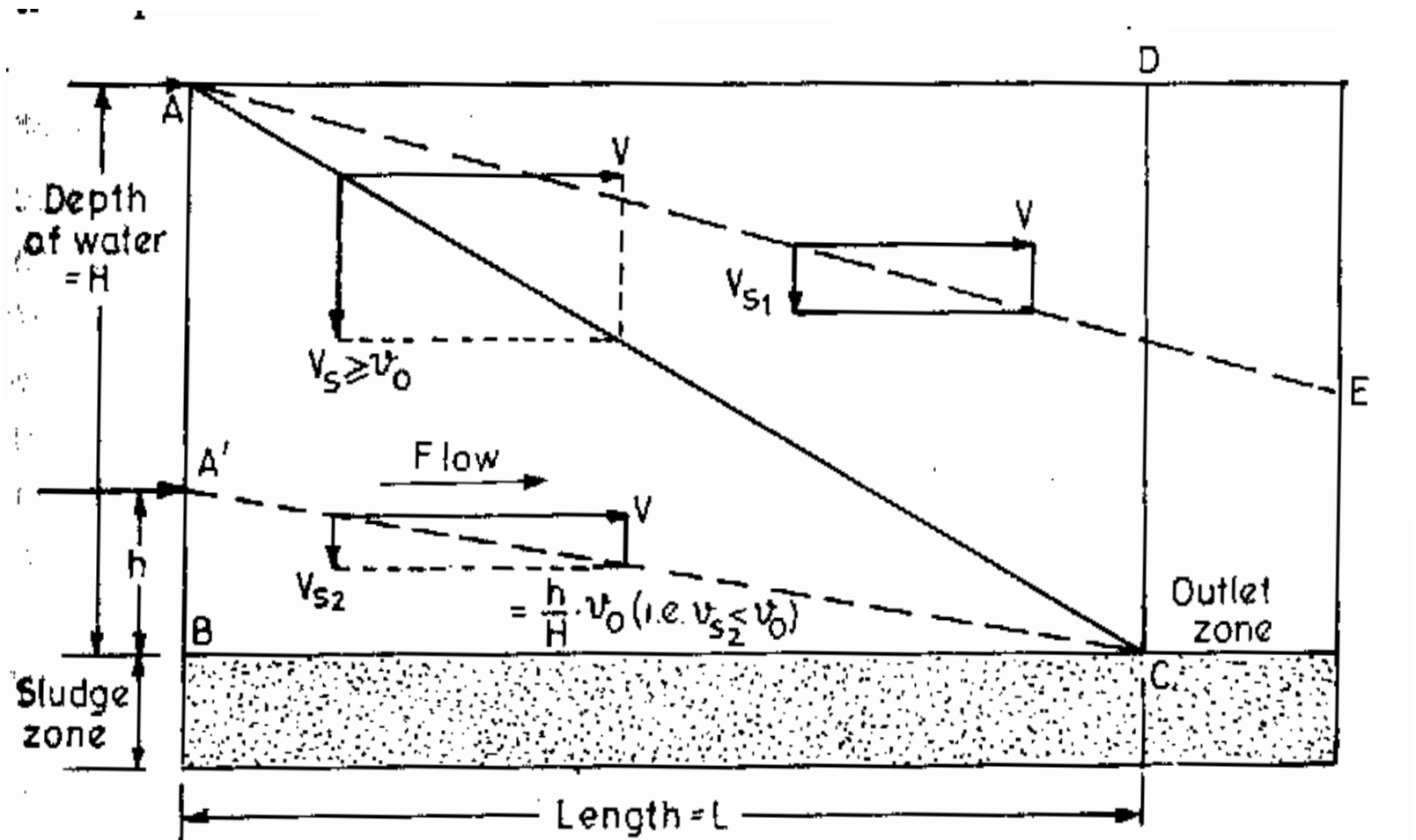


Diagram of a rectangular sedimentation tank (line diagram)

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From the figure, it can be concluded that

- The particle entering at the top of the tank with a velocity less than the settling velocity is settle down as defined by the line AC $\rightarrow v < V_s$
- Some particle that enter below the line AC, with velocity greater than its settling velocity may also settle down provided the condition that, $V_s = (h/H)v_0$ is satisfied.

Also from the figure,

$$V/V_s \rightarrow L/H$$

$$\rightarrow V_s = v * (H/L)$$

$$\rightarrow V_s = \frac{Q}{B*H} * \frac{H}{L} \rightarrow \frac{Q}{As} \rightarrow v_0$$

That is the overflow rate itself.

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Detention period

The theoretical time taken by a particle entering in to the tank to leave the tank or the time detained in the tank and is given by →

$$\frac{\text{Volume of the tank}}{\text{Rate of flow}} \longrightarrow \frac{\text{BLH}}{Q}$$

Problem: Design a sedimentation tank for a purification plant of max. daily demand of 12M.litres. Assume 6 hr. detention period and 20 cm/min. flow velocity.

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Solution:

$$Q = [12 * 10^6 * 6] / [24 * 1000] \rightarrow 3000 \text{m}^3$$

$$v = 0.20 \text{m/min}$$

$$L = \text{velocity} * \text{detention period} \rightarrow 0.20 * 6 * 60 \rightarrow 72 \text{m}$$

$$\text{Cross sectional area} \rightarrow Q/L \rightarrow 3000/72 \rightarrow 41.7 \text{m}^2$$

Assume a depth of 4m

$$B \rightarrow 41.7/4 \rightarrow 10.42, \text{ say } 10.5 \text{m}$$

Assume 0.50m freeboard

$$\text{Overall depth} \rightarrow 4.50 \text{m}$$

$$\text{Size of the tank} \rightarrow 72 \text{m} \times 10.50 \text{m} \times 4.50 \text{m}$$

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Problem: 2 M. liters of water per day passing through a sedimentation tank which is 6m wide, 15m long and having a water depth of 3m. Find

- Detention period
- Ave. flow velocity
- Amount per day of suspended solid if the contamination is 60ppm and sp. gravity is 2. Assume 70% removal in the tank
- Overflow rate

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Solution:

$$Q = 2 \times 10^6 \text{ lit.} \rightarrow 2000 \text{ m}^3/\text{day.} \rightarrow 83.33 \text{ m}^3/\text{hr}$$

$$\text{Detention period} \rightarrow V/Q \rightarrow [6 \times 15 \times 3]/83.33 \rightarrow 3.24 \text{ hr}$$

$$\text{Ave. flow velocity} \rightarrow Q/BH \rightarrow 83.33/3 \times 6$$

$$\rightarrow 4.62 \text{ m/hr} \rightarrow 7.72 \text{ cm/min.}$$

$$\text{Quantity of water} \rightarrow 2 \times 10^6 \text{ lit/day}$$

$$\text{Concentration of particle} \rightarrow 60 \text{ ppm}$$

$$\text{Quantity of material} \rightarrow [2 \times 10^6 \times 60]/10^6 \rightarrow 120 \text{ lit/day}$$

$$\text{Materials removed} \rightarrow @70\% \rightarrow 120 \times 0.70 \rightarrow 84 \text{ lit.} \rightarrow 0.084 \text{ m}^3$$

$$\text{Overflow rate} \rightarrow Q/LB \rightarrow 83.33 \times 10^3 \text{ lit/hr}$$

$$\frac{15 \text{ m} \times 6 \text{ m}}{\rightarrow 926 \text{ lit/hr/m}^2}$$

Sedimentation with coagulation (Type II settling)

The particles of comparatively larger size may settle down in plain sedimentation tank of ordinary detention period. But these particles and even smaller sized particles can easily be settle by increasing their size by changing them in to flocculated particles. Certain chemicals, called coagulants when added to the water which on through mixing forms gelatinous precipitate called floc. These floc as moves downward attracts smaller colloidal particles and become bigger and bigger in size and settle easily

$$\rho_f = \rho_w + kd^{-0.7}$$

Where,

$\rho_f \rightarrow$ density of floc

$\rho_w \rightarrow$ density of water

$k \rightarrow$ coefficient depending on the charecteristics of water and chemicals

$d \rightarrow$ diameter of the particles

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Chemicals used as coagulant

- Alum
- Copperas
- Chlorinated copperas
- Sodium aluminates

Alum → Aluminum sulphate $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$

- When added to water reacts with bicarbonate alkalinities and forms gelatinous precipitate of aluminum hydroxide
- Reaction involves CaSO_4 → imparts hardness
- Reaction includes evolution of CO_2 → corrosiveness
- Optimum dosage is determined by laboratory test

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- Depending on turbidity, 5-85mg/lit
- Normal dosage is 17mg/lit
- Effective in a pH range of 6 -8.5 and made alkaline by adding lime etc.

Copperas → Ferrous sulphate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$)

- Generally added to raw water after mixing with lime
- Forms ferrous hydroxide
- When oxidizes, form ferric hydroxide
- Forms floc
- **Note:** Used when raw water, not coloured
- Cheaper than alum
- Function pH above 8.50
- Dosage is same as Alum

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Chlorinated copperas → chlorine when added to ferrous sulphate

- The resultant reaction is a combination of ferric sulphate and ferric chloride and is known as chlorinated copperas
- The reaction with raw water forms ferric hydroxide → floc formation

Note:

- Effective coagulant for almost all pH range
- Effective for coloured water

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- **Sodium aluminates** → ($\text{Na}_2\text{Al}_2\text{O}_4$)
- Reacts with salts of calcium and magnesium present in water
- Produces calcium and magnesium aluminates
- Note: Approximately 1.50 times costlier than Alum
- Reduced hardness → used as boiler feed water

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- **Comparison of Aluminium and Iron salts as coagulant**
- Iron forms heavy floc and more effective than Alum
- Iron salts - being good oxidizing agent can remove hydrogen sulphide
→ taste and odour
- Used over a wide range of pH
- Iron salts produce staining and promote growth of iron bacteria in distribution system
- Imparts corrosiveness than Alum
- Handling and storage requires skill and care

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Constituents of a coagulation sedimentation tank

- A feeding device
- A mixing device/ mixing basine
- Flocculation tank/ Flocculator
- Settling/ sedimentation tank

Type of feeding devices →

- Dry feeding
- Wet feeding

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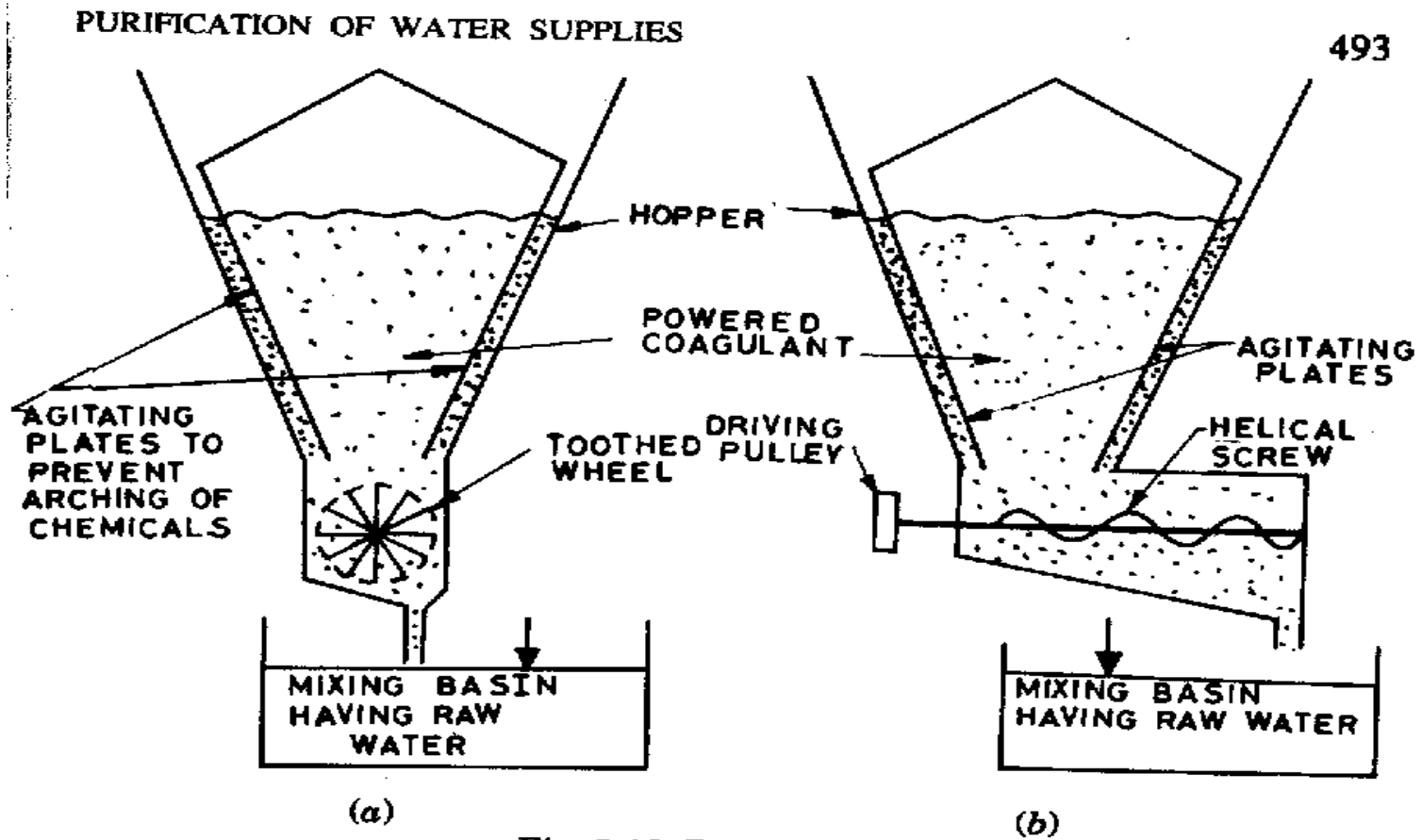


Fig. 9.18. Dry feeders.

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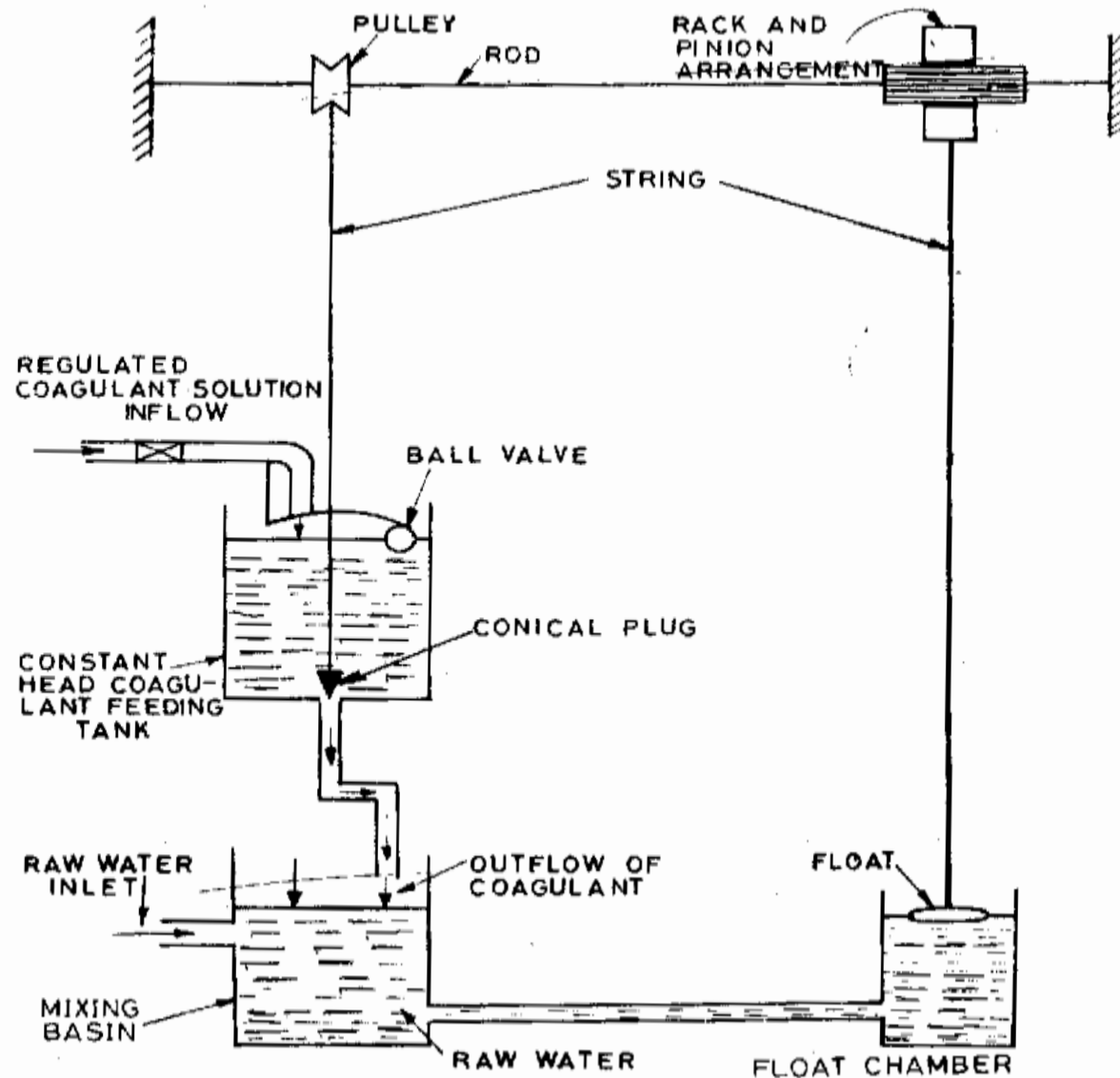


Fig. 9.19. Wet feeding by Conical plug and float arrangement.

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Choice of selection depends on the following

- Characteristics of coagulant and convenient with which it can be applied
- Non uniform chemicals cannot be used as dry
- Alum → wet and dry
- Copperas → not dry feeding, but wet feeding
- Activated carbon → only dry feeding
- Cost of the coagulant and the size of the plant
- Purchase of the coagulant in cheapest form-Then plant is equipped with to use in the same form based on the initial cost of device and cost of coagulant
- If the plant is small, the feeding device should govern (small → dry feeding)
- Large plant → watch and ward for mixing etc.
- The amount of coagulant used
- Very small dose → solution form

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Mixing device

- Around the end baffle
- Over and under the baffle

Problem:

Design the water depth for a mixing basin having around the end baffle in order to meet 48MLD of water. The tank divided in to two similar compartments by providing a longitudinal partition wall and each half may have a clear width of 8m. Assume suitable values of detention period and flow velocity through the basin. The clear distance between baffles may be kept as equal to minimum permissible. Mention the number of channels in the tank and also the overall inside length of the tank.

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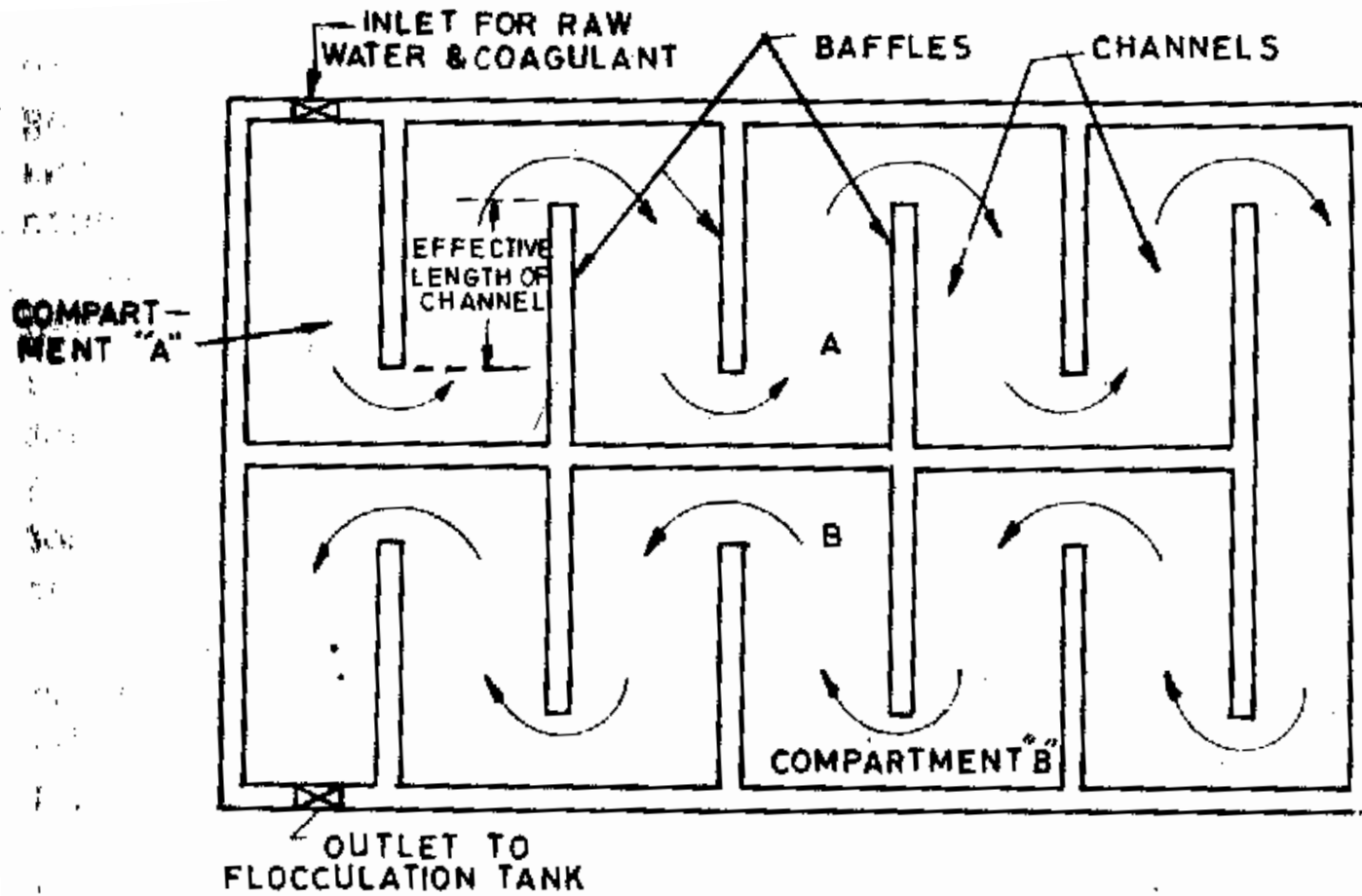


Fig. 9.20. Plan of "Around the end baffle type" mixing basin.

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Fig. 9.20. Plan of "Around the end baffle type" mixing basin.

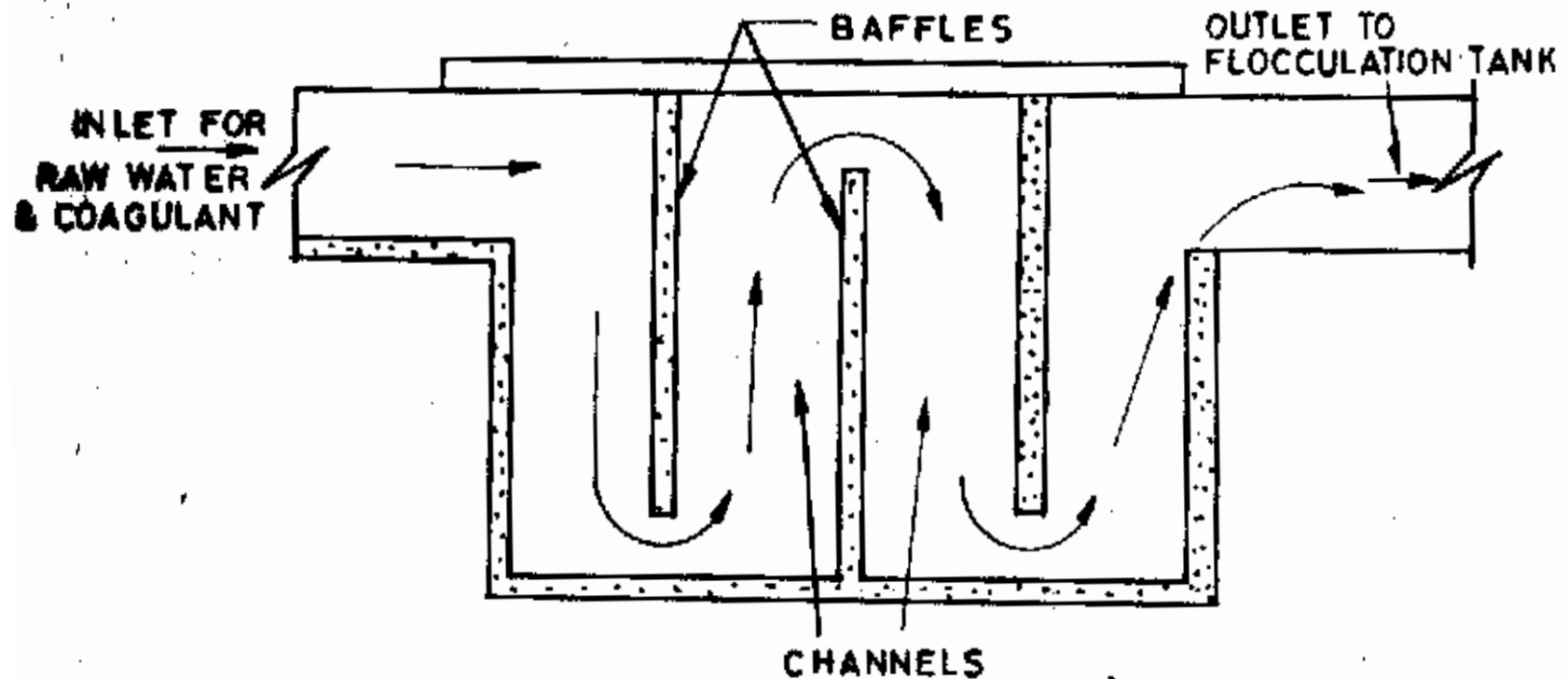


Fig. 9.21. Sectional elevation of "Over and under the baffle" type mixing basin.

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Solution:

Volume of water $\rightarrow 48 \times 10^6 / (24 \times 1000) \rightarrow 2000 \text{m}^3/\text{hr}$

Assume a detention period of 30minutes (20-50 minutes)

Volume of water/30 minutes $\rightarrow 2000/2 \rightarrow 1000 \text{m}^3$

Assume the flow velocity of 0.30m/sec (0.15-0.45m/sec)

Length of flow $\rightarrow \text{velocity} \times \text{time} \rightarrow 0.30 \times 30 \times 60 \rightarrow 540 \text{m}$

Cross sectional area of the channel $\rightarrow 1000/540 \rightarrow 1.85 \text{m}^2$

The distance b/w baffle $\rightarrow \text{assume as } 45 \text{cm (min)}$

Then the depth of water $\rightarrow 1.85/0.45 \rightarrow 4.12 \text{m}$

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Say $\rightarrow 4.2\text{m}$

Clear distance b/w the wall and baffle $\rightarrow 1.50$ times the distance
b/w baffles

$1.5 \times 45 \rightarrow 70\text{cm}$

Effective length $\rightarrow 8 - 2 \times \text{half opening} \rightarrow 8 - 2 \times 0.50 \times 70 \rightarrow 7.30\text{m}$

Number of channels required $\rightarrow 540/7.3 \rightarrow 74$ Nos

That is $74/2 \rightarrow 37$ channels in each half of the tank

Clear length of channel $\rightarrow 37 \times 0.45 + [(37-1) \times (7.5/100)] \rightarrow 19.35\text{m}$

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Flocculator

The best floc will form when the mixture of water and coagulant are violently agitated followed by relatively slow and gentle stirring to permit build up and agglomeration of the floc particles. The water from mixing device is taken to a tank fitted with paddles operated by electric motors, called flocculator, where it is given a slow stirring motion.

Types of Flocculator → flash type mixer and Deflector plate mixer

Flash mixer → Speed of paddles @ 2-3 rpm

- Detention period → 30minutes (20-60minutes)
- Clear distance between paddles/walls → 15-30cm
- The rolling motion provided by the paddles keeps the floc in suspension

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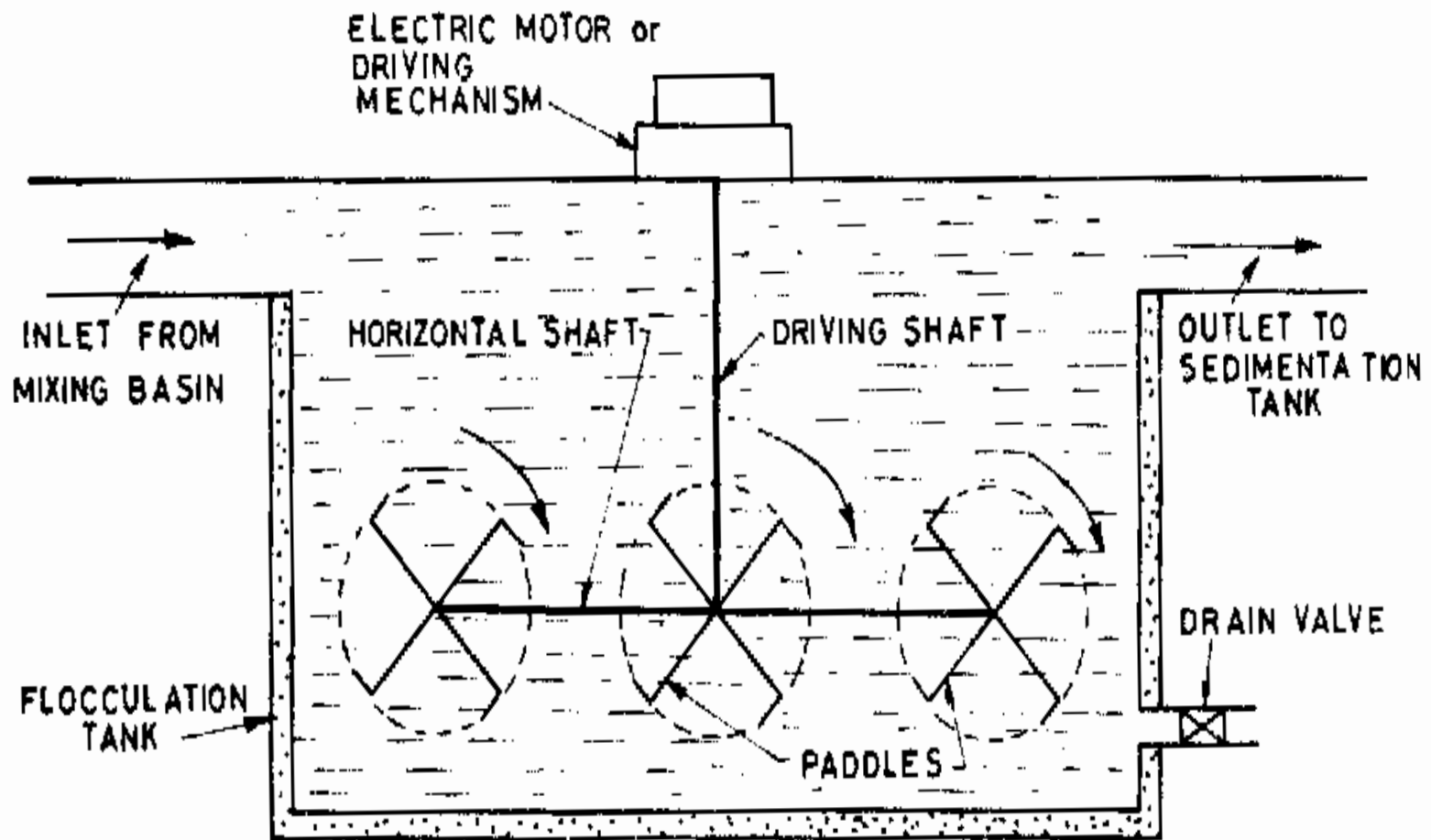


Fig. 9.23. (a) A typical Flocculator fitted with paddles.

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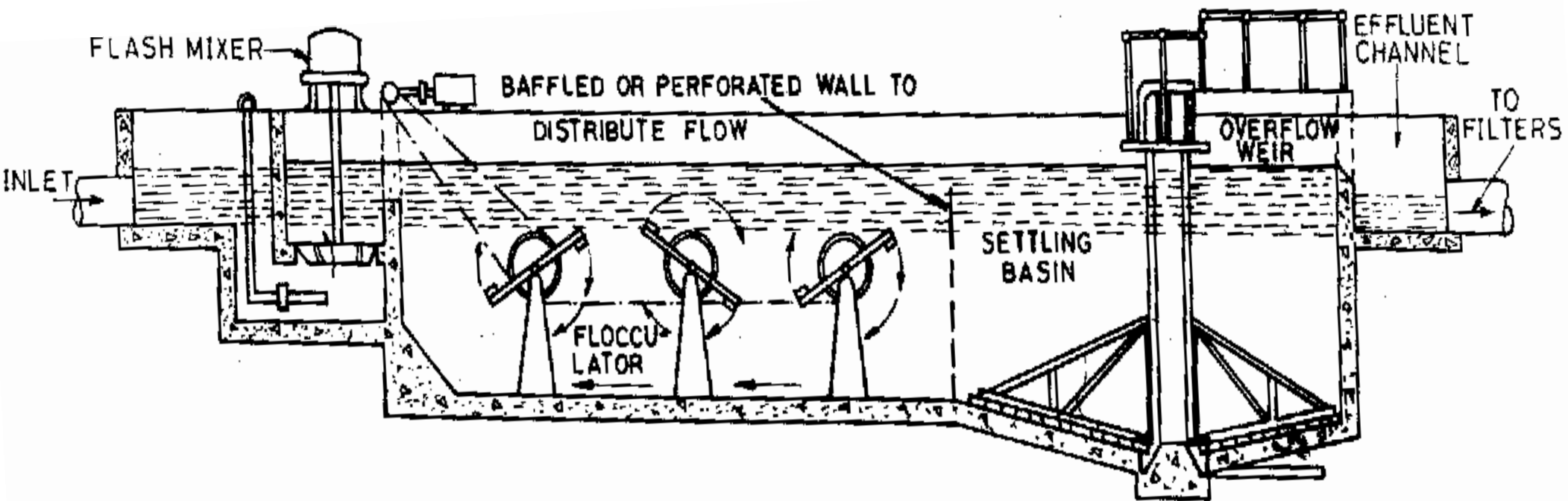


Fig. 9.17. Dorr Co. Clariflocculator.

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Sedimentation tank



Plain sedimentation tank ↔ combined coagulation cum sedimentation tank

Plain sedimentation tank (When coagulant is not used) →

Low detention period → 2 - 4 hr

Higher overflow rate → 1000 – 1250lit/hr/m²

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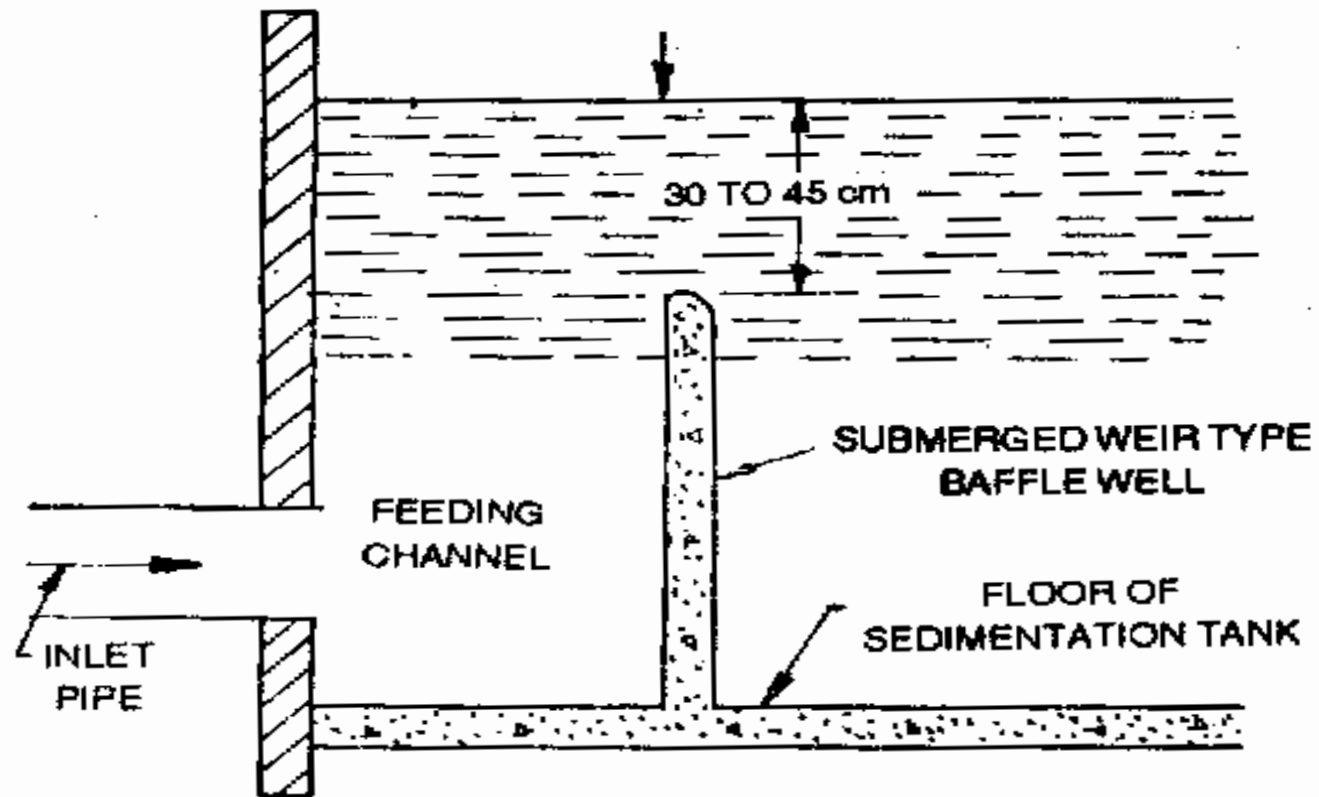
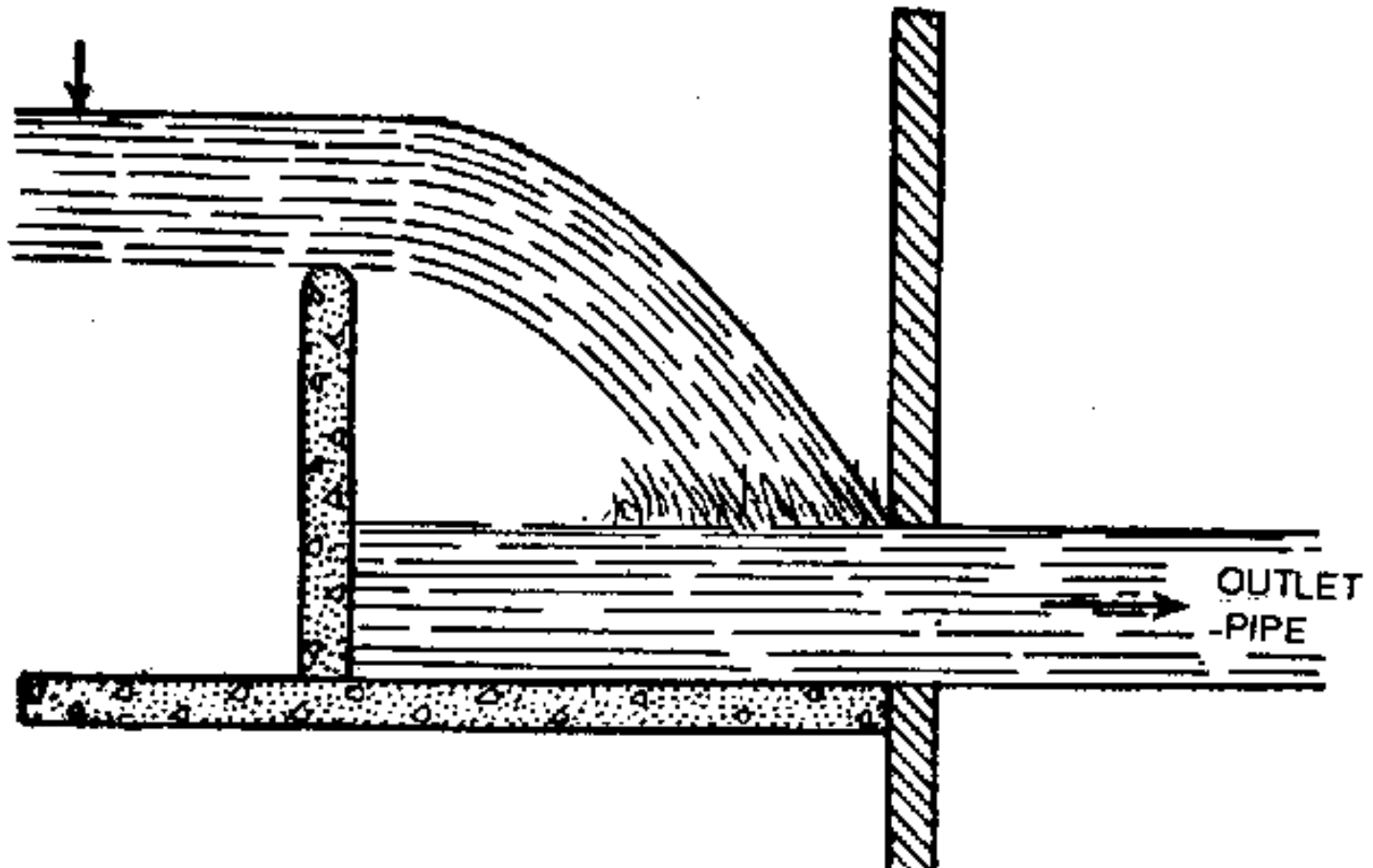


Fig. 9.10. Section of a submerged type or a weir type inlet.

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Combined coagulation cum sedimentation tank →

- Detention period – Flocc chamber → 15-40 minutes
- Detention period – Settling chamber → 2 – 4 hr
- Depth of flocculator → Half of the depth of settling tank
- Depth of settling tank → 3 – 6 m
- Cleaning @6 months

Problem: Design a coagulation sedimentation tank with continues flow for a population of 60,000 people with a daily percapita water demad of 120 litre. Make suitable assumption if needed.

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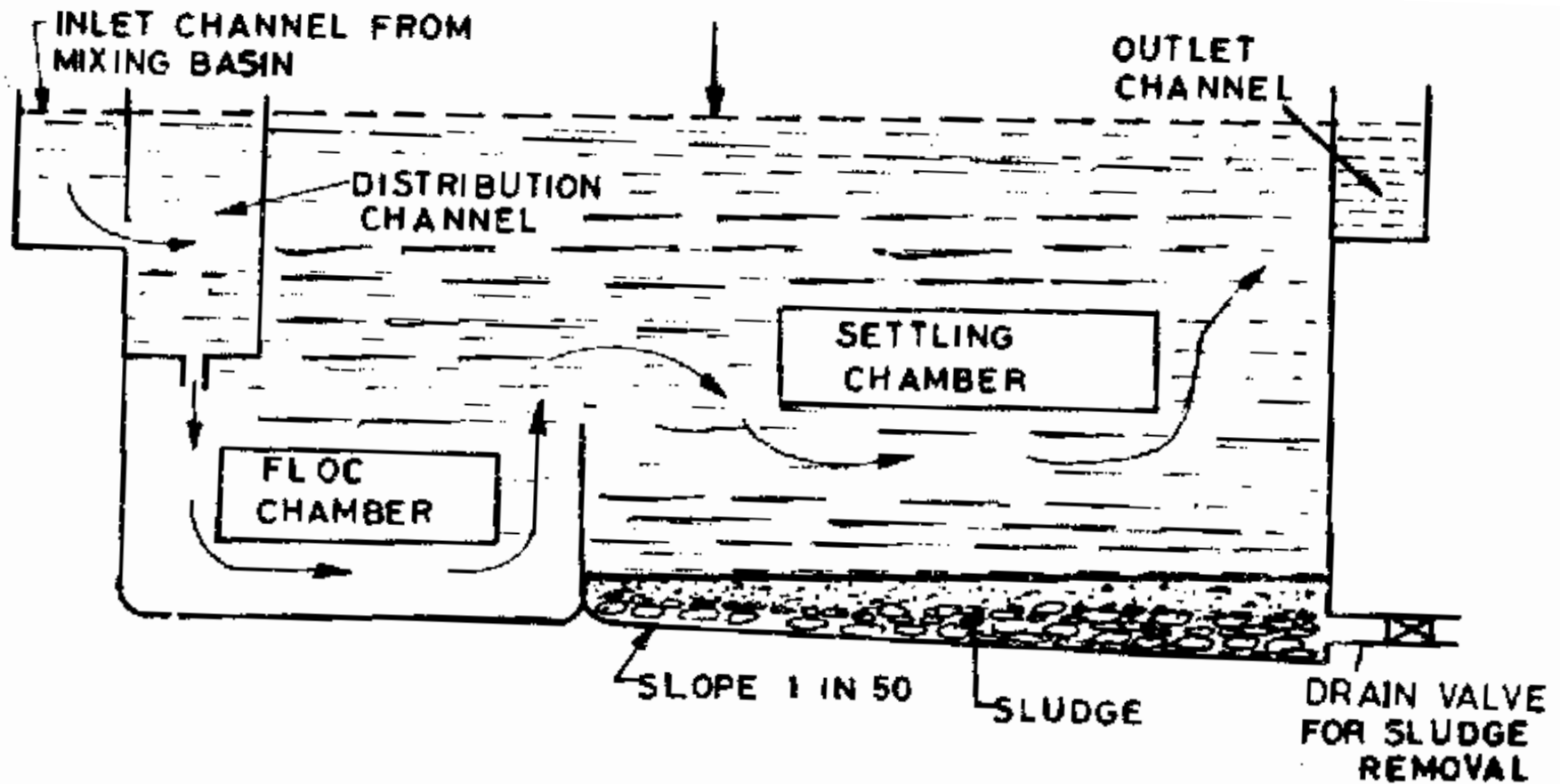


Fig. 9.24. Coagulation-Sedimentation tank.

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Solution:

Population $\rightarrow 60,000$

Quantity of water $\rightarrow 60,000 \times 120 \text{ lit/day} \rightarrow 7.20 \times 10^6 \text{ lit/day}$

Assume the daily max. as 1.80 times of daily ave. demand $\rightarrow$

Quantity of water $\rightarrow 7.20 \times 10^6 \text{ lit/day} \times 1.80 \rightarrow 12.96 \times 10^6 \text{ lit/day}$

Assuming a detention period of 4hr, water to be treated $\rightarrow$

$12.96 \times 10^6 \times (4/24) \rightarrow 2.16 \times 10^6 \text{ lit.} \rightarrow 2.16 \times 10^3 \text{ m}^3$

Hence, capacity of the tank $\rightarrow 2.16 \times 10^3 \text{ m}^3$

Assume an overflow rate of 1000 lit/hr/m^2

$Q/BL \rightarrow 1000 \rightarrow \text{or } BL \rightarrow Q/ \text{ overflow rate} \rightarrow$

$$\rightarrow \frac{12.96 \times 10^6 \text{ lit/hr}}{24 \times 1000} \rightarrow 540 \text{ m}^2$$

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Assume a width of 12m

Then, the length of the tank $\rightarrow 540/12 \rightarrow 25\text{m}$

The depth of the tank $\rightarrow \text{Capacity of tank/plan area} \rightarrow \frac{2.16 \times 10^3 \text{m}^3}{540 \text{m}^2} \rightarrow 4\text{m}$

Assuming, 50cm freeboard, overall depth $\rightarrow 4.50\text{m}$

Hence size of the tank $\rightarrow 45\text{m} \times 12\text{m} \times 4.5\text{m}$

Design of flocculator

Assume the depth of the chamber $\rightarrow \text{Half of the tank} \rightarrow 0.50 \times 4.50 \rightarrow 2.25\text{m}$

Assume, 20minutes detention period (flocculator)

Capacity of the chamber $\rightarrow \frac{12.96 \times 10^6 \times 20}{24 \times 60}$
 $\rightarrow 180\text{m}^3$

The plan area required $\rightarrow 180/2.25 \rightarrow 80\text{m}^2$

The length of the flocculator $\rightarrow 80/12 \rightarrow 6.67\text{m}$, say $\rightarrow 6.70\text{m}$

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Filtration → Filtration is the process of passing water through a layer of a granular material.

Aim

- To remove very fine suspended impurities, from the effluent from the sedimentation tank.
- To remove pathogenic bacteria

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RESULT

- Odour free water
- Tasty water
- Colourless water
- Free from pathogenic organism in hygienic point of view

Theory of Filtration

- Mechanical straining
- Sedimentation and flocculation
- Biological metabolism
- Electrolytic action (process)

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Mechanical straining → according to aperture size → The water gets filtered by arresting the impurities present as the fluid particles pass through the granular space between the filter media

Sedimentation and flocculation → Acts as tiny sedimentation tank → The impurities in the effluent water from coagulation sedimentation tank is a gelatinous material and will collect within the voids of sand particles as it passes through the media under gravity or pressure. These voids with gelatinous material will act as minute flocculation sedimentation tank attracting and depositing particles smaller than the void space, improving its performance as a filter again and again.

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Biological Metabolism → The living organism/bacteria present in sand particles use the organic matters for their survival and convert them in to harmless compound. These compounds forms a layer known as dirty skin and which again absorb and strain the impurities. This process is known as biological metabolism and the dirty layer which assists and enhances the process of filtration is called the dirty skin or schmutzdecker.

Electrolytic action → Normally the sand particles and impurities are oppositely charged. These attract each other and neutralize them by changing the character of water. The exhausted particles again charge by cleaning.

Classification of filters

Based on rate of filtration

Slow sand filters

Rapid sand filters



Rapid gravity filters ↔ Pressure filters

Based on pressure

Pressure filters

gravity filters



Slow sand filters ↔ Rapid sand filters

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Slow sand filters

Components →

- Enclosure tank
- Filter media
- Base material
- Under drainage system
- Inlet and outlet arrangements
- **Enclosure tank**
 - An open watertight tank
 - Depth → 2.50-3.50m
 - Plan area → 100-2000m²

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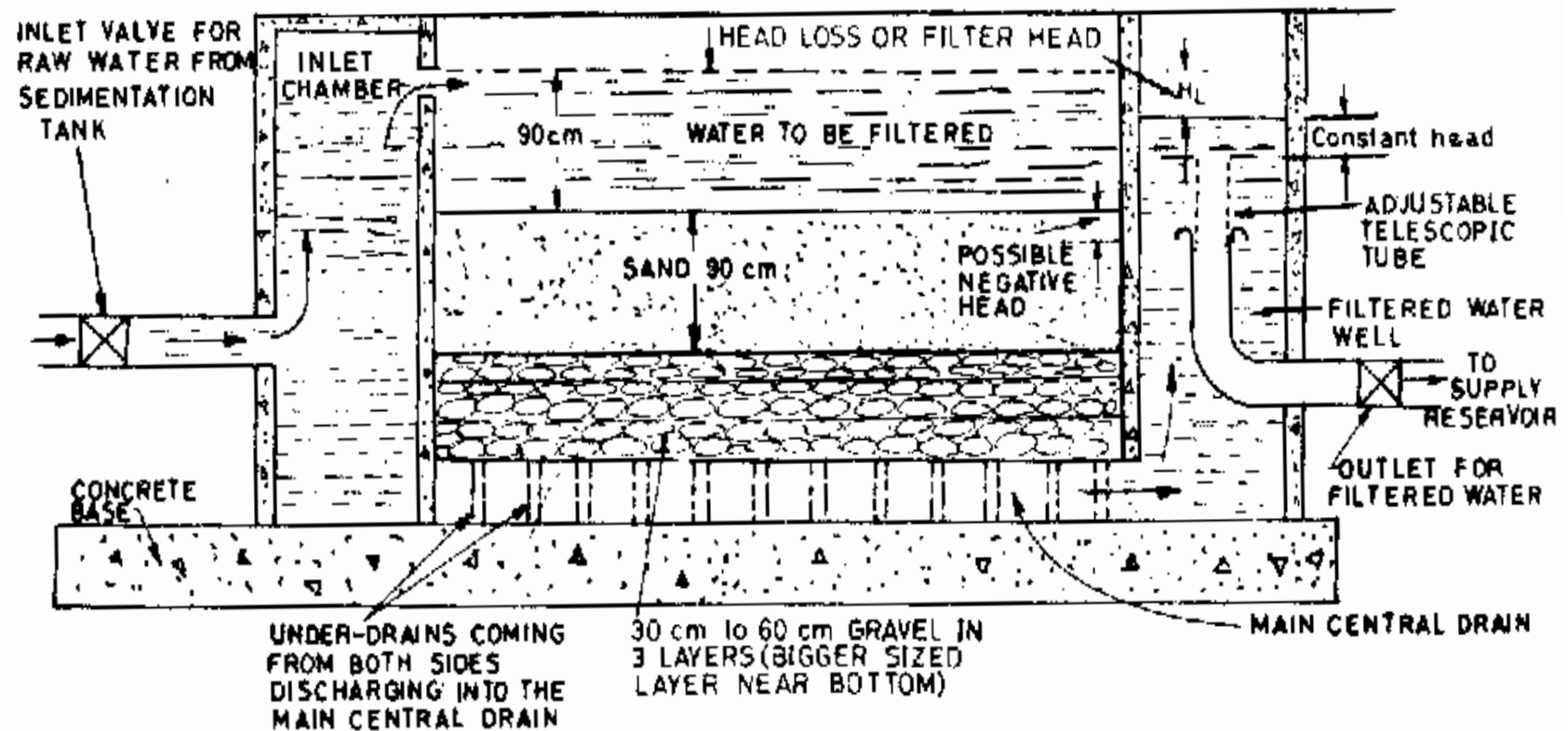


Fig. 9.27. Typical section of a slow sand filter.

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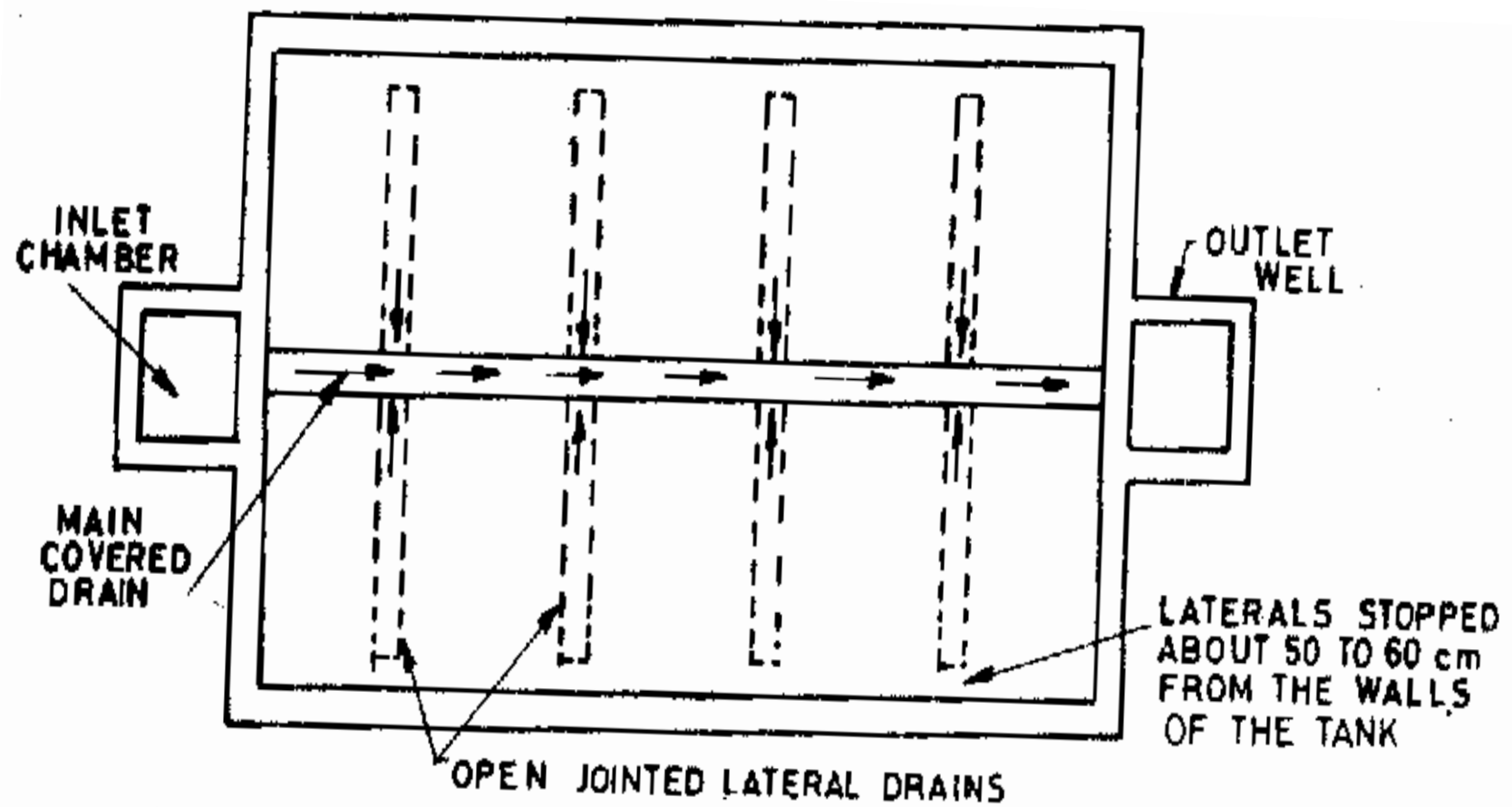


Fig. 9.28. Plan of under drainage system for slow sand filter.

Filter Media

- A sand layer of 90 to 120 cm height
- Normally 4 or 5 layer
- Finer particles as top layer
- Top 15cm, uniformly graded
- Uniformity coefficient

At top → 1.8

Mid level → 2.50

At bottom → 3

- Effective size – D₁₀ → 0.2 to 0.4mm
- It should be free from dirt and impurities
- It should be hard and durable
- It should be uniform in nature and size
- It should not lose its weight more than 5%, after being placed in HCl for 24 hrs.

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Base material

- 3 to 4 layers of 15-20 cm thick gravel

Top most layer	3 - 6mm
	6 - 12mm
↓	12 - 20mm
	20 - 40mm
Bottom	40 - 65mm

Under drainage system

- A sloped floor to collect the water in the central width wise drain
- Open jointed laterals are placed 3 - 4 m c/c
- Central drain collects the water from laterals and delivers to the outlet chamber.

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Inlet and outlet arrangements

- Inlet is a suitable size (square), chamber
- Inlet allow the entering water to distribute uniformly on filter bed
- Outlet chamber is also a similar one
- In order to maintain constant head, a telescopic(adjustable) pipe is fitted

Note:

- The loss of head is minimum possible → 15-30cm
- The maximum → 0.70 -1.20m, above which cleaning is required
- The water treated with coagulants should not be permitted to enter the slow sand filters
- The depth of water on the filter bed should not varies much, normally kept equals to the depth of sand bed

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- The loss of head called filter head is kept approximately equal to 0.70-0.80 times the depth of sand, to put it out of service for cleaning
- Cleaning of slow sand filters are done by scrapping and removing 1.50-3cm, top layer
- The pure water comes out only if dirty skin layer is formed
- Generally cleaning depends on the impurities presents → 1-2 months
- Rate of filtration → 100-200lit/hr/m²
- Efficient against bacteria removal as high as 98-99%
- Remove odour and taste, by removing organic impurities

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- Colour removal → up to 50mg/l
- Uses → For small water supply schemes
- Uneconomical, due to small rate of filtration and large area requirements

Problem:

Design a slow sand filter bed for the following data

Population → 50,000

Per capita demand → 150lit/person/day

Rate of filtration → 180lit/hr/m²

Length of bed twice its width

Assume 1 unit out of 6 as standby

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Solution:

Quantity of water $\rightarrow 50,000 \times 150 \times 1.8 \rightarrow 13.5 \times 10^6 \text{lit/day} \rightarrow 562.50 \text{m}^3/\text{hr}$

Surface area $\rightarrow Q/\text{rate of filtration} \rightarrow \frac{562.50 \times 10^3 \text{lit/hr}}{180 \text{lit/hr/m}^2}$
 $\rightarrow 3125 \text{m}^2$

Area of each unit $\rightarrow 3125/5 \rightarrow 625 \text{m}^2$

Also, $L \rightarrow 2B$

Hence, $2B^2 = 625$

$B \rightarrow 17.67, \text{ Say } \rightarrow 18 \text{m}$

$L \rightarrow 36 \text{m}$

Hence, provide 6 units of $36 \text{m} \times 18 \text{m}$

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Rapid sand filters

Components of Rapid sand filter

- Enclosure tanks
- Open rectangular water tight tank,
- Depth → 2.5 to 3.5 m
- Filler area → $10-80 \text{ m}^2$
- Number of units → $1.22 \quad Q$
Where Q → plant capacity in MLd
Min → 2 units

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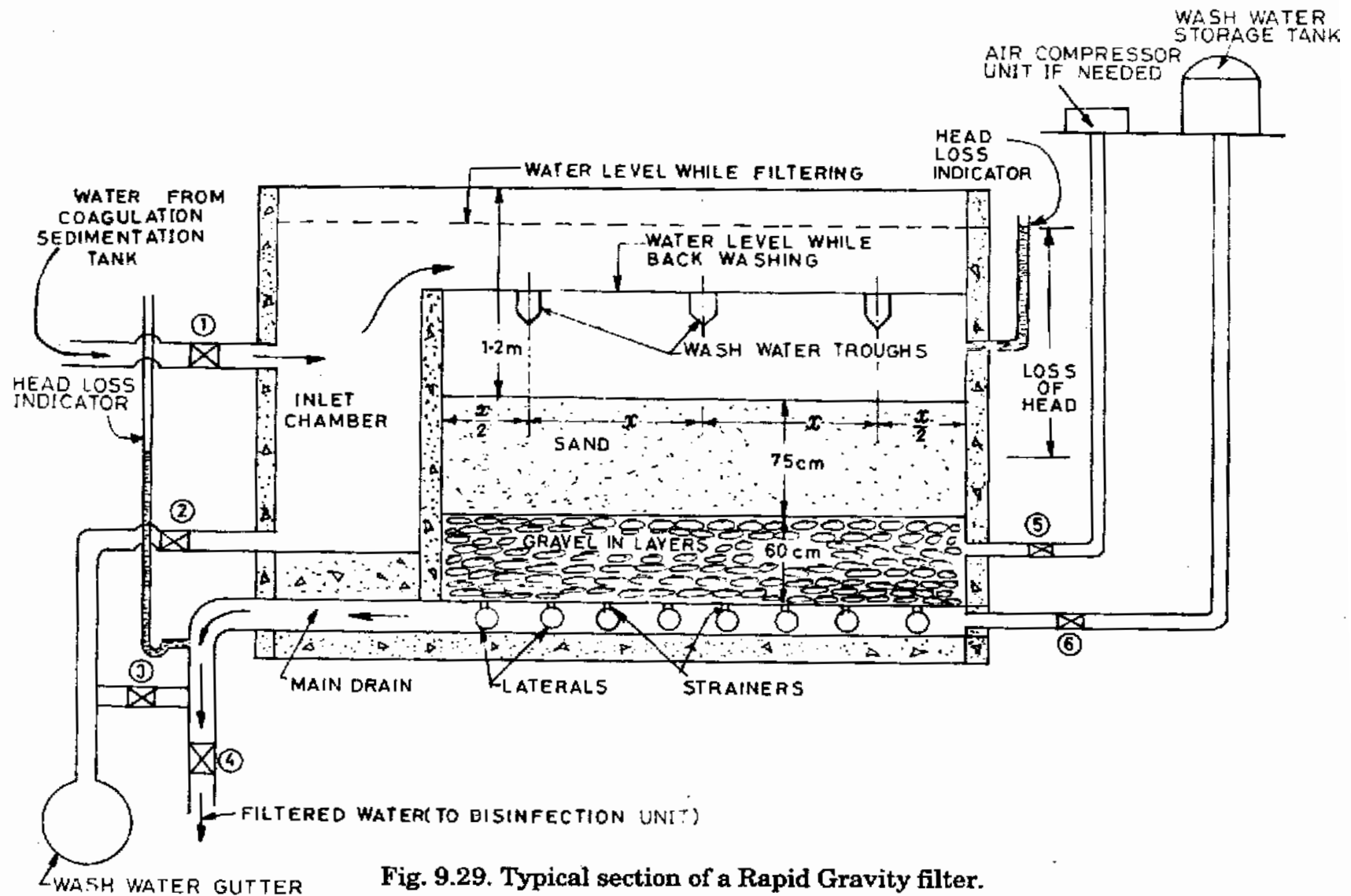


Fig. 9.29. Typical section of a Rapid Gravity filter.

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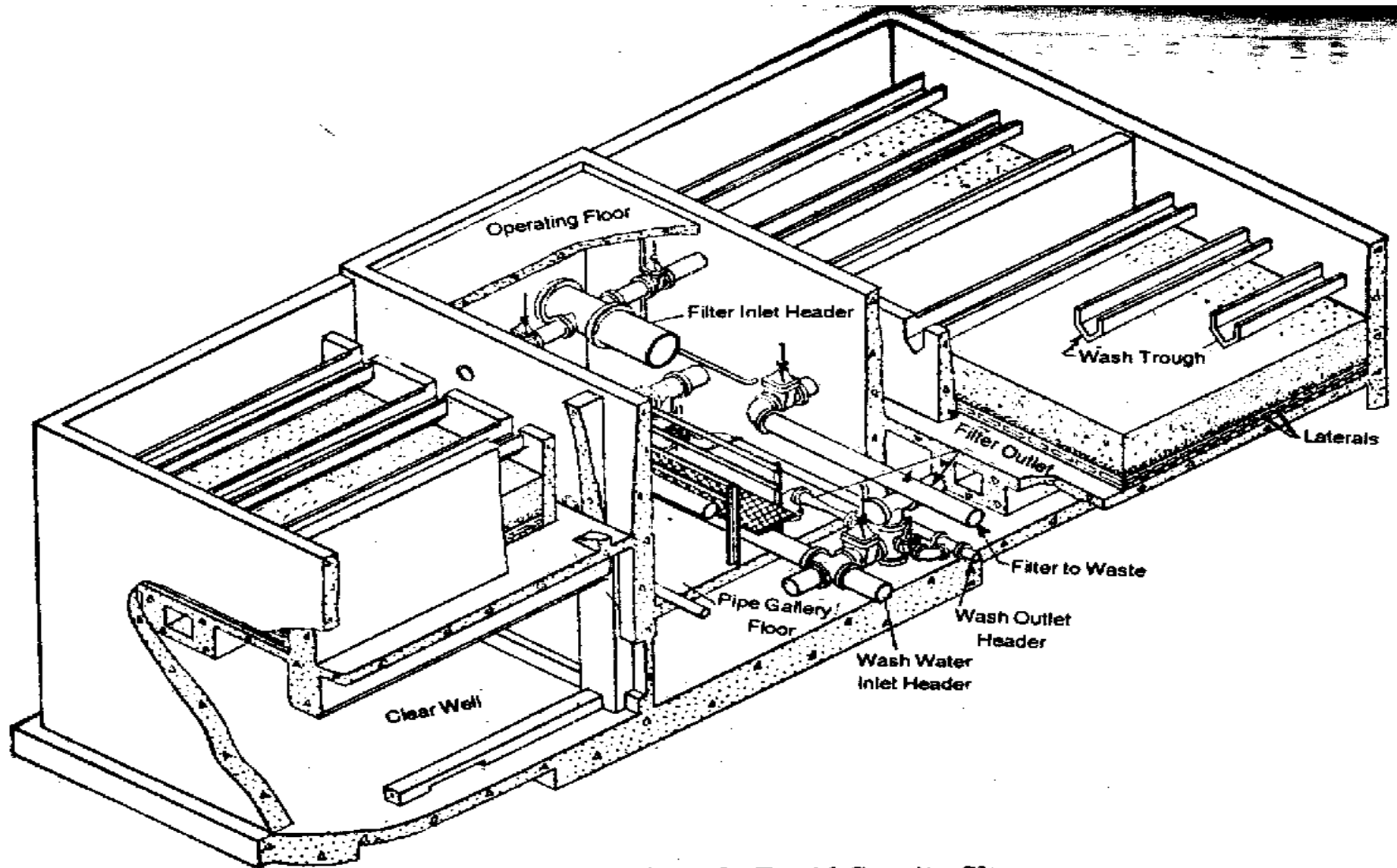


Fig. 9.30. Isometric view of a Rapid Gravity filter.

Filter Media

- Sand bed → 60-90 cm depth, each layer 15-20 cm
- D₁₀ → 0.35 to 0.55mm
- Uniformity coefficient → 1.3-1.7
- Finer to coarse towards bottom

Base Material

- Gravel bed → 60 - 90cm

Top most layer	3 - 6mm
	6 - 12mm
↓	12 - 20mm
	20 - 40mm
Bottom	40 - 65mm

Note: Carefull grading and packing is important for smooth function, especially in backwashing

TREATMENT OF WATER - CONTD

Under drainage system

- Manifold and lateral system →
- Perforated pipe system
- Pipe and strainer system

Perforated pipe system

- 6-13mm dia. holes are made, inclined 30° with vertical, near bottom
- Placed 7.5cm (6mm) and 20cm (13mm)
- Sometimes holes are staggered
- Sometimes brass bushings are inserted
- Placed over 40-50 mm cement concrete block.

TREATMENT OF WATER - CONTD

Pipe and Strainer system

- Laterals are attached to manifold
- Instead of perforation, strainers are fixed at suitable intervals (15cm, c/c)
- Sometimes strainers are fixed on main pipe without laterals
- When strainers are used, rate of back washing is as low as 250-300 lit/min/m²
(Low washing) against 700-800lit/min/m² (High washing) for other types

TREATMENT OF WATER - CONTD

Design Considerations

- Total cross-sectional area of perforation is about 0.2% of filter area
- The cross-section area of 6mm dia. pipe is 4 times the perforation in it
- The cross-sectional area of 13 mm dia. pipe 2 times the perforation
- The c/s area of manifold should be twice that of laterals
- l/d of laterals, >60
- Maximum velocity in the manifold is 1.80 to 2.4 m/sec

TREATMENT OF WATER - CONTD

Other appurtenants

- **Wash water trough**
- square or v shape
- Any material such as iron or CI
- 1.5 to 2m c/c
- Provided with small slope
- As large as possible

TREATMENT OF WATER - CONTD

Air compressor unit

- Duration of application → 4min or so
- Rate → 600 – 800 lit/min/m²
- Application → through lateral or separate pipe

Rate controller

- Venturi rate controller → to regulate the flow
- Head loss indicator (Piezometer) → A mercury gauge is attached to both the filter bed and filtered water drain

TREATMENT OF WATER - CONTD

Back washing

Rate → 15-90 cm rise/minute, ave. → 45cm

Duration → 10-30 minutes

Pressure → 40 kN/m²

Frequency → 24 - 48 hrs

Problems of sand filters

- Air binding and negative head
- Formation of mud balls
- Cracking of filters

TREATMENT OF WATER - CONTD

Air binding and negative head

Normally there should be a loss of head in filter bed as and when the water percolates through the voids of sand grain due to friction. This decrease in pressure is called the loss of head or head loss. The head loss immediately after commissioning of the filter unit will be as low as about 10-15 cm. But as the time increases, the deposition of impurities within the voids of sand particles may increase and correspondingly the head loss may also increase even up to 2.5 to 3.5 m max. Due to the increase of friction, a negative head is formed just below the top of layer of 10-15 cm thick and is called the negative head. The negative head causes to releases, air bubbles, which stick on sand particles resulting problems on efficient and proper working of the filter unit. The air binding may be due to the development of negative head, growth of algae, rising temperature etc.

TREATMENT OF WATER - CONTD

The various remedial measures are:

- Prevent development of negative head, max. $\rightarrow$ 1..2m
- Preventive measures for growth of algae
- Necessary measures to control the temperature rise, as and when the water percolates through the filter media
- Allowing the water to supersaturate with air.

TREATMENT OF WATER - CONTD

Formation of mud balls

The mud particles from the atmosphere may attract and accumulate on the surface of sand grains forming a solid mass. As the time increases the impurities may deposit more and more and the size and weight of the solid thus formed called mud balls may increase. These mud balls sink through the filter media and finally deposit within the voids of the gravel particles of base material, resulting clogging. Due to the continuous process, the entire base material becomes clogged resulting the efficient and proper functioning of the unit.

TREATMENT OF WATER - CONTD

Remidial measures

- Mechanical racking of mud balls and back washing
- Backwashing with high pressure at the initial stages
- Backwashing with manual breaking
- Total replacement

Note: After washing the bed, caustic soda is applied in 10cm on the bed, left for 12hrs. After 8hrs. of agitation washed until clear water is obtained

TREATMENT OF WATER - CONTD

Cracking of filters

The top layer of fine sand may generally cause formation of cracks, and mud particles will be deposited within these cracks. The cracking of top layer may increase due to the passage of time and finally affects the working of the filter bed

.

Remedial measures

- Removal of the mud deposit from the cracks.

TREATMENT OF WATER - CONTD

Efficiency and Performance

- Rate of filtration → 3000-6000 lit/hr/m²
- Removal of bacteria → 80-90%
- Removal of turbidity → 35-40 mg/l
- Turbidity → 10 unit on cobalt scale

Uses

- Most efficient and economic for public water supply scheme

TREATMENT OF WATER - CONTD

Problem:

Design a rapid sand filter with its components to meet 4 MLD.

Assume the following data

Rate of filtration 5000/lit/hr/m².

Dia. of perforation 13 mm.

Length =1.5 times the width.

The discharge of a rectangular flat bottom through is given by

$1.376bd^{3/2}$. Where

b →width, d →depth

TREATMENT OF WATER - CONTD

Water required → 4 MLD

Allow for washing → 3-4%

$$\rightarrow 3/100 \times 4 = 0.12 \text{ MLD}$$

Therefore total → 4.12 MLD

=====

Assume 30 minutes for washing

Therefore, Q → $\frac{4.12}{23.5} = 0.175 \text{ ML/hr}$

Rate of filtration → 5000 lit/hr/m²

Area of filter bed → $\frac{0.175 \times 10^6 \text{ lit/hr}}{5000 \text{ lit/hr/m}^2}$

$$\rightarrow 35 \text{ m}^2$$

TREATMENT OF WATER - CONTD

Assume 2 units

Therefore area of 1 unit $\rightarrow 35/2 = 17.5\text{m}^2$

L $\rightarrow 1.5B$

$B \times 1.5B \rightarrow 17.5$

$1.5B^2 \rightarrow 17.5$

B $\rightarrow 3.42\text{m}$

L $\rightarrow 3.42 \times 1.5 \rightarrow 5.13\text{m}$, say $\rightarrow 5.2\text{m}$

Length $\rightarrow 5.2\text{m}$

Therefore B $\underline{17.5/5.2} \rightarrow 3.36\text{m}$, say $\rightarrow 3.40\text{m}$

Provide 2 units of $5.20\text{ m} \times 3.40\text{m}$

TREATMENT OF WATER - CONTD

Design of laterals

$$\begin{aligned}\text{Total area of perforation} &\rightarrow 0.2\% \text{ of filter area} \\ &\rightarrow \frac{0.2 \times 5.2 \times 3.4}{100} \\ &\rightarrow 0.0354\text{m}^2\end{aligned}$$

Assume the c/c distance of laterals as 15cm

$$\begin{aligned}\text{No. of laterals} &\rightarrow 5.2/0.15 \rightarrow 34.67 \\ &\rightarrow 35\text{nos} \\ \text{Total no. of laterals on both sides} &\rightarrow 35 \times 2 \\ &\rightarrow 70 \text{ nos.}\end{aligned}$$

TREATMENT OF WATER - CONTD

Assume 'n' is the no. of perforations/each lateral

$$\text{Area of perforation} \rightarrow 0.0354\text{m}^2$$

$$0.0354 \times 10^4 \rightarrow n \times \pi/4 \times 1.3^2 \times 70$$

$$\text{Therefore } n \rightarrow 3.76$$

$$\rightarrow 4.\text{nos}$$

The c/s area of laterals = 2 times the area of perforation in it

$$2 \times 4 \times (\pi/4) \times 1.3^2 \rightarrow 10.61\text{cm}^2$$

$$(\pi/4) \times d^2 \rightarrow 10.61$$

$$d \rightarrow 3.67\text{cm, say } \rightarrow 3.70\text{cm}$$

Hence provide 70 nos. of 3.7 cm dia laterals on both sides with 4 nos. of 1.3 cm dia of holes, on each.

c/s area of main drain (manifold) $\rightarrow$ 2 x total area of laterals

$$\rightarrow 2 \times 70 \times (\pi/4) \times 3.70^2$$

$$\rightarrow 0.15\text{m}^2.$$

$$\pi/4 d^2 \rightarrow 0.15 \times 10^4$$

$$d \rightarrow 0.437\text{m}$$

$$\rightarrow 45 \text{ cm}$$

Length of lateral

$$\rightarrow \frac{3.4 - 0.45}{2}$$

$$\rightarrow 1.475\text{m}$$

l/d

$$\rightarrow \frac{1.475}{0.037} \rightarrow 40.97 < 60$$

Velocity of flow within the laterals

Assume rate of washing

→ 45cm/min

Wash water discharge

Q

→ $A \times V$

→ $(5.2 \times 3.4) \times (0.45/60)$

→ $0.1326 \text{ m}^3/\text{sec}$

=====

Velocity in the lateral

→ Q/A

→ $\frac{0.1326 \text{ m}^3/\text{sec}}{70[(\pi/4)(0.037)^2]}$

→ 1.76 m/sec

Velocity in main drain

→ Q/A

→ $\frac{0.1326}{\pi/4 (0.45)^2}$

→ 0.834 m/sec

- Max. Value of velocity is 1.8 to 2.4 m/sec, design is OK

Design of Trough

No. of wash water troughs

$$\rightarrow 5.2/3 \rightarrow 1.73$$

Say,

$$\rightarrow 2 \text{ no. of troughs}$$

Discharge in each trough

$$\rightarrow Q/2$$

$$\rightarrow 0.1326/2 = 0.066 \text{ m}^3/\text{sec}$$

Discharge in trough

$$\rightarrow 1.376 b d^{3/2}$$

Assume,

$$\rightarrow 25 \text{ cm}$$

0.066 m³/sec

$$\rightarrow 1.376(0.25) d^{3/2}$$

$d^{3/2}$

$$\rightarrow 0.1977$$

d

$$\rightarrow 0.334 \text{ m}$$

$$\rightarrow 0.35 \text{ m}$$

Assuming a free board of 5cm, size of trough

$$\rightarrow 20 \text{ cm} \times 40 \text{ cm}$$

TREATMENT OF WATER - CONTD

Pressure filters

- Just like small rapid gravity filters, the difference is the filtration is under pressure
- Pressure → 30-70m (300-700kN/m²)
- Diameter of the tank → 1.50-3.00m
- Length of the tank → 3.50-8.00m
- Rate of filtration → 2-5 times that of rapid gravity filter
- Rate of filtration → 6,000-15,000lit/hr/m²
- Efficiency → Less efficient in killing bacteria (80%) and turbidity removal, than rapid gravity
- Uses → Not recommended for large water supply schemes

TREATMENT OF WATER - CONTD

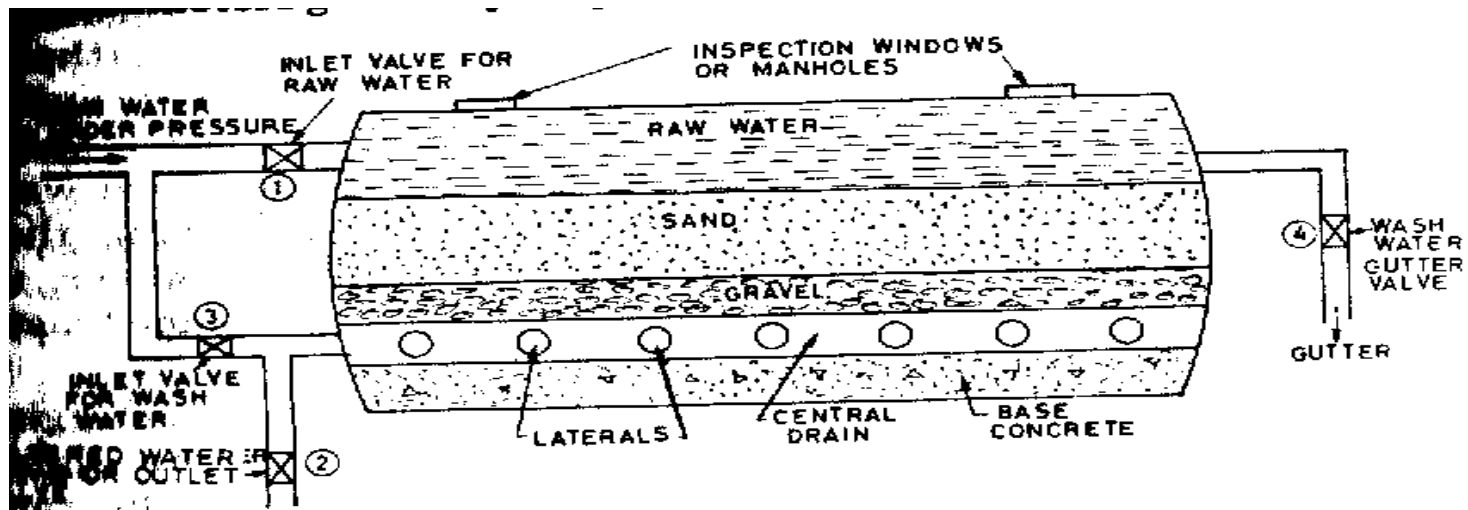


Fig. 9.37. (a) Horizontal pressure filter.

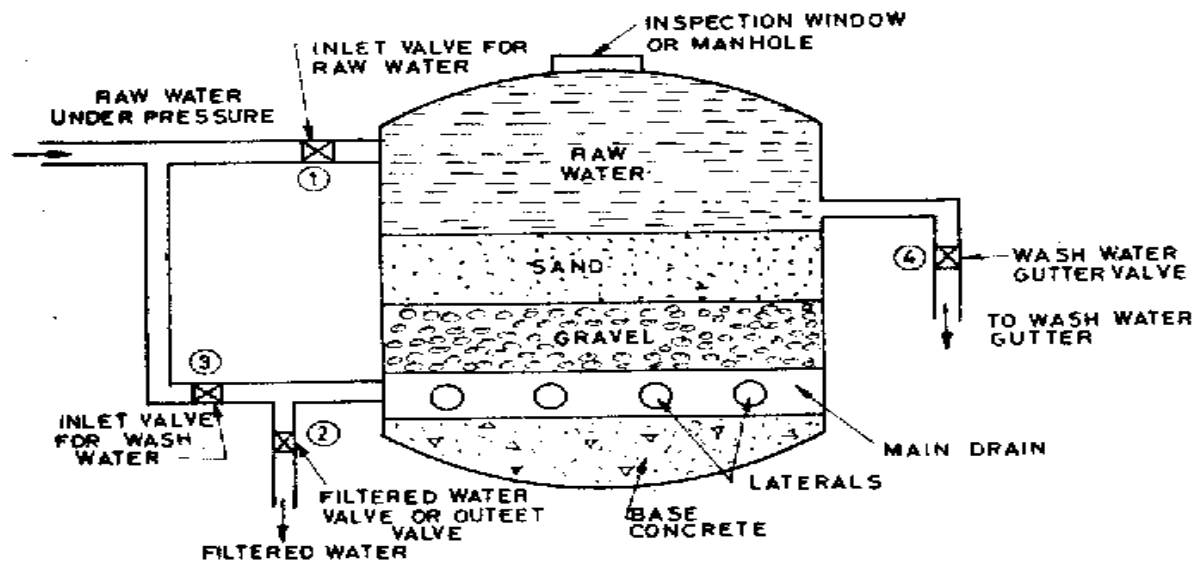


Fig. 9.37. (b) Vertical pressure filter.

TREATMENT OF WATER - CONTD

Advantages

- A compact machine, handled easily, automatic units can be designed
- Higher rate of filtration hence, less space and material for the same volume.
- Sedimentation, coagulation tanks can be avoided
- More flexible as the rate of filtration can be changed by changing pressure of raw water.
- For small scale supply, proved to be economical
- Filtered water is under pressure and need not required further pumping in most cases.

Disadvantages

- The overall capacity of the tank is small
- Less efficient in killing bacteria and removing turbidity .
- Uneconomical for large supply

TREATMENT OF WATER - CONTD

- As the process is in a closed tank proper inspection is difficult
- Cleaning and replacement of material is difficult
- Working of wash water troughs is not perfect
- As the raw water is to be kept under high pressure, high rate of pumping, and make effluent poorer

Other types of filters

- Roughening filters
- Diatomaceous filters

TREATMENT OF WATER - CONTD

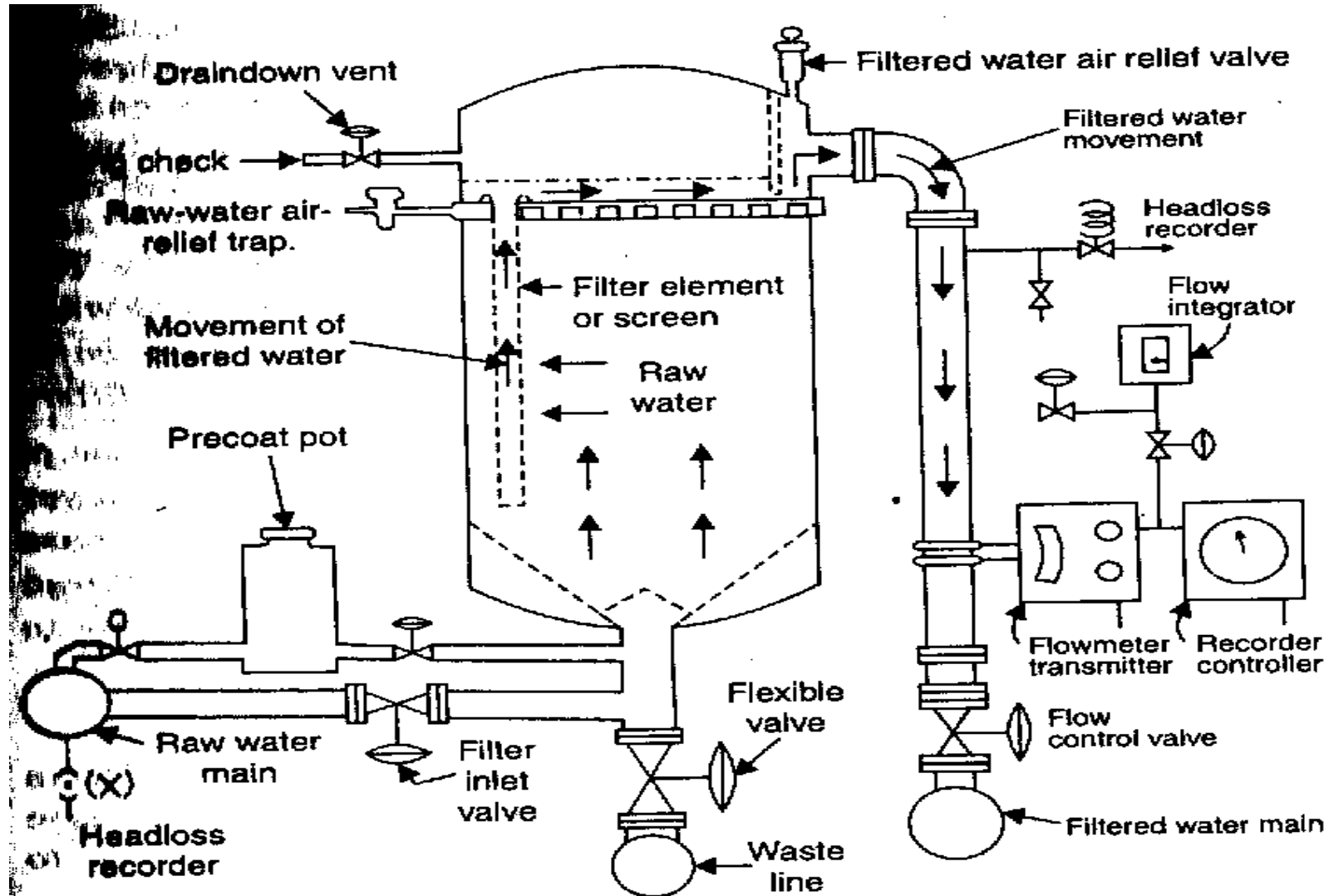


Fig. 9.38. Schematic diagram of a diatomite filter.

TREATMENT OF WATER - CONTD

DISINFECTION

- **Disinfection of water** → effluent from filters again contains pathogenic organism, and it become essential to remove or kill the same organism before used for drinking
- **Residual sterilizing effect** → There are chances of contamination of water from the disinfection plant during transmission etc. and requires some amount of disinfectant in the distribution line to make the water safe against possible future contamination

TREATMENT OF WATER - CONTD

- **Minor methods of disinfection**

- Boiling

- Treatment with excess lime

- Treatment with ozone

- Treatment with Iodine

- Treatment with Ultraviolet

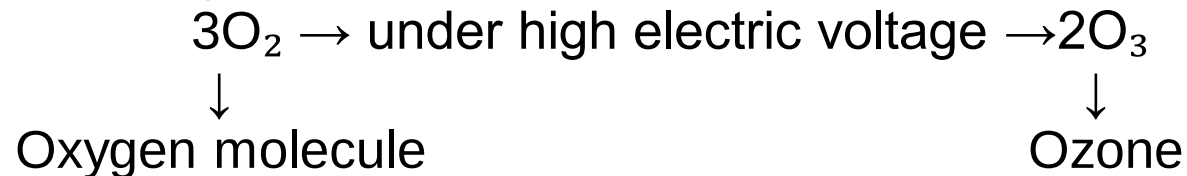
- Treatment with potassium permanganate

TREATMENT OF WATER - CONTD

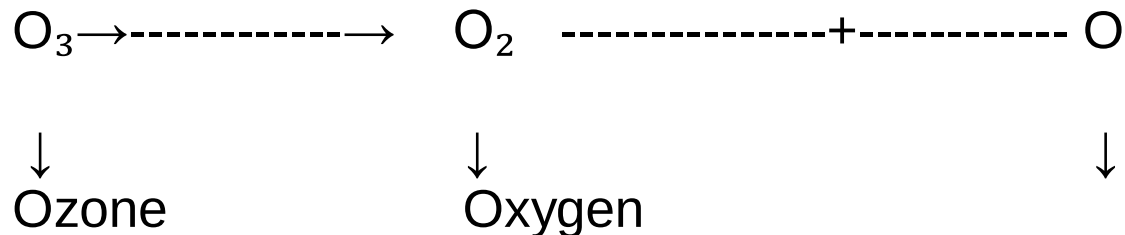
Treatment with excess lime

- Lime is used for water softening
- 4-43mg/lit of excess lime may remove 99.3-100% bacteria [pH → 9.5]
- Requires removal of excess lime by methods like recarbonation

Treatment with ozone → Ozone is an unstable allotropic form of oxygen, containing three atoms



Then readily breakdown →



TREATMENT OF WATER - CONTD

Nascent oxygen

- Nascent oxygen is a powerful oxidizing agent and removes organic matter and bacteria from water
- Ozone is bubbled through the water in a separate chamber having inlet and outlet arrangement
- 2—3mg/lit Ozone → make 0.1mg/lit residual Ozone for a contact period of 10mins.
- Detects by orthotolidine test [same yellow colour of 0.1mg/lit → 0.15mg/lit]

TREATMENT OF WATER - CONTD

Advantages of Ozone treatment

- Being unstable, nothing will be there in distribution
- Remove colour, taste, and odour
- Pleasing and tasty water

Disadvantages

- Costlier than chlorination
- Possible where electricity is easily and cheaply available
- No assurance against future contamination
- Ozonizer should be installed in the plant itself [as it cannot be supplied in cylinder]
- Less efficient in killing bacteria than chlorine

TREATMENT OF WATER - CONTD

Bromine and Iodine treatment

- 8mg/lit for 5mint. Contact period
- Available in the form of pills also
- Normally used in small supply, private plant, Army troop etc.

Treatment with Ultraviolet

- Ultra violet rays → Wave length of about, 1000-4000m μ
- Produced by passing electric current through mercury enclosed in quarts bulb
- The bulb is then immersed in water 10cm or below

Advantages

- Pure odourfree, colorless water with turbidity of below 15mg/lit
- Kills all type of bacteria
- Normally used for sterilizations at hospitals

Disadvantages

- Very costly
- Possible interruption by electricity

TREATMENT OF WATER - CONTD

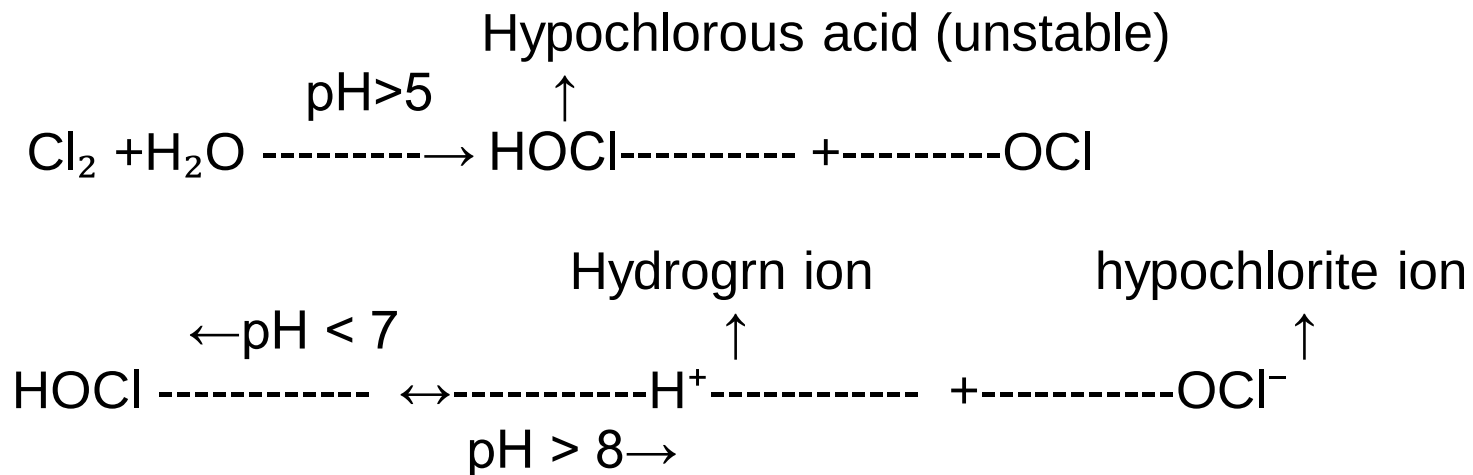
Treatment with potassium permanganate →

- Dosage -----1-2mg/lit with a contact period of 4-6hrs.
- 0.05-0.1mg/lit -----used even in chlorinated water
- The treated water is used after 48hrs.
- Kills only 98% bacteria
- Acts as oxidizing agent to oxidize organic matters
- A precipitate on porcelain surface

TREATMENT OF WATER - CONTD

Chlorination →

- Chlorine is the best and most ideal disinfectant and widely used all over the world
- The reactions →



TREATMENT OF WATER - CONTD

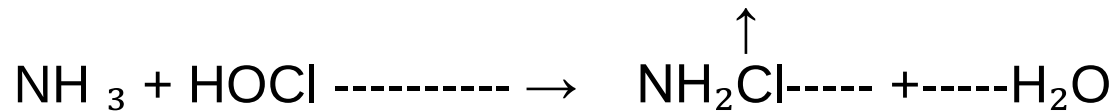
Free available chlorine → Hypochlorous acid Hypochlorite ion and chlorine

- Out of the above three, hypochlorous acid is more effective [80 times than hypochlorite ion] disinfectant → As HOCl is unstable it may dissociate effectively at a $\text{pH} > 8$
- But in between pH 5 and 7 it may exist in solution
- Hence the aim is to keep the pH slightly less than 7

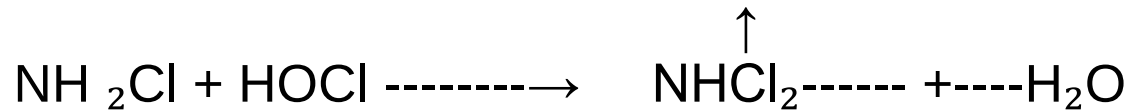
TREATMENT OF WATER - CONTD

Other chemical equations are →

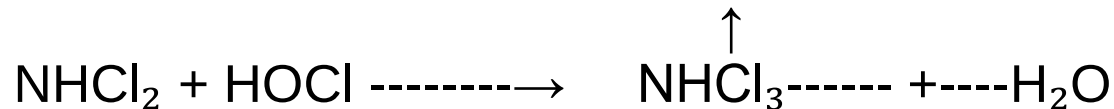
Monochloramine → above pH 7.5



Di chromine → pH 5 - 6.5



Nitrogen trichloramine → pH below 4.4



TREATMENT OF WATER - CONTD

Note:

- At pH range of slightly less than 7, di chloramines is predominant

Chloramines are less effective, 25 times than free chlorine

- Combined chlorine with ammonia in the form of chloramines is called combined chlorine and is much less effective compared to free chlorine
- Chloramines immediately react with organic impurities [S^{--} , Fe^{++} , Mn^{++} , NO_2^- etc.] to form chloride
- Then the remaining chlorine reacts with ammonia to form chloramines
- The demand of chlorine for the above said reactions are called chlorine demand and the remaining chlorine is called free chlorine

TREATMENT OF WATER - CONTD

Dosage → varying amount of chlorine is applied for a contact period of 10 mins. And test for residual chlorine, a dose which gives 0.20mg/lit residual chlorine is determined. This dosage minus the residual chlorine gives the chlorine demand

Various forms of applications of chlorine

- Liquid chlorine as chlorine gas
- Hypochlorite → bleaching powder
- Chloramines → A mixture of ammonia and chlorine
- Chlorine dioxide

TREATMENT OF WATER - CONTD

Liquid as chlorine gas form

- Chlorine gas → A greenish yellow gas -2.50 times heavier than air
- Liquid form → Amber coloured liquid -1.5 times heavier than water
- Liquid form → When subjected to a pressure about 700 kn/m^2
- [increase in temperature-require more pressure]
- Solubility in water → 1% at 10°C , 0.61 at 40°C
- Availability → 50 kg. Cylinder
- Storage → At a temp. of $38-40^\circ\text{C}$

Problems →

- 10mg/lit in air causes irritation
- 20mg/lit causes inconvenience
- 1000mg/lit causes death in 5 minutes

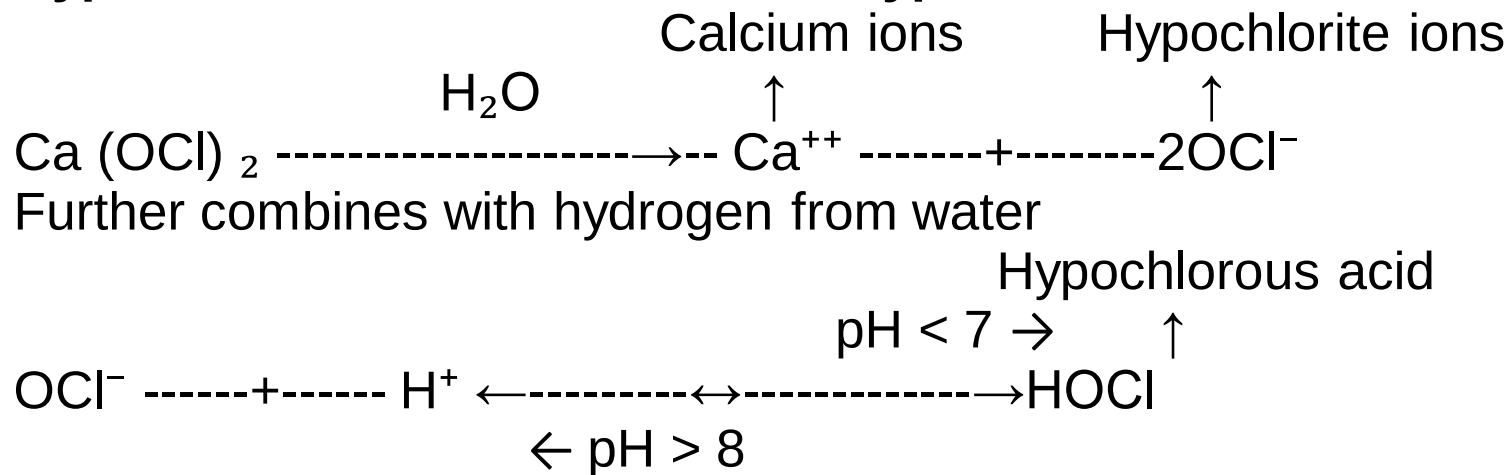
TREATMENT OF WATER - CONTD

Advantages

- Can be stored long period without risk of deterioration
- Cheap and quickly available
- Occupies less space for storage
- Easily and cheaply transported
- Dosage can be determined easily and hence no chances of under/ over dosage
- Initial cost of plant is low
- A powerful disinfectant and exist in residual form
- Uniformly applied in water
- Operation requires less skilled supervision
- No formation of sludge

TREATMENT OF WATER - CONTD

Hypochlorite → Calcium/sodium hypochlorite



The above process is known as hypo chlorination

Note: Pure hypochlorite contains 70% free chlorine in the form of OCl^- value

Commercial form → Perchloron

TREATMENT OF WATER - CONTD

Bleaching powder

- Chlorinated lime/ Calcium oxychlorite [CaOCl_2]
- Contains about 30% free chlorine
- Unstable - reacts with moisture temp. etc.

Advantages →

- Available in packet form
- Chlorine content does not lose due to storage
- They can be applied in dry form

Disadvantages →

- They raise pH value
- They contain very low amount of chlorine

TREATMENT OF WATER - CONTD

Chlorine tablets →

Market forms → Halazone tablets (costly)-Manufactured by environmental Engineering Research Institute, Nagpur

Dosage → 0.50mg/20 lit

Advantage → 15 times more effective than halazone tablets

TREATMENT OF WATER - CONTD

Chloramines

- Chlorine with ammonia
- Ammonia is applied for 20 mins. ---- 2 hr before application of chlorine

Equipment → Ammoniator

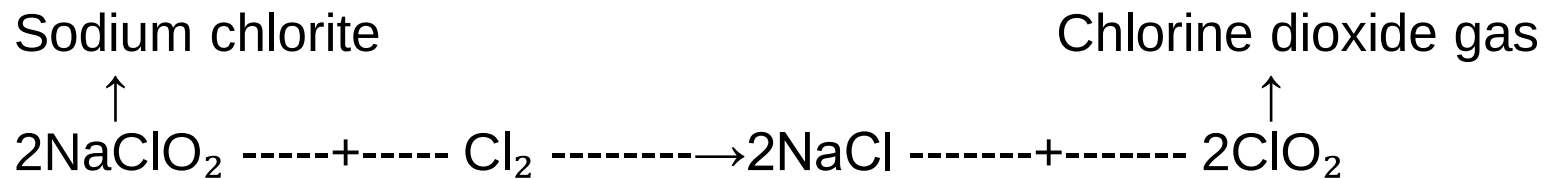
Advantages →

- Do not cause bad taste and odour as chlorine
- Very useful when phenols are present in water → causes bad taste with chlorine
- Stable and safe against future pollution

TREATMENT OF WATER - CONTD

Chlorine dioxide gas(ClO_2)

Produced by passing chlorine gas through sodium chlorite



Advantages →

- 2.50 times effective than chlorine
- Used when water containing phenolic and organic compounds [Develop taste and odour with Cl_2]
- Used when water is with high ph as 8-10

Disadvantages → Costly and unstable

Dosage → 0.50-1.50mg/lit

TREATMENT OF WATER - CONTD

Methods of chlorination

- Plain chlorination
- Pre-chlorination
- Post chlorination
- Double chlorination
- Breakpoint chlorination
- Super chlorination
- Di chlorination

TREATMENT OF WATER - CONTD

Plain chlorination → Treatment in which only chlorination is done

- Used when the water is more or less pure with less turbidity (20-30mg/lit) → Lake water

Dosage → 0.50mg/lit

Pre-chlorination →

- Applied before filtration/ even sedimentation
- Reduce load on filter bed
- Reduce the odour, colour, alga, organic impurities
- Applied such that 0.20-0.50 mg/lit as residual

TREATMENT OF WATER - CONTD

Post chlorination →

- Ordinary method
- Applied to the filtered water
- Applied such that 0.20-0.50 mg/lit as residual

Double chlorination →

- Pre and post chlorination is done simultaneously

TREATMENT OF WATER - CONTD

Breakpoint chlorination → Break point is the point, which further addition of chlorine appears as free (residual)

Let, A-B → Killing bacteria

C-D, → Oxidation of organic matter

C → Breakpoint

A-B' → An imaginary line, if water is pure (no chlorine consumption)

When chlorine is added to the water, it first of all reacts with the ammonia presents in the water so as to form chloramines. With the increase of chlorine, the residual chlorine also increases. But some amount of chlorine is consumed for killing bacteria as represented by the line AB deviating from line AB' as shown in the figure. As on adding chlorine, the residual chlorine suddenly reduces as shown by the curve BC, which is due to the consumption for oxidation of organic matters present on water. Further addition of chlorine will constantly increase the residual chlorine content as shown by the straight line from point C. The point B is called the breakpoint and the addition of chlorine beyond this point is called the breakpoint chlorination.

TREATMENT OF WATER - CONTD

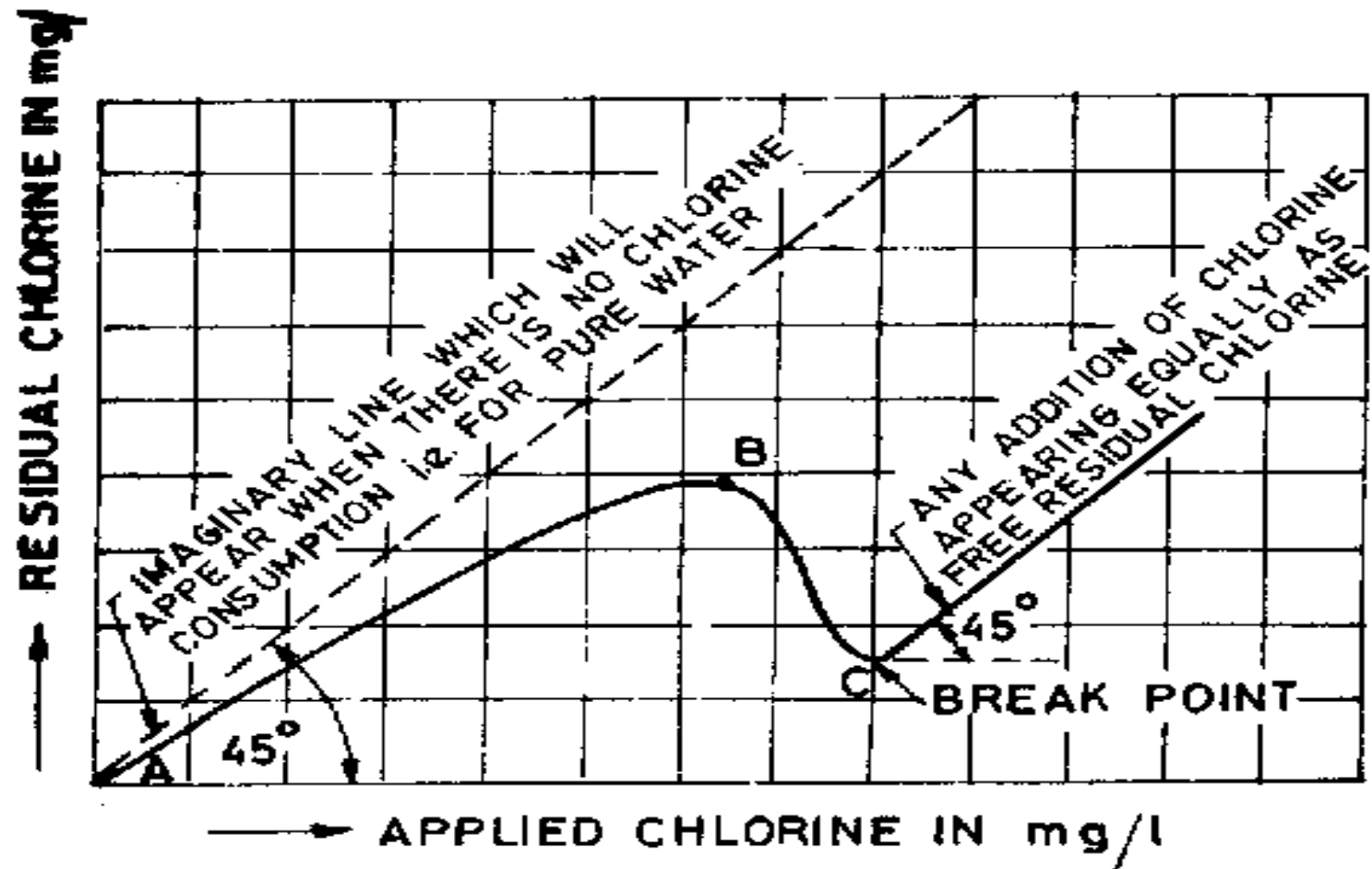


Fig. 9.42. Fig. indicating break-point chlorination

TREATMENT OF WATER - CONTD

Super chlorination →

- Applied overdose as high as 5-15mg/lit
- Used when water is highly polluted
- Residual chlorine is up to, 1-2mg/lit
- Requires de chlorination

De chlorination →

- Removal of excess chlorine that is more than 2mg /lit

Agents used →

- Sulphur dioxide (SO_2) → Dosage, 0.30-0.60mg/lit (Depending up on the SO_2 present-ratio of SO_2 to excess chlorine is 1.12:1, with an excess of 25%)

Activated carbon → Burned wood or sawdust under controlled condition and temperature (500-800°C)

Darco, Nuchar etc. are, market forms

Sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) Cheap and economical

Sodium sulphate (Na_2SO_3)

Ammonia (NH_4OH) → easily react with chlorine and economical

TREATMENT OF WATER - CONTD

Water softening → Removal of hardness to satisfy the requirements

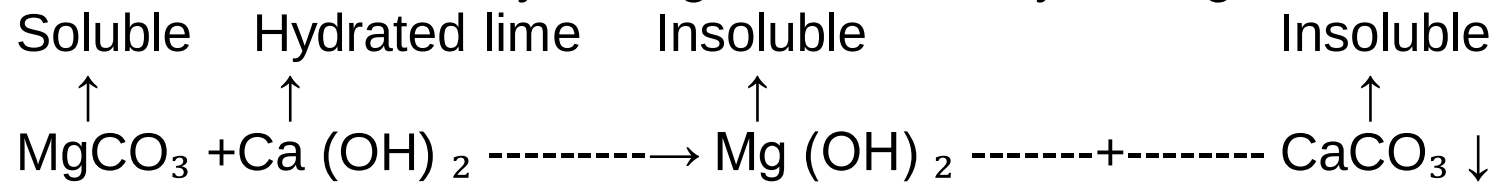
- Temporary hardness of water [carbonate hardness] → Due to the presents of carbonate and bicarbonate of calcium and magnesium
- CaCO_3 , dissolves in water containing CO_2 and exists in the form of bicarbonates in natural water

Removal → By boiling

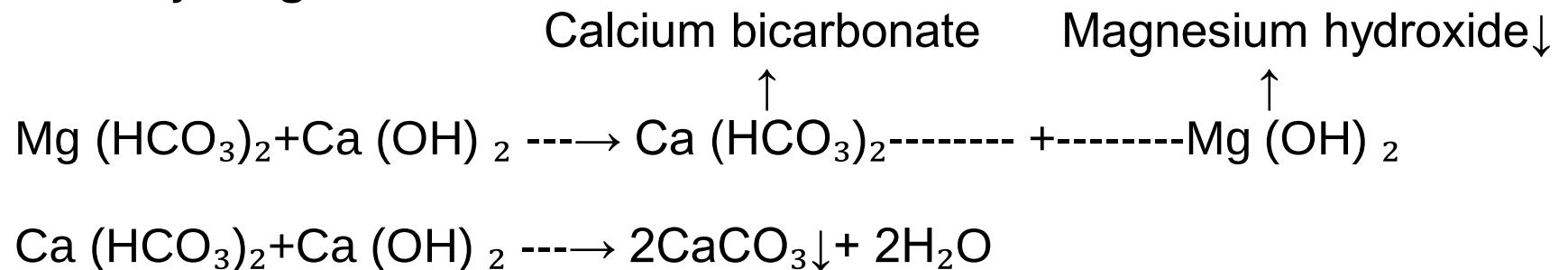


TREATMENT OF WATER - CONTD

The magnesium carbonate (MgCO_3) is fairly dissolves in water and cannot be removed by boiling, but can be by adding lime $\rightarrow$



Similarly **Magnesium bicarbonate** $\rightarrow$



TREATMENT OF WATER - CONTD

Permanent hardness [Bicarbonate hardness] → due to presents of sulphate, chlorides, and nitrates of calcium and magnesium. Ca^{++} , Mg^{++} , Fe^{++} , Mn^{++} etc. also contribute hardness to the water

Methods of removal of hardness →

- Lime soda process
- Base-exchange process/zeolite process
- Demineralization

TREATMENT OF WATER - CONTD

Lime soda process

Lime (Ca(OH)_2) and soda ash (Na_2CO_3) are added to the water which reacts with the Ca. and Mg. salts so as to form insoluble precipitate of CaCO_3 and Mg(OH)_2

The chemical reactions are $\rightarrow$



Noncarbonate hardness of calcium



Noncarbonated hardness

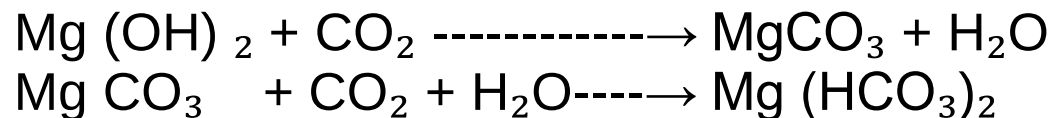
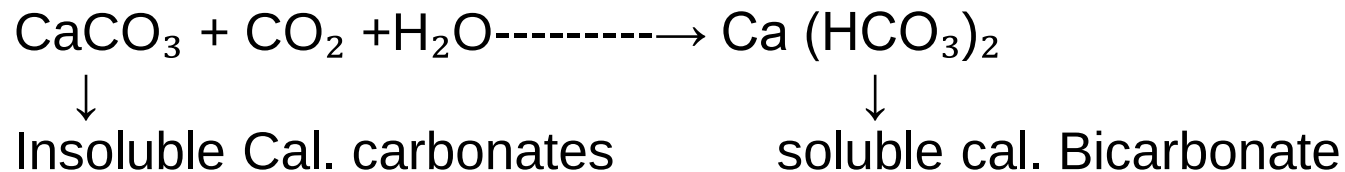


TREATMENT OF WATER - CONTD

- Lime removes the carbonate and bicarbonate hardness (temporary)
- Similarly the noncarbonated hardness of Mg. is converted in to non carbonate hardness of Ca.
- Similarly the lime removes the CO_2 , from the water
- Soda then removes the non carbonate hardness of Ca. also

Re carbonation process →

When CO_2 pass through the water containing finely divided particles of CaCO_3 , it combines with CaCO_3 to form soluble bicarbonate



TREATMENT OF WATER - CONTD

Note: normally CO_2 , is applied as pressurized liquid
Normally most of the hardness is due to carbonates
Alum, lime, soda → Are added together as a single process

Advantages of lime soda process

- Economical
- Easily combined with treatment without trouble
- When used along with coagulant, quantity of coagulants can be reduced
- Increased pH, reduce corrosion of distribution pipes
Increased causticity, cause killing pathogenic bacteria, especially when Calcium and magnesium hydroxide alkalinity is between 20-50mg/lit
- Helps to reduce the total mineral content
- Remove Iron and manganese, to some extent

TREATMENT OF WATER - CONTD

Disadvantages

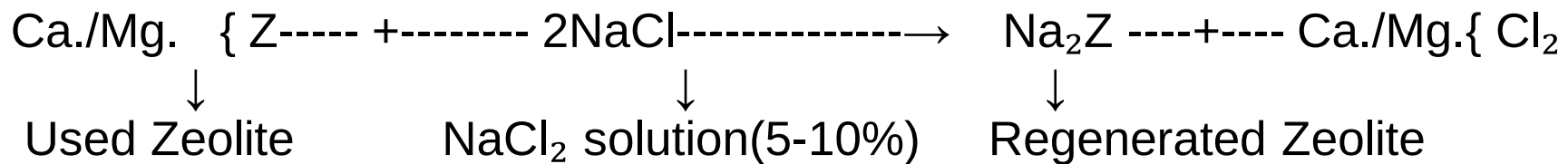
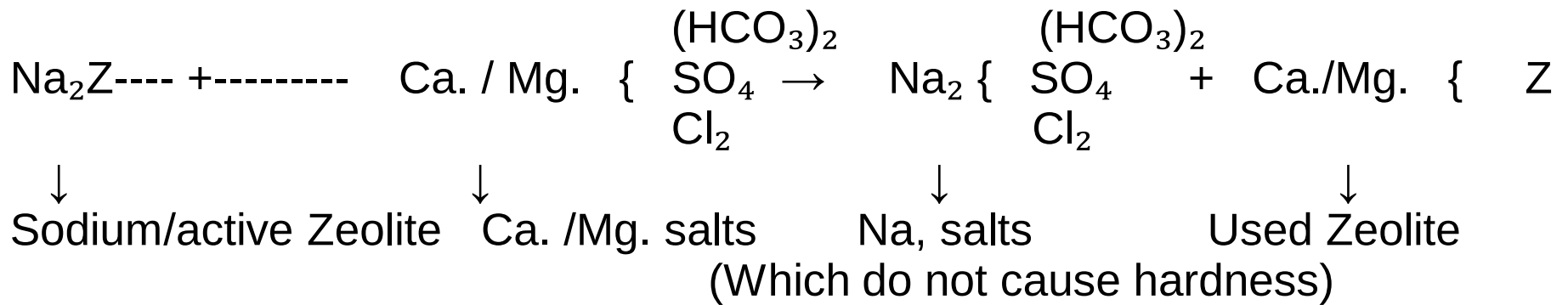
- A large quantity of sludge
- Careful operation and skilled supervision
- Incrustation of pipes and trouble in filter bed, if recarbonation is not done properly
- No zero hardness as CaCO_3 is slightly soluble in water, hence remain hardness up to about 50mg/lit

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Zeolite/ Base exchange/ Cation exchange process

- Zeolite are the natural salts or clay which are hydrated silicates of sodium and aluminium, having the general formula as $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot x\text{SiO}_2 \cdot y\text{H}_2\text{O}$ (green sand-green coloured)
- Synthetic Zeolite → Resines (Permutit, a white coloured-manufactured from feldspar, kaolin, clay and soda)

Sodium Ion of the Zeolite gets replaced by the Ca. And Mg. ions present in water



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- The Ca. and Mg. Zeolite can be regenerated by 5-10%, solution of sodium chloride
- The Zeolite softener resembles as filter bed with Zeolite as media
- Washing is reversed with brine solution (10%) for regeneration of Zeolite
- The excess brine is removed by washing with fresh water

Advantages→

- Zero hardness→ can be used for specific purpose/ in industries
- Plant is automatic, compact easy to separate
- No sludge is formed
- R.M.O. cost is less.
- Remove ferrous iron and manganese.
- No difficulty to treat water of varying quality.
- No incrustation.

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Disadvantages→

- Turbid water, not suited, filter bed function, trouble
- Form sodium bicarbonate in water which causes priming and foaming in boiler feed water.
- Unsuitable for water containing iron and manganese, the iron and manganese zeolite cannot be regenerated in to Na. zeolite

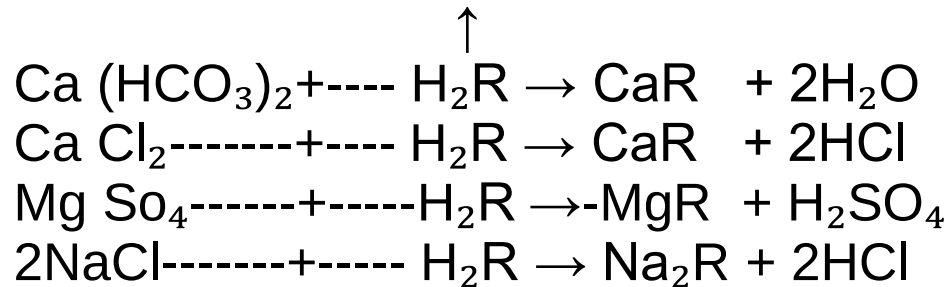
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Demineralization Process or (Deionization) →

- The process involves first cation exchange process as in zeolite process (H₂ is exchanged instead of Na₂)
- Then again subjected to anion exchange process
- The cation exchange resins are produced by sulphonation of phenol aldehyde condensation products.

The reactions are

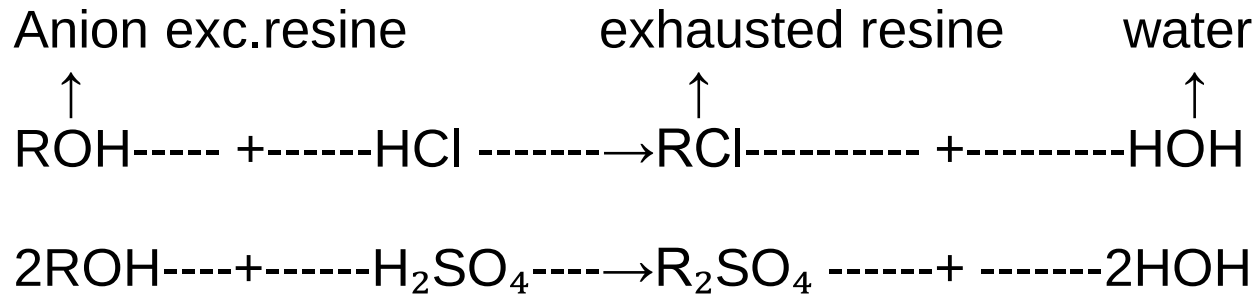
cation exchange resin.



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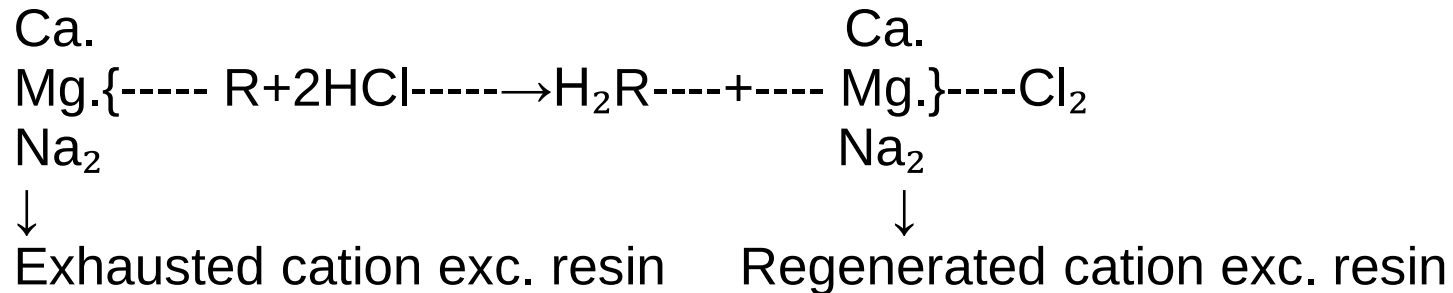
- The water coming out of the cation exchange process will contain diluted HCl , H_2SO_4 , Carbonic acid etc. and can be removed by passing through the anion exchange bed
- Anion exchange resins are produced by condensation of amine with formaldehyde
- Replace Cl^- , SO_4^{2-} ions

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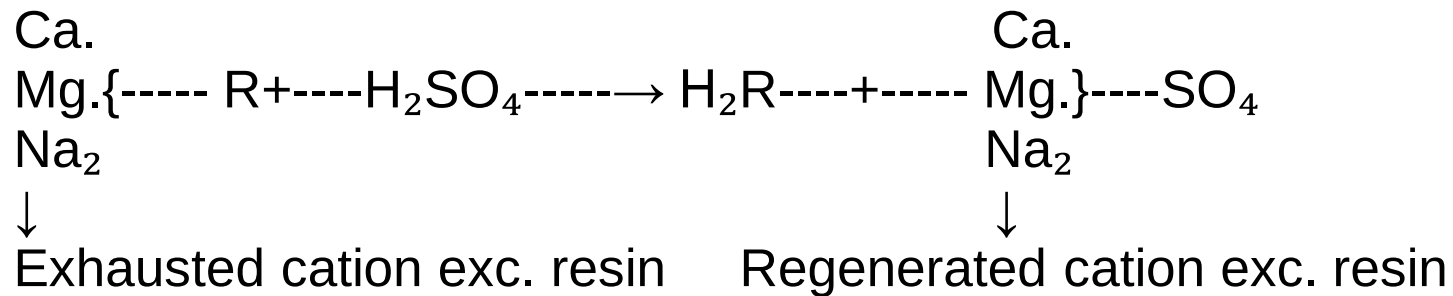


Resultant water will be fresh ionized water

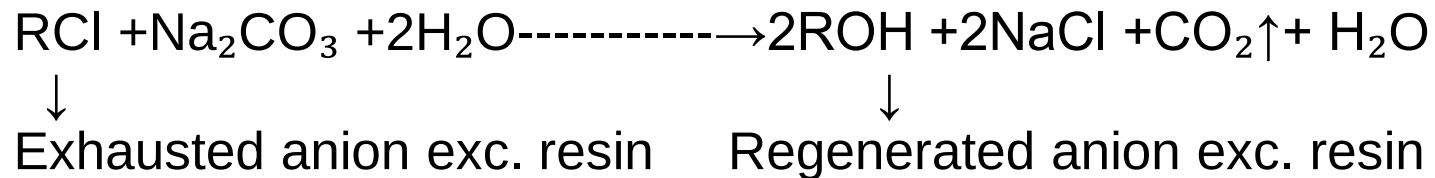
Regeneration



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Similarly Exhausted anion exchange resin can be regenerated by treating them with sodium carbonate solution



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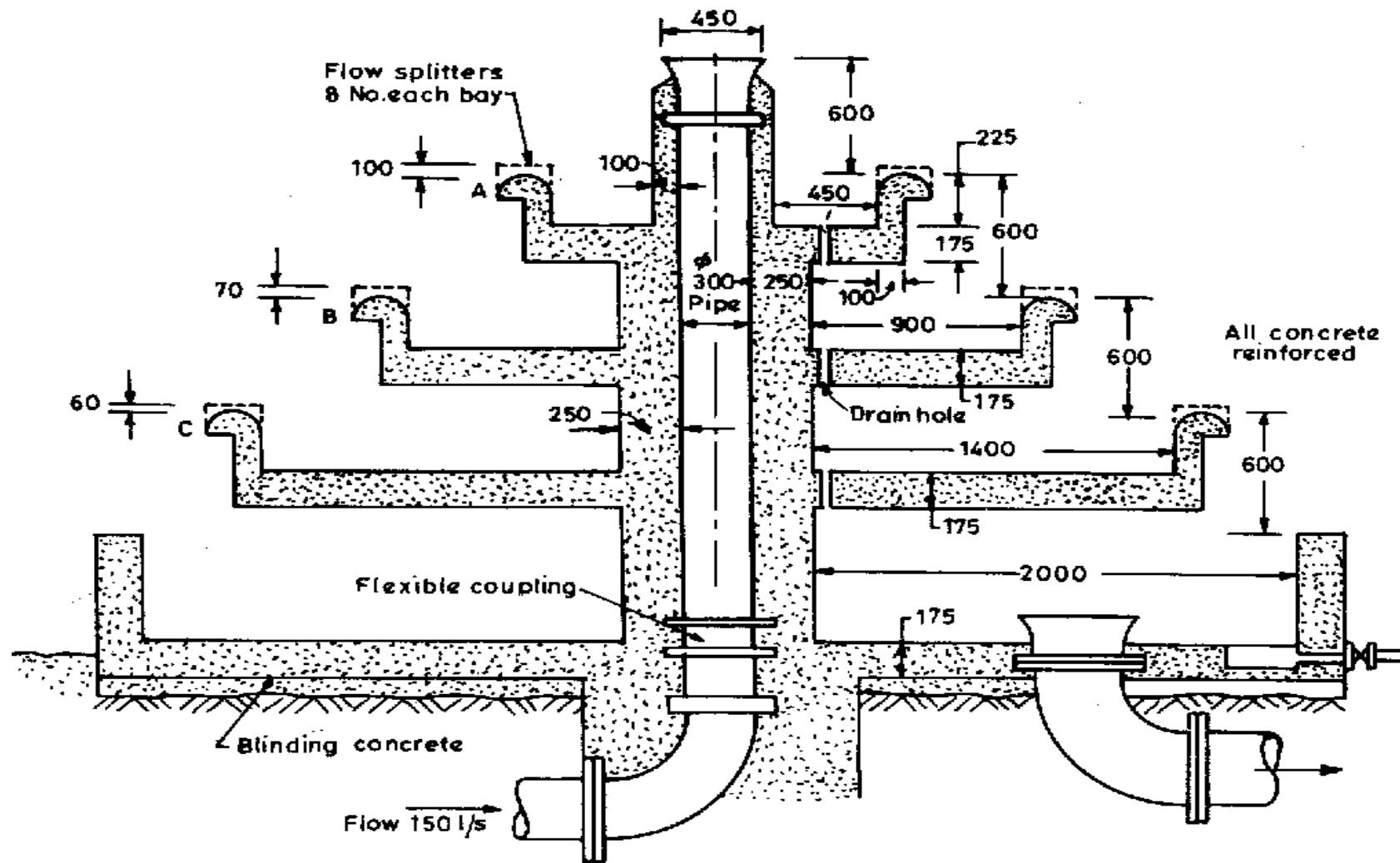


Fig. 9.48. (a) Section through a circular Cascade aerator.