L-23
Filtration

Environmental Engineering-I

Contents

- Theory of filtration, Slow sand filter
- Rapid sand, Dual multimedia Roughing and pressure filters-Operation and design.

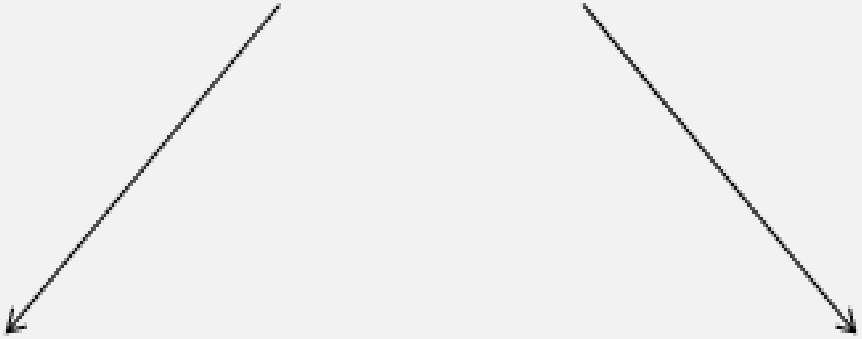
Introduction

- It is a solid-liquid separation process in which the liquid passes through a porous medium to remove as much fine suspended solids as possible.

Applications:

- In water treatment plants, a polishing step to remove small flocs and other particles that are not removed in settling

FILTRATION



Actual filtration
process by which the water is cleaned

Backwashing
cleaning of filter medium

- During filtration; Water containing suspended matter is applied to the top of the filter bed
- As the water filters through the porous medium, the suspended matter in the fluid is removed by a variety of mechanisms.
- These mechanisms are described in next few slides

MECHANISMS INVOLVED IN FILTRATION

1. Mechanical Straining

- Simplest action during filtration.
- Suspended particles having size more than that of filter voids are arrested and removed, when water passes through filter media.
- Takes place in few centimeters of depth of filter media.

2. Sedimentation

- Finer particles are arrested by sedimentation.
- Continuous voids of filter media acts as ‘tube settler’ i.e. shallow depth sedimentation tank.
- All colloids are removed by this action

3. Biological Action

- After few days of working of filter, upper grains of sand layer becomes coated with a reddish brown coloured sticky deposit.
- It consists of organic matter and Fe, Mg, Al and silica.
- Further after 2-3 weeks, a film consisting of algae and protozoa etc is developed.
- **This film is known as ‘dirty skin’ or ‘Schmutzdecke’.**
- Organic impurities in water are used as food by this film, thus removing the organic matter from water.

4. Electrolytic Action

- Particulate matter is removed by electrostatic action.
- Charge on filter medium neutralizes charge on floc particles, thereby permitting the floc to be removed.
- During back washing the electrostatically removed material is removed and thus charge on filter material is replaced.

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TYPES OF FILTER PART I

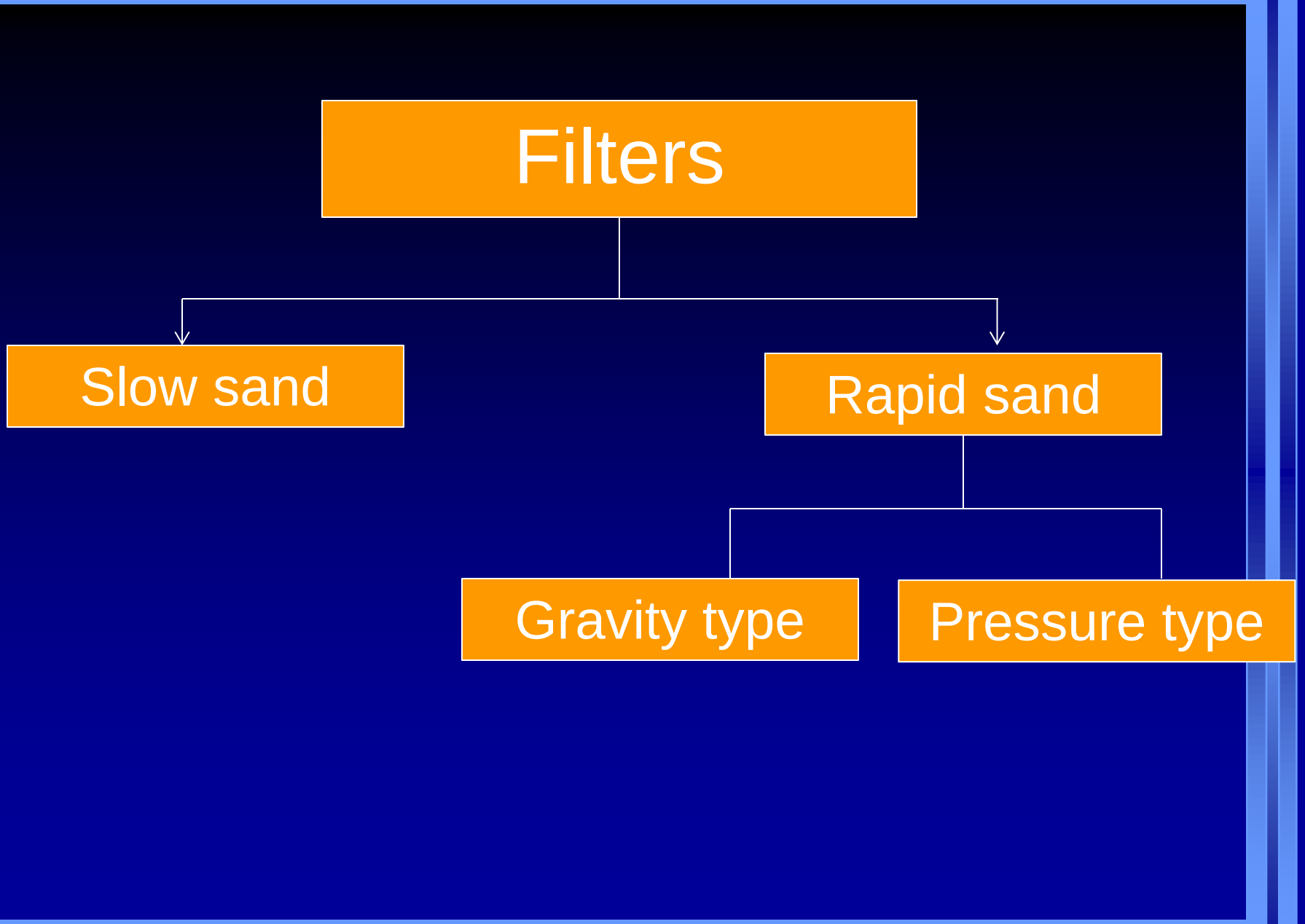
Classification

1. Slow sand filter
2. Rapid sand filter

- Gravity type
- Pressure type

- Filter differs w r t

i. Head required for filtration
ii. Rate of filtration
iii. Composition of filter media
iv. Method and frequency of cleaning


Filters
Slow sand
Rapid sand
Gravity type
Pressure type

Filter media

- Commonly used filter materials are

i. Sand
ii. Anthracite
iii. Garnet sand or limenite
iv. Other locally available material

Sand

- Cheapest and widely used
- Sand should be free from clay, silt, loam and SS and organic matter.
- **Effective size**: -It is sieve size in mm through which 10% of sand by weight passes.
- **Uniformity coefficient (C_u)** :- Ratio of sieve size through which 60% of sand passes to the effective size of sand.

i.e. $C_u = D_{60} / D_{10}$

- Essentials of filter sand

1. Shall be hard
2. Shall be free from clay, fine particles, grains and dirt
3. Ignition loss should not exceed 0.7%
4. Soluble fraction in HCl shall not exceed 5%.
5. G_s = 2.55 to 2.65
6. Wearing loss shall not exceed 7%
7. Effective size shall be

i. 0.2 to 0.3 mm for slow sand filters
ii. 0.45 to 0.7 mm for rapid sand filters

8. The uniformity coefficient shall be

i. 3 to 5 for slow sand filter
ii. Not less than 1.3 and not more than 1.7 for rapid sand filter

Anthracite

- Substitute for sand
- Can be used in conjunction with sand
- Cost is more as compared to sand

Garnet sand

- Heavier than normal sand (Gs = 4.2)
- Used in mixed media filters.

Locally Available Material

- Shredded coconut husk, burnt rice husk, crushed glass and metallic ores can be used as filter media

Coconut husk

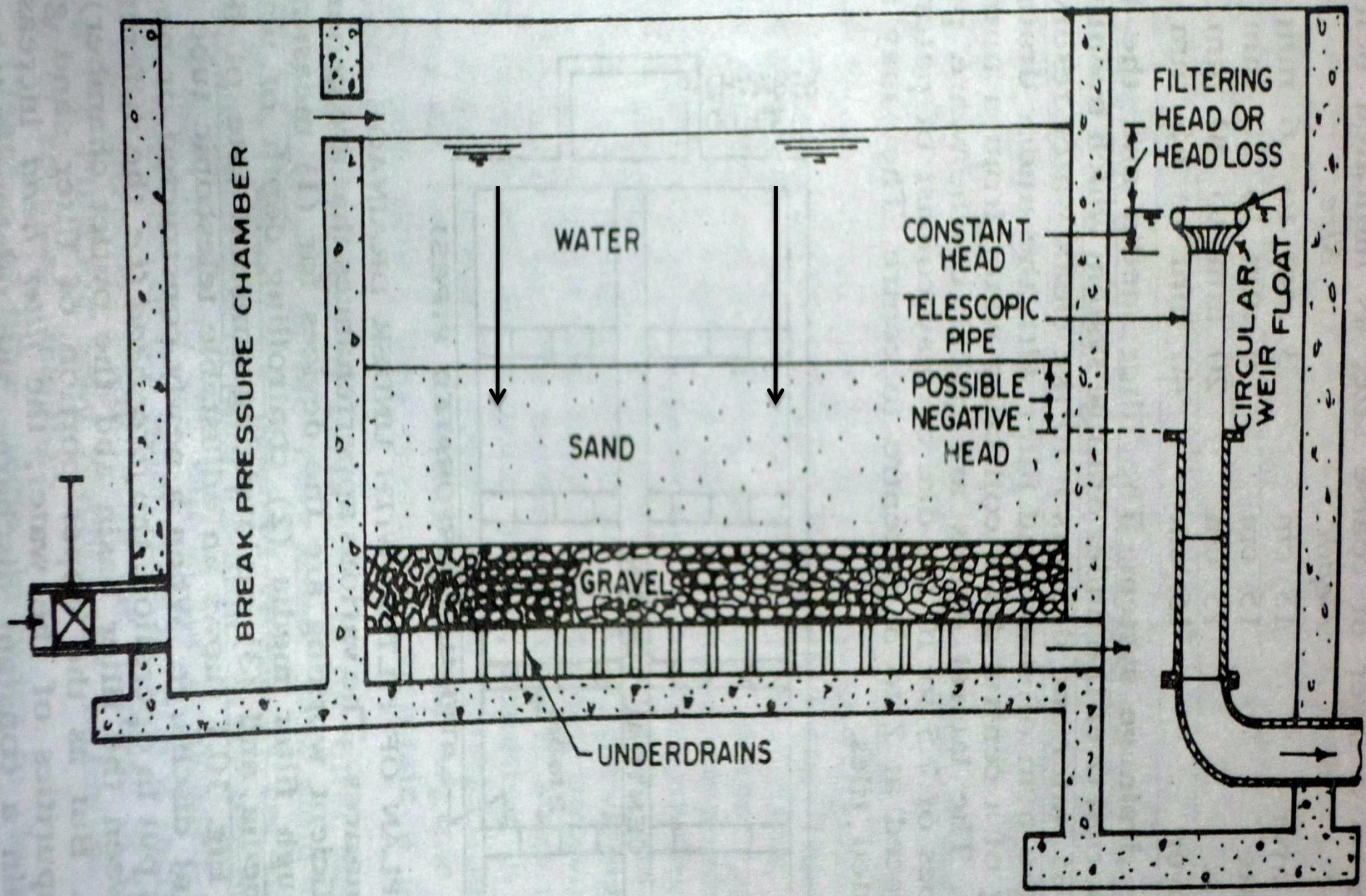
Rice husk

Crushed glass

Gravel

- The layers of sand may be supported on gravel, which permits the filtered water to move freely to the under drains, and allows the wash water to move uniformly upwards.
- Should be hard, durable, rounded, free from flat or long pieces and impurities

SLOW SAND FILTER: ESSENTIAL FEATURES PART-II


BREAK PRESSURE CHAMBER
WATER
SAND
GRAVEL
UNDERDRAINS
CONSTANT HEAD
TELESCOPIC PIPE
POSSIBLE NEGATIVE HEAD
FILTERING HEAD OR HEAD LOSS
CIRCULAR WEIR
FLOAT

1. Enclosure tank

- SSF is open basin, **rectangular shape** and built below finished ground level.
- Floor has Bed slope of **1:100 to 1:200** towards central drain
- **Surface area (A_s) of tank varies from 50 to 1000 m^2.**
- **Filtration rate – 100 to 200 lit/m^2/hr.**
- **Depth – 2.5 to 4 m**

2. Filter media: Sand

- Thickness of sand layer - **90 to 110 cm**
- Effective size – **0.2 to 0.35** *(Common value -0.3)*
- Coefficient of uniformity – **2 to 3** *(Common value - 2.5)*

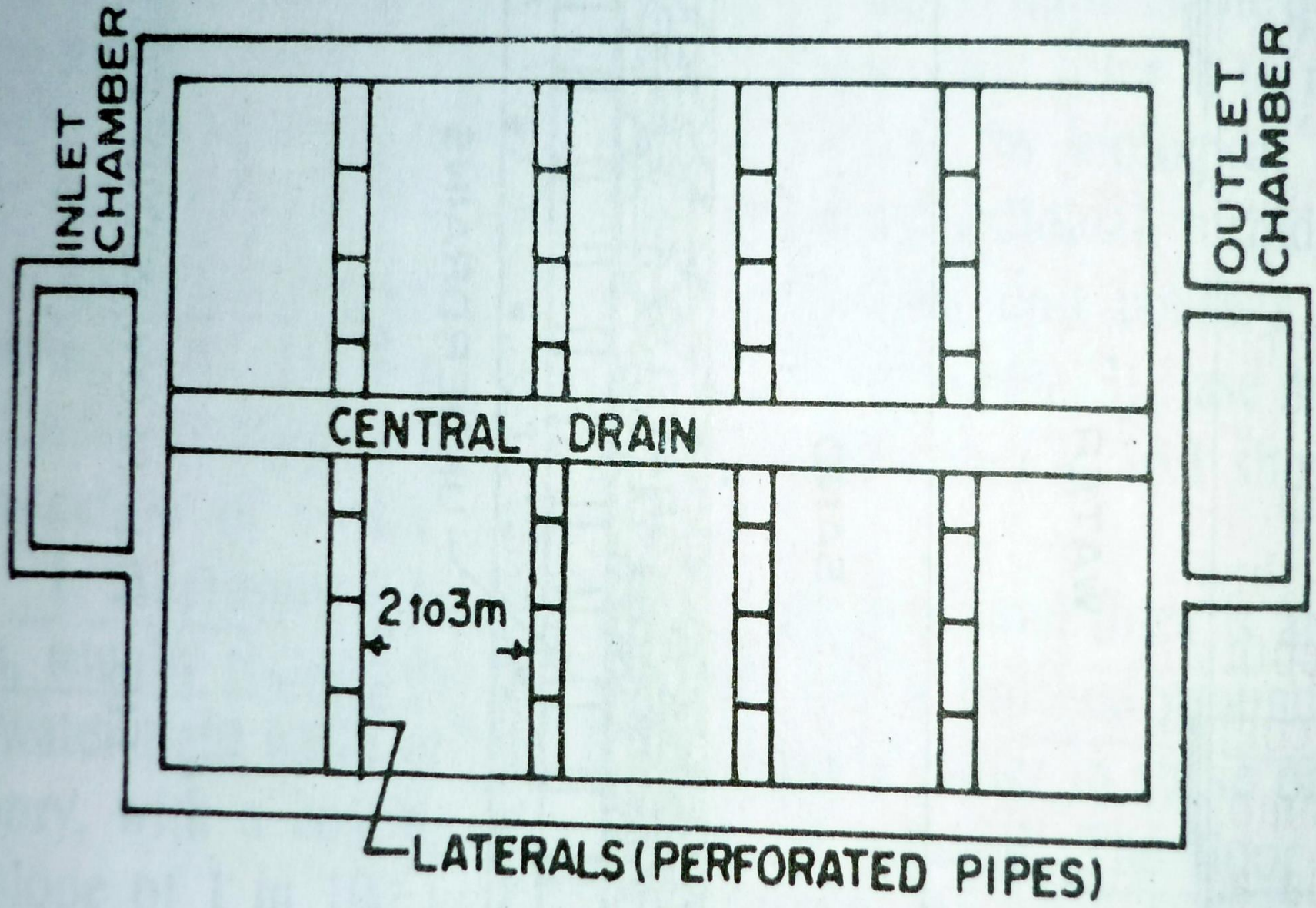
3. Base material: Gravel

- Thickness of gravel bed - **30 to 75 cm**

Layer	Depth	Size in mm
topmost	15 cm	3 to 6
Intermediate	15 cm	6 to 20
Intermediate	15 cm	20 to 40
Bottom	15 cm	40 to 65

4. Under drainage system

- **Base material and filter media are supported by under drainage system.**
- Under drainage system collects filtered water and delivers it to the reservoir
- Laterals – earthenware pipes of **7.5 to 10 cm dia.**
- Spacing of laterals- **2 to 3 m c/c**


INLET CHAMBER
OUTLET CHAMBER
CENTRAL DRAIN
2 to 3m
LATERALS (PERFORATED PIPES)

5. Appurtenances

Devices are required for

i. Measuring head loss through filter media
ii. Controlling depth of water above filter media
iii. Maintaining constant rate of filtration through the filter

Working of slow sand filter

- In a slow sand filter impurities in the water are removed by a combination of processes: **sedimentation, straining, adsorption, and chemical and bacteriological action.**
- During the first few days, water is purified mainly by mechanical and physical-chemical processes. The resulting accumulation of sediment and organic matter forms a thin layer on the sand surface, which remains permeable and retains particles even smaller than the spaces between the sand grains.

- As this layer (referred to as “Schmutzdecke”) develops, it becomes living quarters of vast numbers of micro-organisms which break down organic material retained from the water, converting it into water, carbon dioxide and other oxides.
- Most impurities, including bacteria and viruses, are removed from the raw water as it passes through the filter skin and the layer of filter bed sand just below.

- The purification mechanisms extend from the filter skin to approx. **0.3-0.4 m below** the surface of the filter bed, gradually decreasing in activity at lower levels as the water becomes purified and contains less organic material.
- When the micro-organisms become well established, the filter will work efficiently and produce high quality effluent which is virtually free of disease carrying organisms and biodegradable organic matter.
- **They are suitable for treating waters with low colors, low turbidities and low bacterial contents.**

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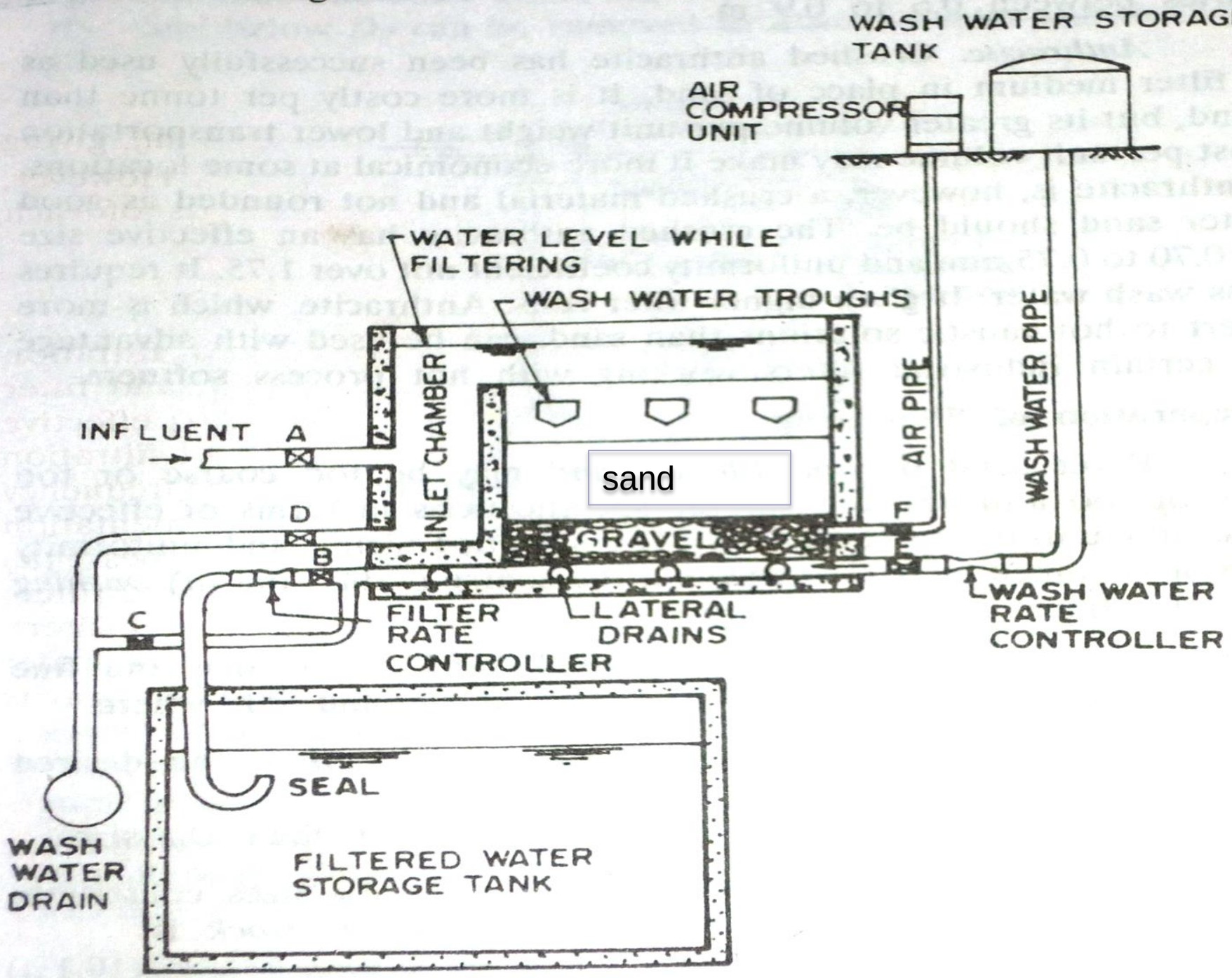
PART-III
RAPID SAND FILTER (GRAVITY TYPE)
ESSENTIAL FEATURES

remain submerged.



Enclosure tank

- Smaller in size, therefore can be placed under roof.
- Rectangular in shape and constructed of concrete or masonry.
- Depth – 2.5 to 3.5
- **Surface area – 20 to 50 m^2.**
- **L/B ratio – 1.25 to 1.35.**
- **Designed filtration rate are 3000 to 6000 lit/m^2/hr**

Filter media

- Should be free from dirt, organic matter and other SS.
- It should be hard and resistant.
- Depth of sand media – **0.6 to 0.9 m**
- Effective size – **0.35 to 0.6 mm** (Common value 0.45)
- Uniformity coefficient – **1.2 to 1.7** (Common value -1.5)

Estimation of sand depth

- The depth of sand bed should be such that flocs should not break through the sand bed.
- **Depth varies from 60 to 90 cm**
- Min depth required is given by **Hudson's formula**

$$[(q \cdot D^3 \cdot H) / I] = B_i \times 29323$$

Where,

- q = Filtration rate in $m^3/m^2/hr$ [Assumed filtration rate x Factor of safety (2)]

(Factor of safety 2 is taken to cater emergency situation)

- D = sand size in mm
- H = terminal head loss in m
- l = depth of sand bed in m
- B_i = Break through index

  = 4×10^{-4} to 6×10^{-3}

Base material

- Depth 45 to 60 cm

Layer	Depth	Size in mm
topmost	15 cm	3 to 6
Intermediate	15 cm	6 to 12
Intermediate	15 cm	12 to 20
Bottom	15 cm	20 to 50

Estimation of gravel size gradation

- To start with, a size gradation of 2 mm at top and 50 mm at bottom is assumed.
- The required depth (l) in cm of a component of gravel layer of size d (mm) can be computed by following equation

$$\mathbf{l = 2.54 \,.\, K \,.\, (\log d)}$$

K can be taken as 12

d = gravel size in mm

Under drainage system

- Objectives of under drainage system

1. To collect filtered water uniformly over the area of gravel bed
2. It provides uniform distribution of back wash water without disturbing or upsetting gravel layer and filter media

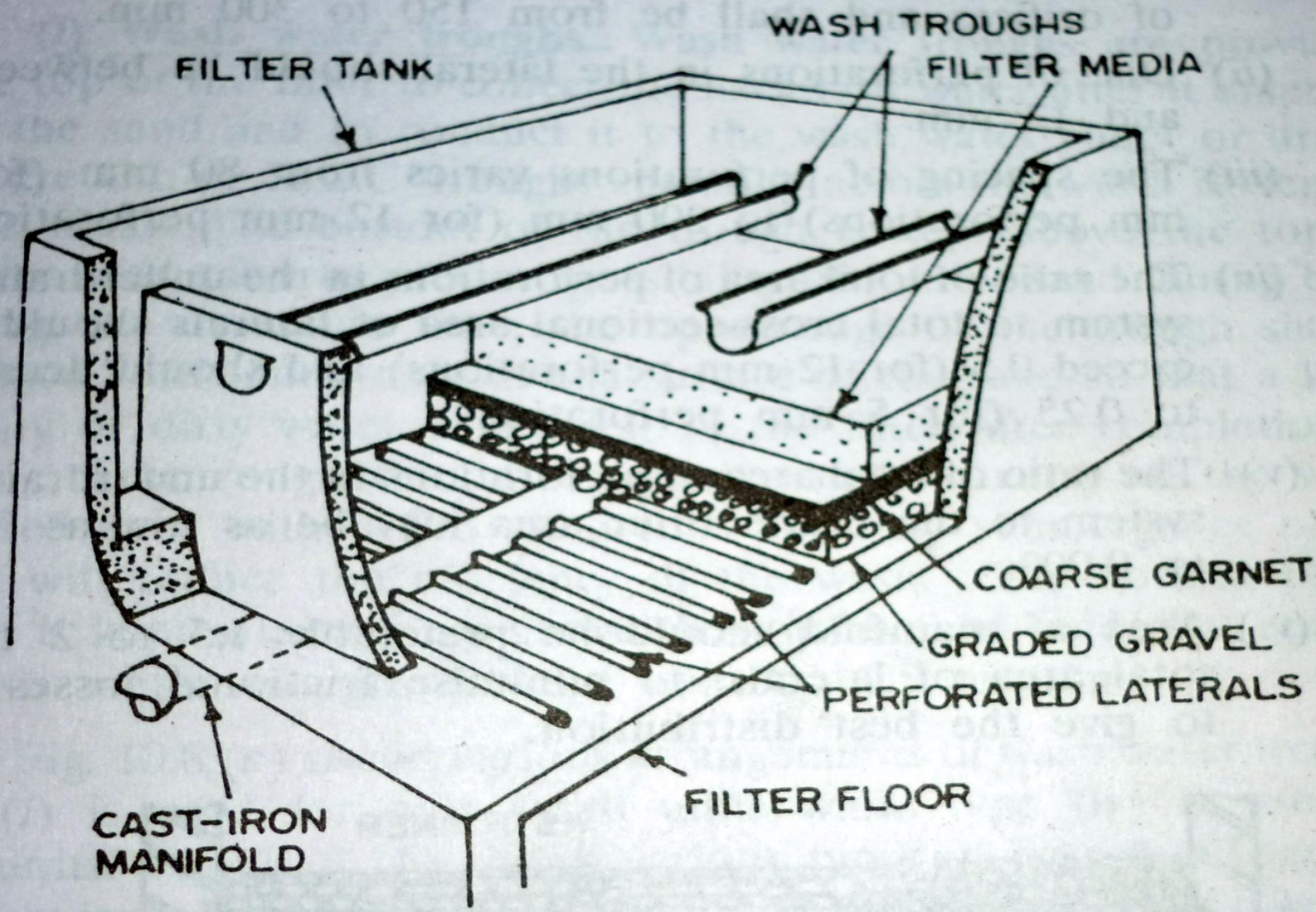
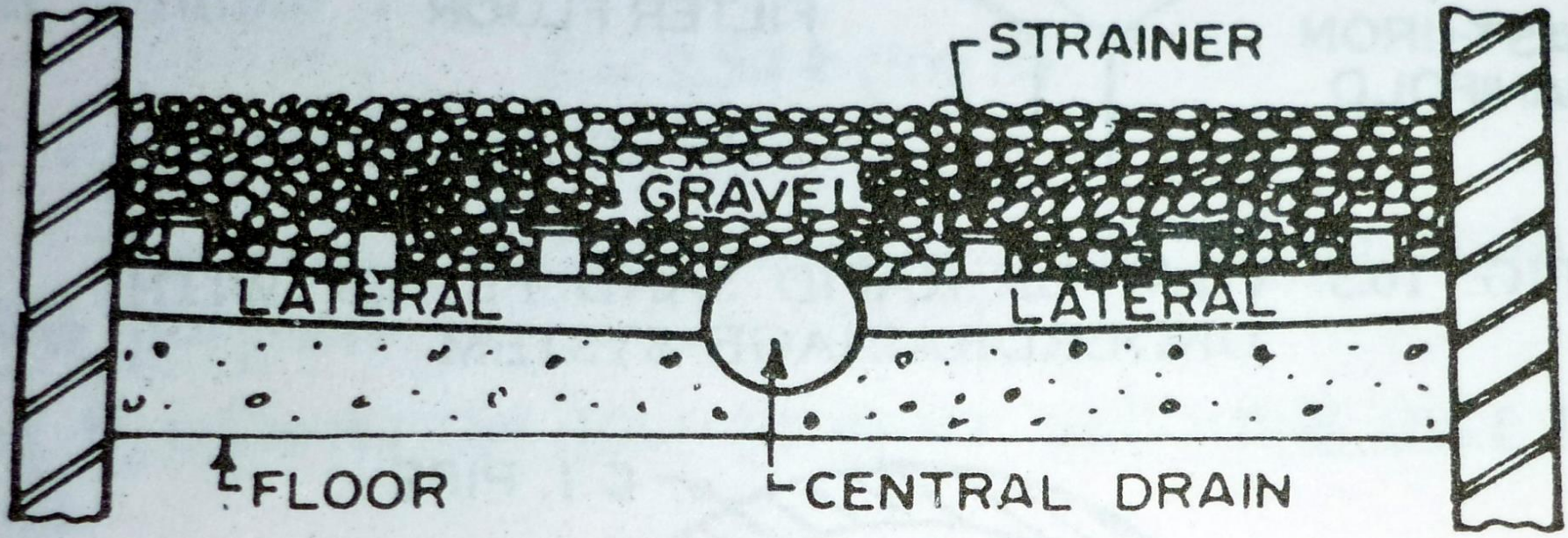
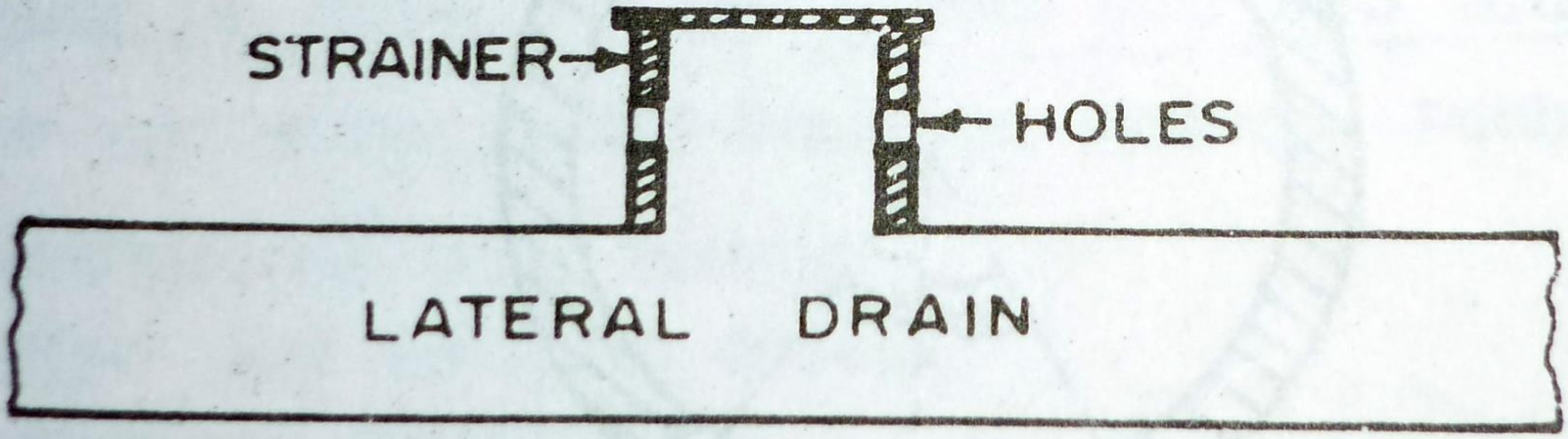


FIG. 10.5. VIEW OF RAPID SAND FILTER WITH UNDERDRAINAGE SYSTEM



(a) SECTION OF UNDERDRAINAGE SYSTEM

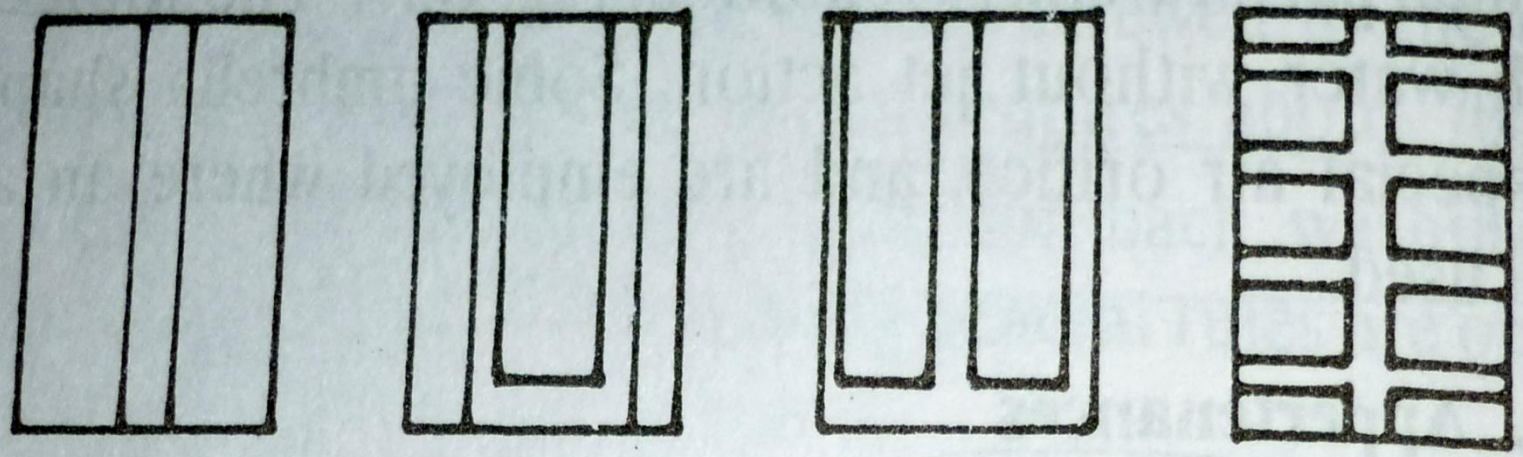


(b) LATERAL WITH STRAINER

Nozzles

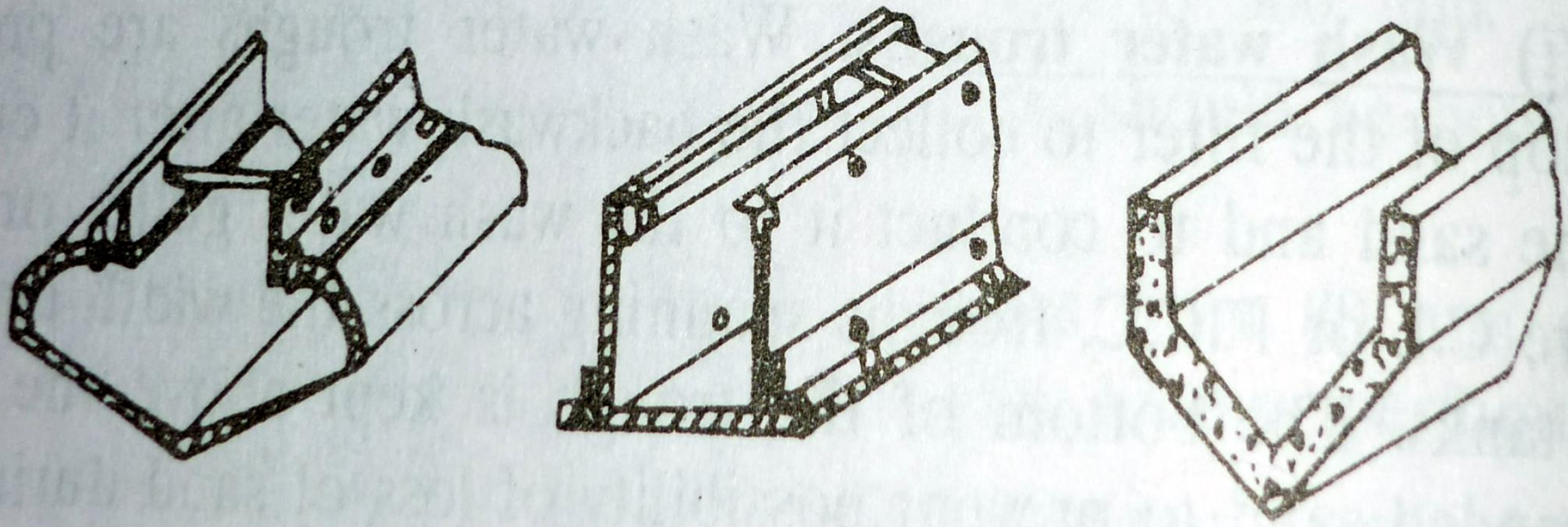
Appurtenances

1. Wash water troughs
2. Air compressors
3. Rate control device



(i) (ii) (iii) (iV)

(a) ARRANGEMENT OF WASH-WATER TROUGHS



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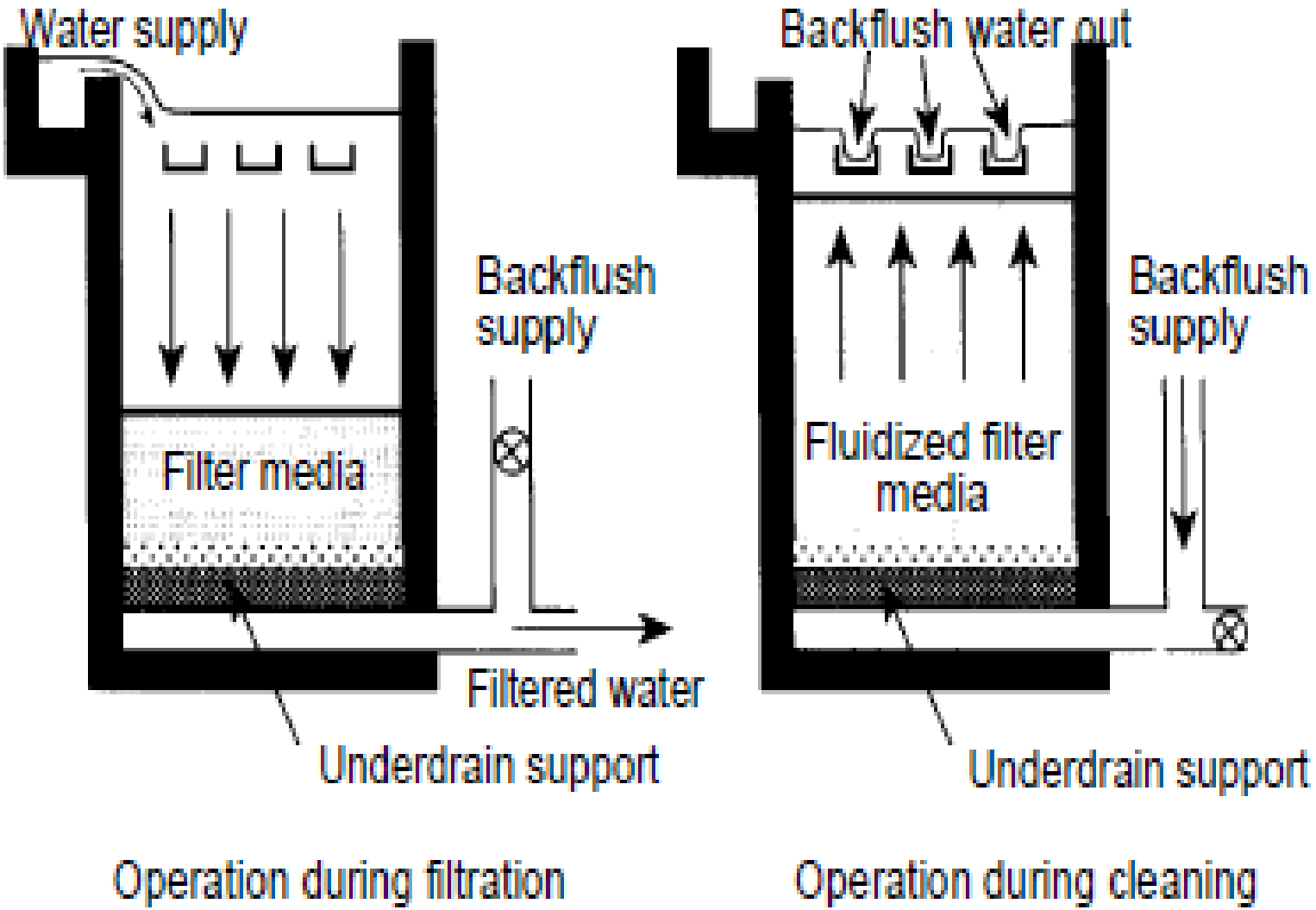
WORKING AND BACKWASHING OF RSF

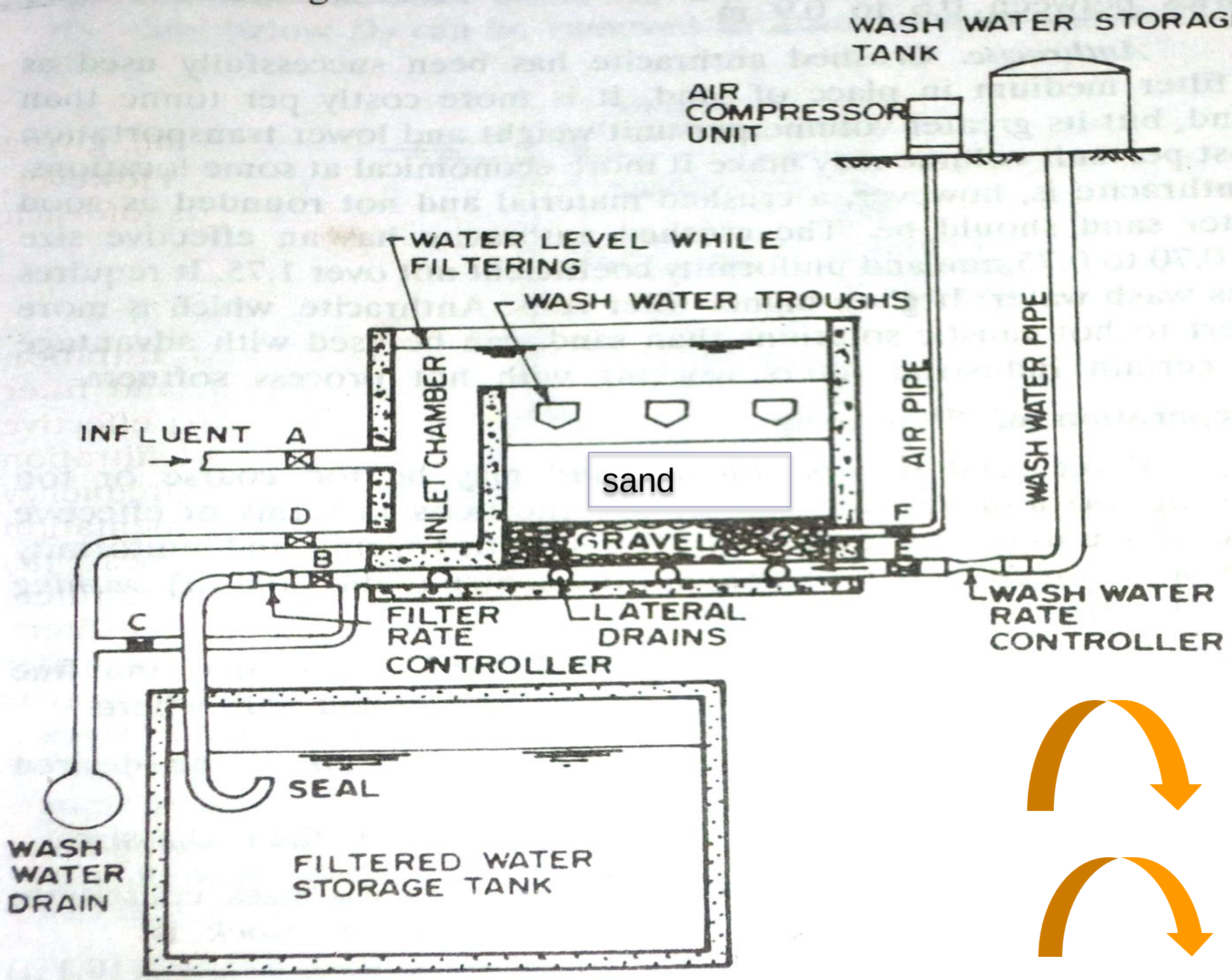
Rapid Sand Filtration



Working

- All valves are kept closed except valves A and B.
- Valve A is opened to permit water from clarifier
- Valve B is opened to carry filtered water to clear water sump
- **Head of 2m over sand bed is maintained**
- **Designed filtration rate are 3000 to 6000 lit/m^2/hr**

remain submerged.



- Filter run depends on quality of feed water
- Filter run may range between less than a day to several days
- **Objective of backwash is to remove accumulated particles on the surface and within the filter medium**
- Backwash is performed using wash water or air scouring.

Back washing

- Filter is back washed when head loss through it has reached the maximum permissible.
- RSF are washed by sending air and water upwards through the bed by reverse flow through the collector system.
- **2% - 4% filtered water is used for backwashing**

Steps in back washing

1. Close influent valve A
2. Close effluent valve B
3. Open air valve F, so that air blows at rate of **1 to 1.5 m^3 free air /min/m^2** of bed area for **@ 2 to 3 min**. this will break up the scum and loosen the dirt.
4. Close the air valve F and open the wash water valve E gradually to prevent the dislodgement of finer gravel.

5. Open the wastewater valve D to carry wash water to drain. Continue backwashing till wash water appears fairly clear.
6. Close the wash water valve E. Close the wastewater valve D. wait for some time till all matter in bed settles down.
7. Open valve A slightly, open valve C for carrying filtered water to drains for few minutes.
8. Close the valve C and open valve B. Open valve A completely to resume normal filtration

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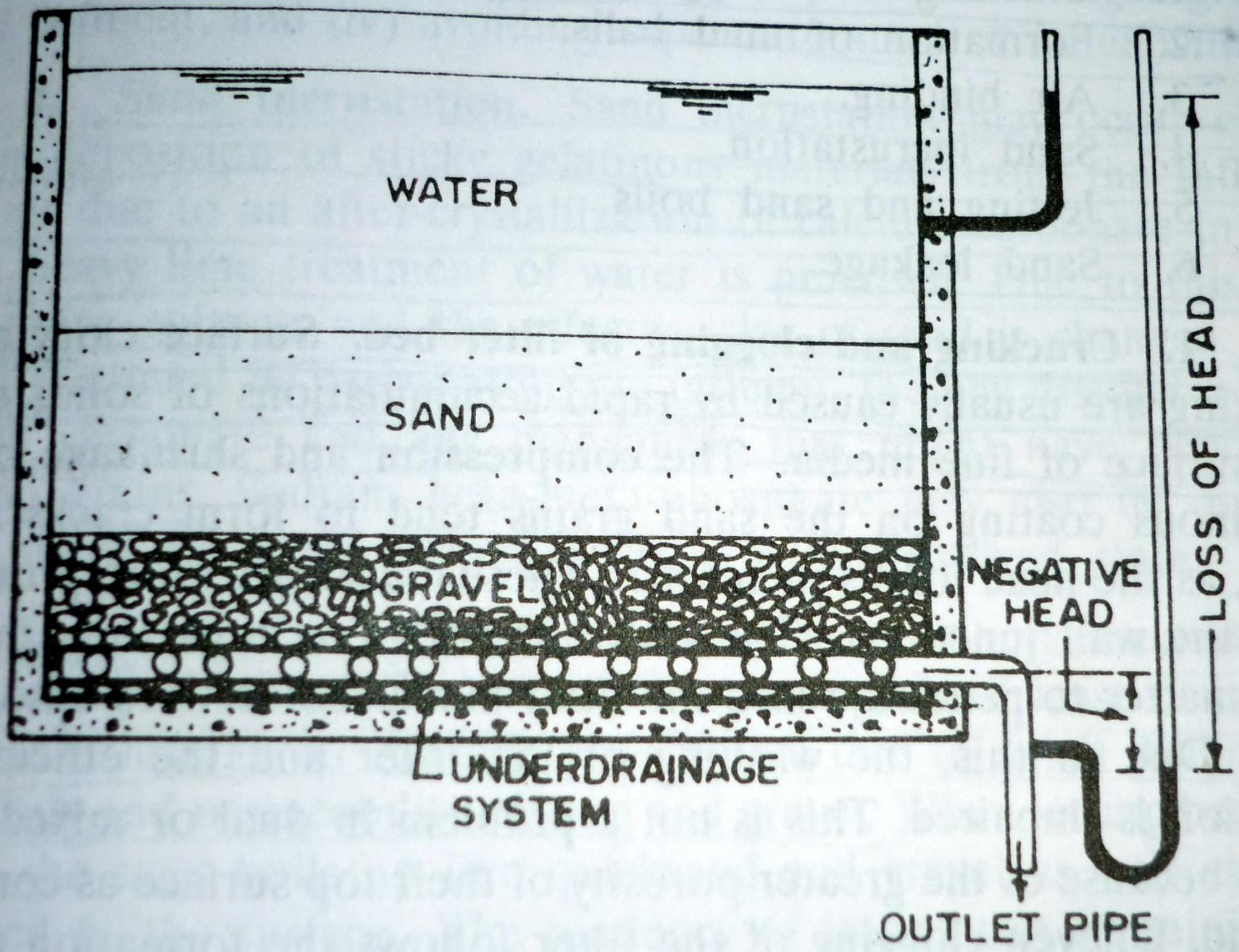
Negative head and filter troubles

Loss of head and Negative head

- When clean bed is put into operation the loss of head will be small usually in order of **15 to 30 cm.**
- During filtration impurities get arrested in the voids and head loss goes on increasing.
- Loss of head can be measured by using two piezometric tubes as shown in figure


WATER
SAND
GRAVEL
NEGATIVE HEAD
LOSS OF HEAD
UNDERDRAINAGE SYSTEM
OUTLET PIPE

- As thickness or depth of suspended matter on the sand bed increases, the head loss increased.
- A stage comes when frictional resistance exceeds the static head above the sand bed.
- At this stage, lower part of sand bed and under drainage system are under partial vacuum or negative head.
- Because of negative head water is being sucked rather than being filtered.

- In RSF head loss may be **2.5 to 3.5 m**
- **Permissible negative head may be 0.8 to 1.2 m.**
- Filter run is terminated and filter is then backwashed when these values are reached.
- Frequency of backwashing is 2-4 days for RSF in normal conditions

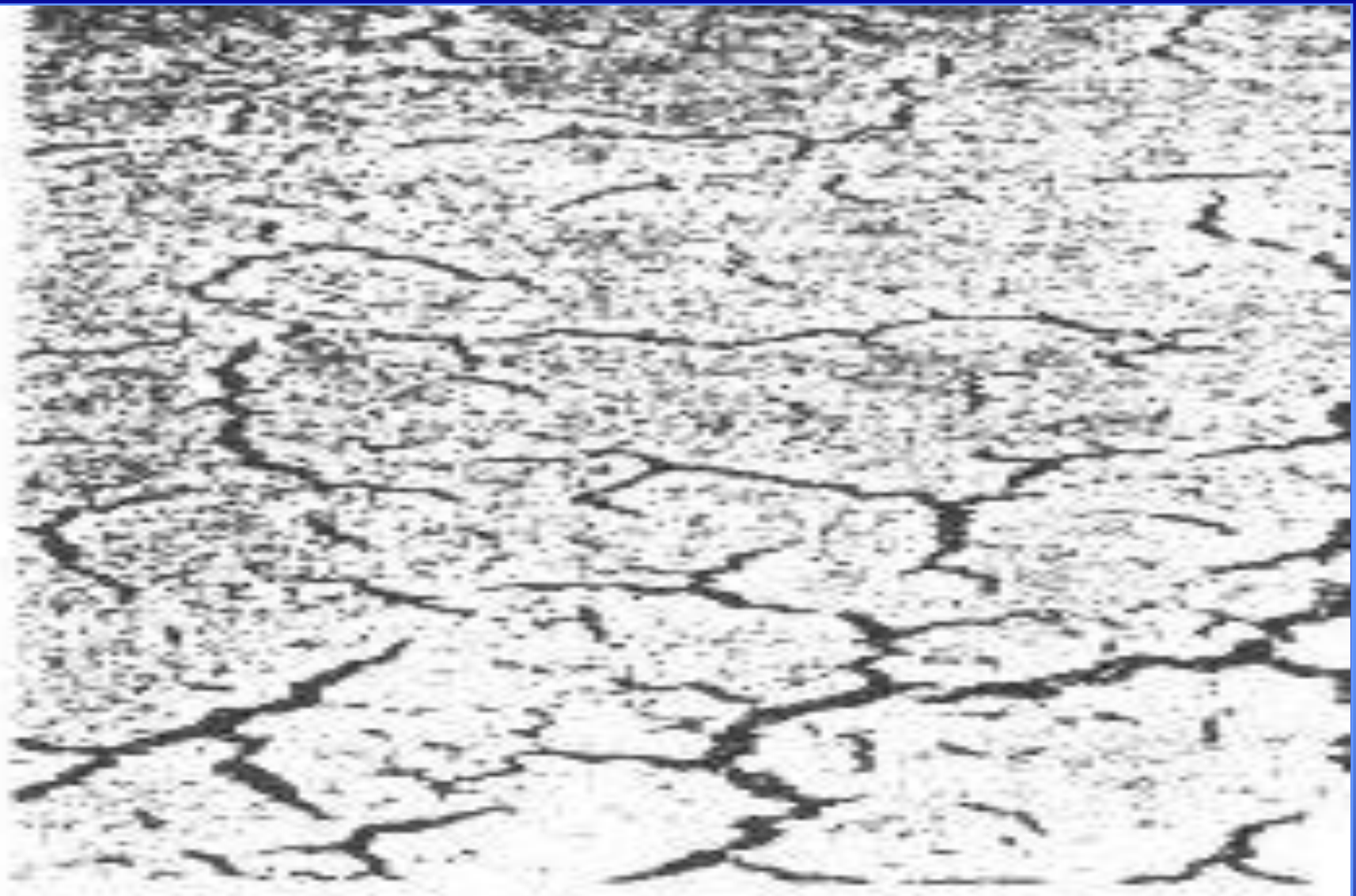
FILTER TROUBLES
PART - IV

Following filter troubles are commonly observed

1. Cracking and clogging of filter bed
2. Formation of mud balls
3. Air binding
4. Sand Incrustation
5. Jetting and Sand boils
6. Sand leakage

1. Cracking and clogging of filter bed

- Surface clogging and cracking are usually caused by rapid accumulation of solids on the top of filter media.
- Cracks are more at wall junctions.



Cracks in the Filter Bed

2. Formation of mud balls

- Mud balls are formed because of conglomeration of turbidity, floc, sand and other binders.
- Formed because of insufficient washing of sand grains.
- Size may be pea size to 2 to 5 cm or more in dia.

3.Air binding

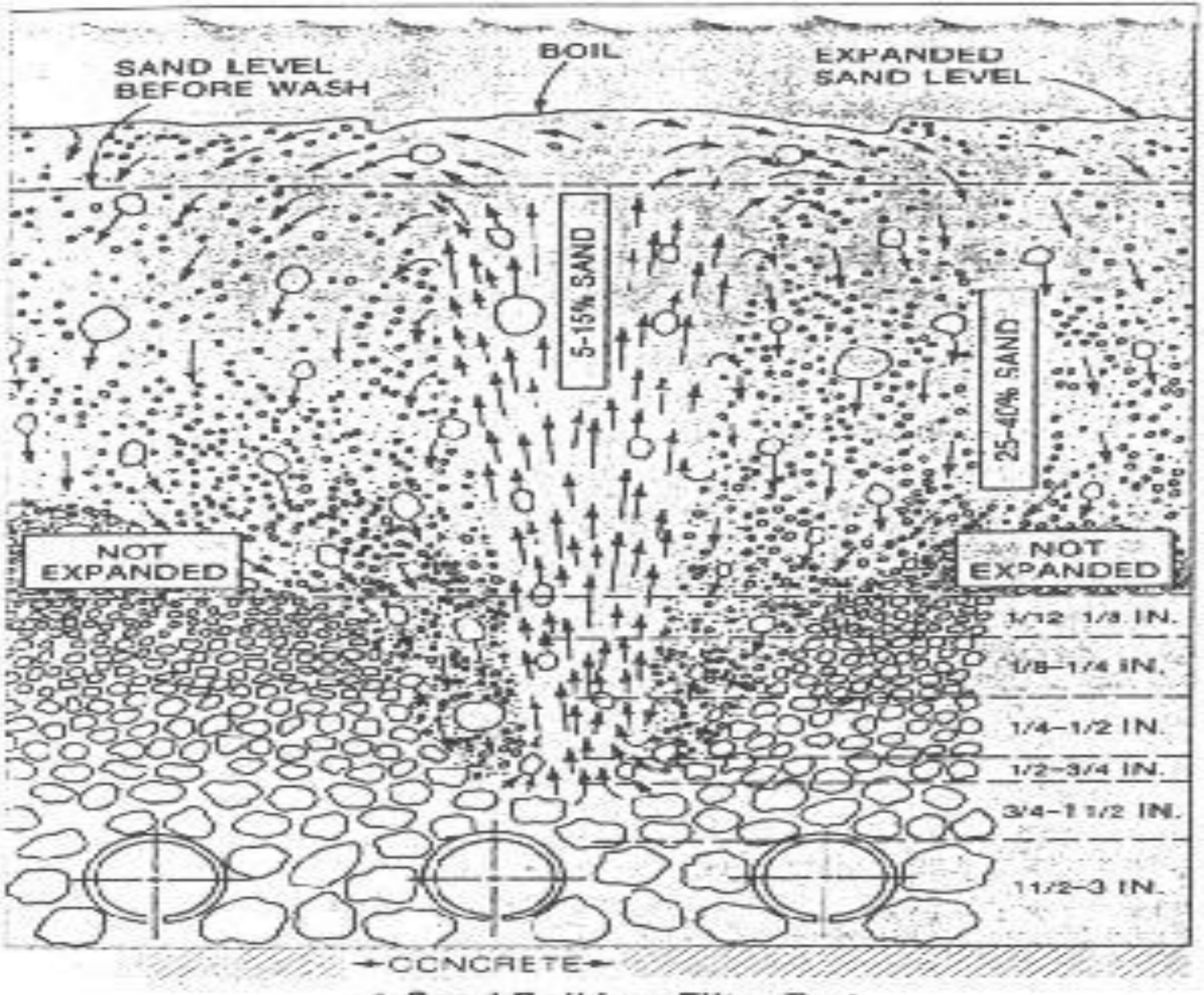
- It is caused by release of dissolved gases and air from water to form bubbles.
- These bubbles occupy void space of the filter media sand and drainage system.
- It is caused by negative head loss, warm water and increased DO in water.
- It can be minimized by avoiding excess head loss, warming of water, control of algal growth and avoiding super saturation of water with air.

4. Sand Incrustation

- It occurs due to accumulation of sticky gelatinous material or crystallization of calcium carbonate.
- Sand grains enlarge in size and effective size changes
- **Carbonization of water can be done to prevent this problem.**
- Some times **Sodium hexa-meta Phosphate can be added to keep calcium carbonate in dissolved state**

5. Jetting and Sand boils

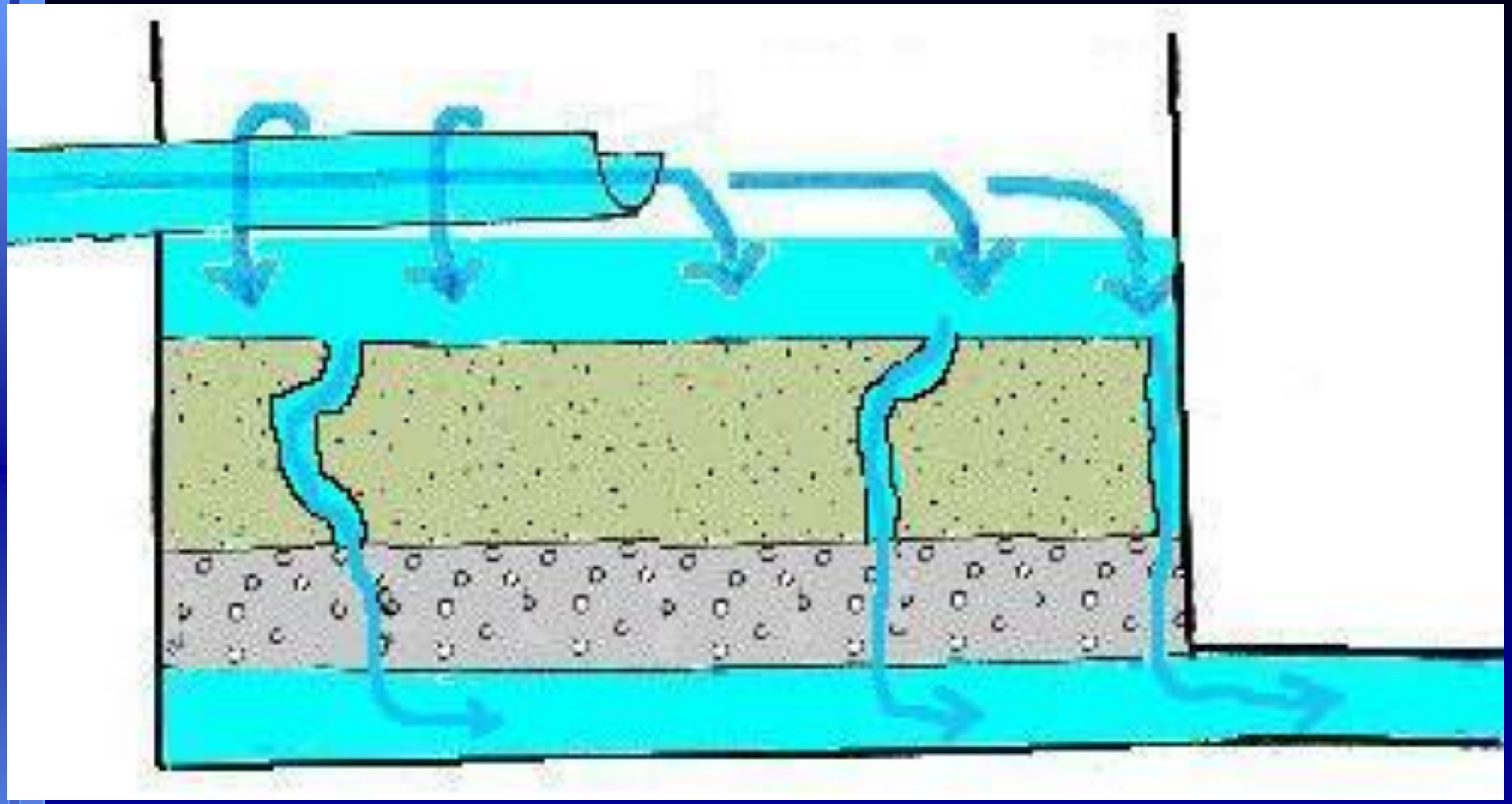
- These are produced when during backwashing water follows path of least resistance and break through to the scattered points due to small differences in porosity and permeability.
- Jetting can be avoided by surface wash or air scour.
- Use of 8 cm thick layer of coarse garnet is also recommended.



A Sand Boil in a Filter Bed

6. Sand leakage

- It results when smallest gravels are displaced during backwashing.
- Water will enter the under-drainage system unfiltered.
- It can be reduced by properly proportioning of sand and gravel layer.
- In between sand and gravel garnet layer can be used to tackle this type of problem.



Pressure Filter

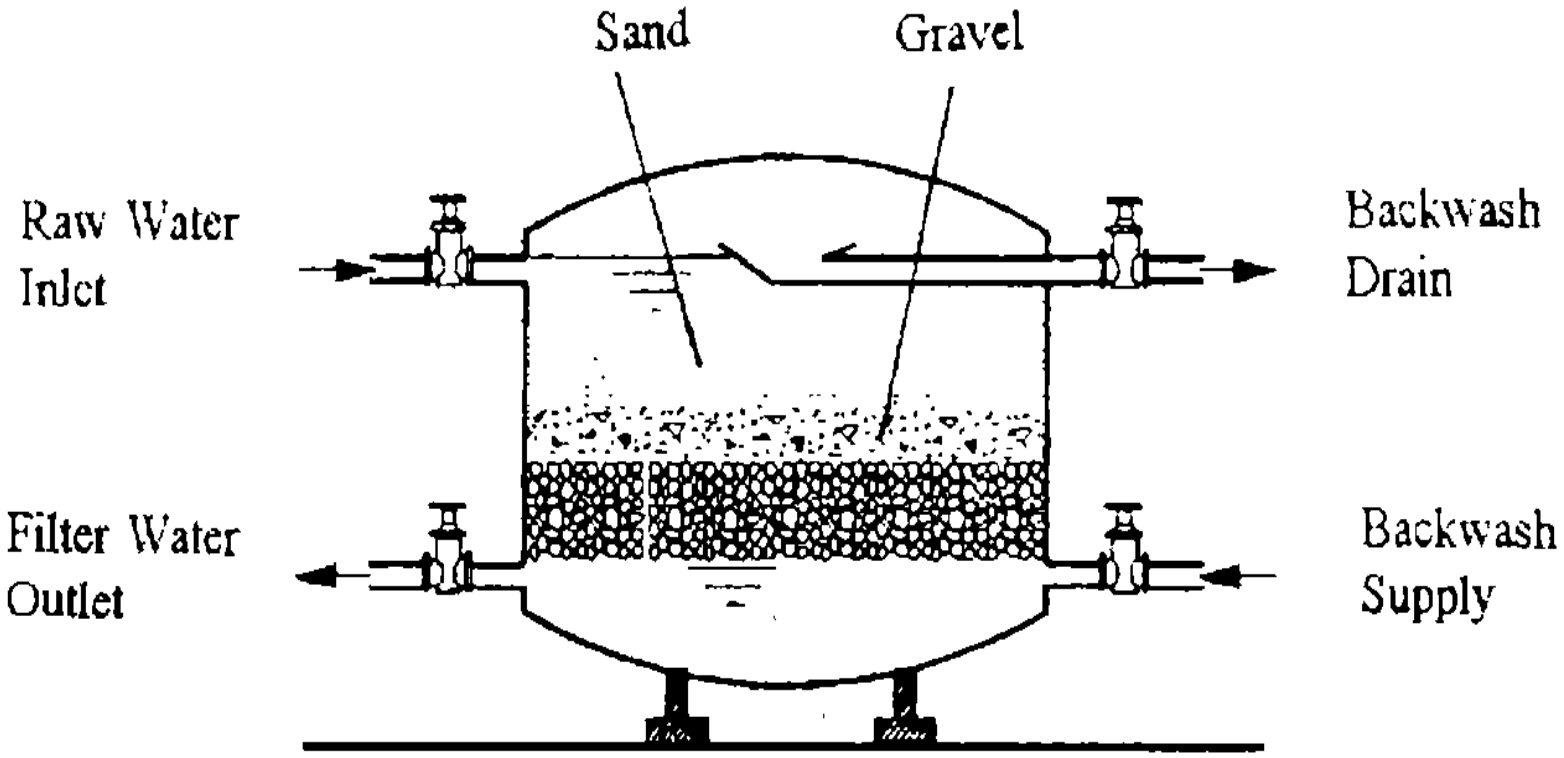


Figure 2. Pressure filter

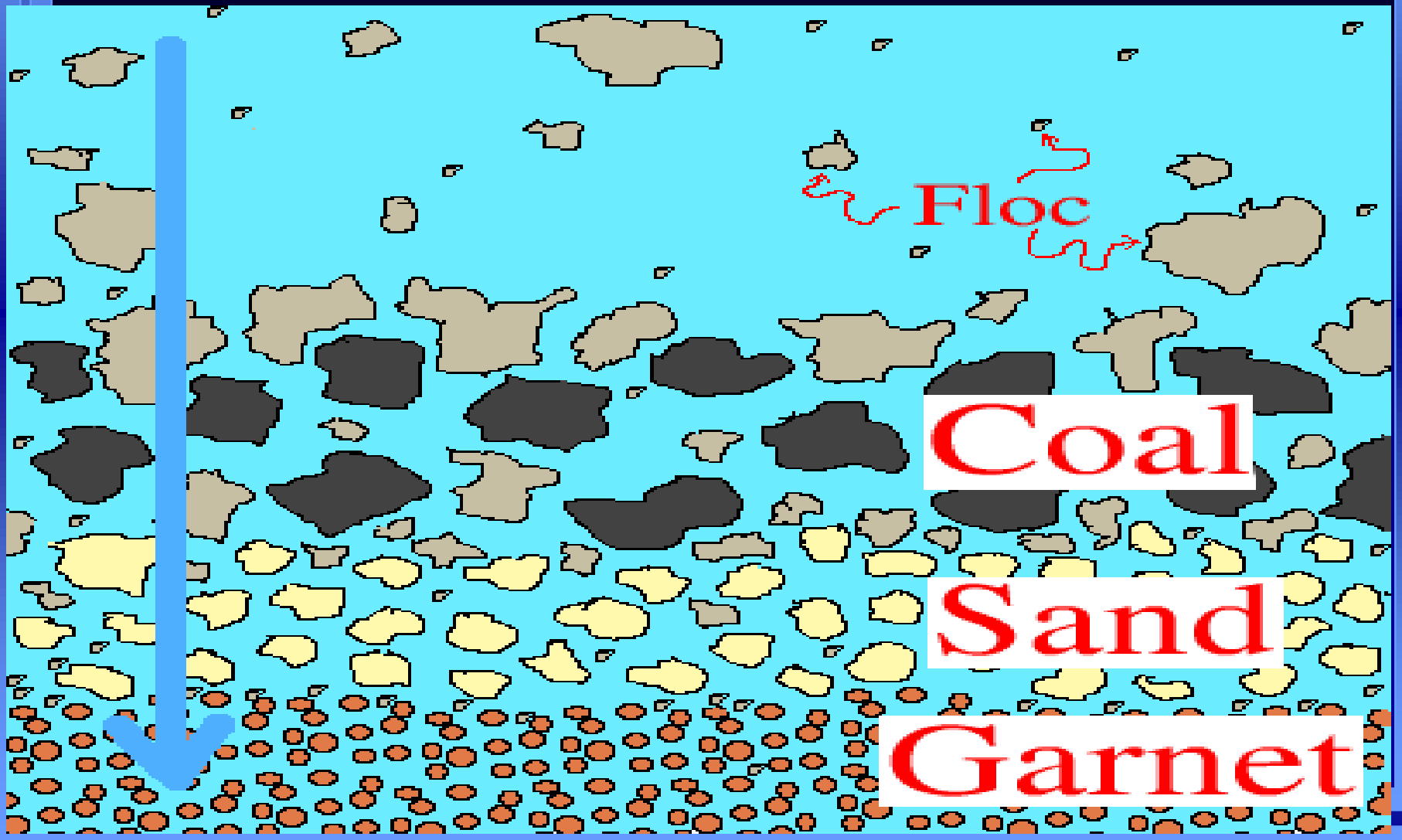
- Pressure filters are of the same construction as gravity-type filters but the filter bed together with the filter bottom is enclosed in a watertight steel pressure vessel. The driving force for the filtration process here is the water pressure applied on the filter bed.
- Pressure filters are commercially available as complete units. They are not so easy to install, operate and maintain, particularly as it is not readily possible to inspect the condition of the media.

- For this reason they are not very well suited for application in small treatment plants in developing countries.
- **Pressure applied is 3 to 7 kg/cm^2**
- **Dia. For verticals – 2 to 2.5 m**

For horizontals – 2.5 to 8 m

- **Rate of filtration 6000 to 15000 lit/m^2/hr**

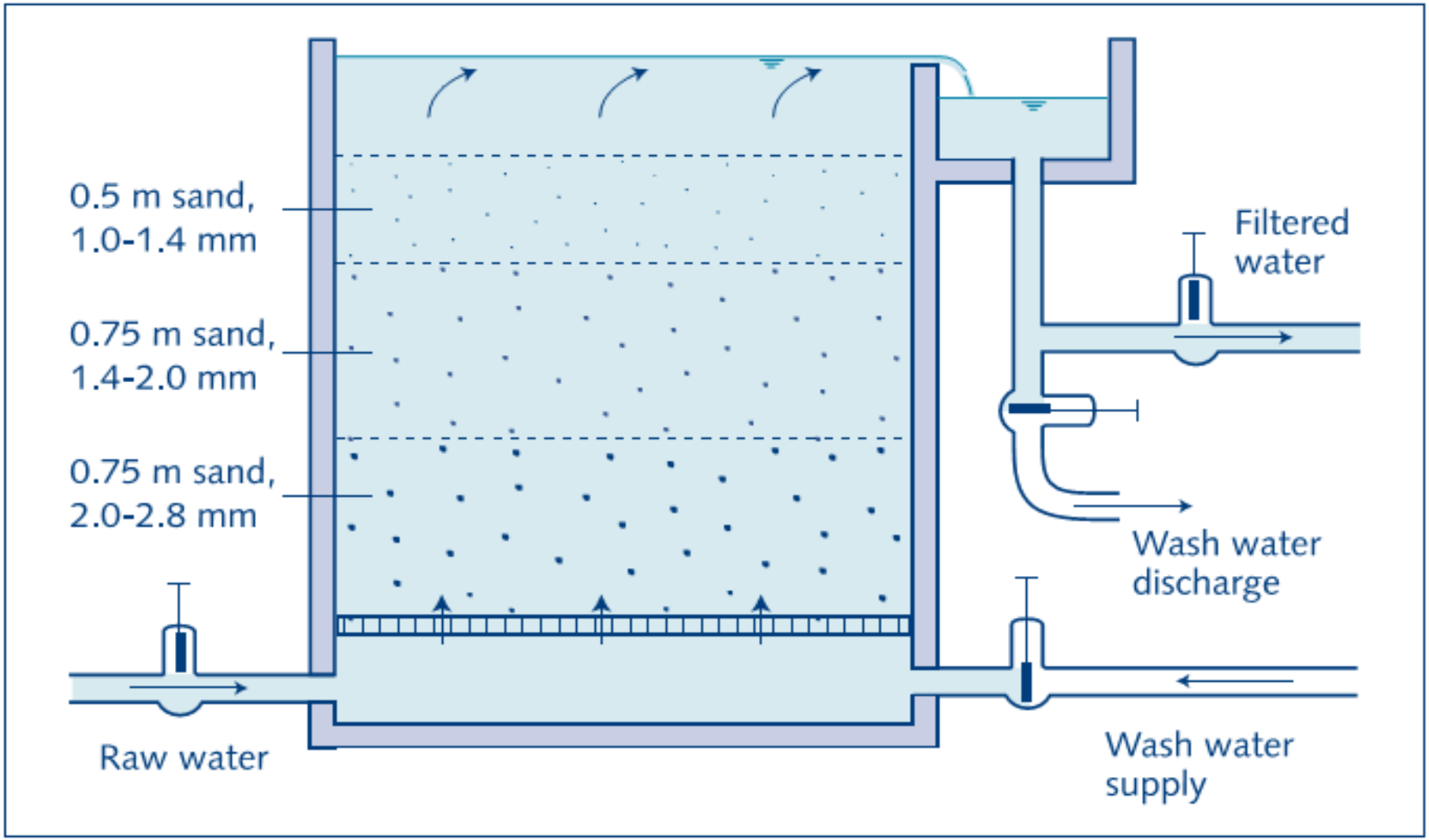
Dual and Multimedia filter



- The media in a dual or multi-media filter are arranged so that the water moves through media with progressively smaller pores. The largest particles are strained out by the anthracite.
- Then the sand and garnet trap the rest of the particulate matter though a combination of adhesion and straining. Since the particles in the water are filtered out at various depths in a dual or multi-media filter, the filter does not clog as quickly as if all of the particles were all caught by the top layer.

- The media in a dual or multi-media filter must have varying density as well as varying pore size so that they will sort back into the correct layering arrangement after backwashing.
- Anthracite coal is a very light (low density) coal which will settle slowly, ending up as the top layer of the filter.
- Garnet is a very dense sand which will settle quickly to the bottom of the filter.

Upflow filter



DIFFERENCE BETWEEN SSF AND RSF

Item	Slow sand Filter	Rapid sand Filter
Rate of filtration	100 to 200 lit/m^2/hr	3000 to 6000 lit/m^2/hr
Loss of head	15 cm initial to 100 cm final	30 cm initial to 3 m final
Surface area	large	small
Coagulation	Not required	required

Filter media of sand	Effective size – 0.2 to 0.35 and C_u = 2 to 3 Depth – 105 cm	Effective size – 0.35 to 0.60 and C_u = 1.2 to 1.7 Depth – 75 cm
Base material of Gravel	Size – 3 to 65 mm Depth – 30 to 75 cm	Size – 3 to 40 mm Depth – 60 to 90 cm
Under drainage system	Split tile laterals or perforated pipe laterals	Perforated of laterals with nozzles or strainer system
Method of cleaning	Scrapping of top layer 15 to 25 mm	Backwashing with compressed air and water
Amount of wash water	0.2 to 0.6 % of filtered water	2 to 4 % of filtered water

Period of cleaning	1 to 2 months	2 to 3 days (24 hrs usually)
Penetration of SS	Superficial	Deep
Further treatment needed	Chlorination	Chlorination
Efficiency	Very efficient in bacterial removal but can not remove colour and turbidity	Less bacterial removal efficiency but can remove colour and turbidity
Economy	High initial cost	Less initial cost

Flexibility	Not flexible in meeting variations in demand	Quite flexible in meeting variations in demand
Skilled supervision	Not required	Required as it involves backwashing
Depreciation cost	Relatively low	Relatively high

Objective Questions

1. Cleaning interval for RSF is _____. (3-4 months / 6 to 8 months / 1-2 yrs / 24 hrs).
2. For slow sand filters period of cleaning is _____. (1 to 2 days /1 to 2 yrs /1 to 2 months/no cleaning is required)
3. _____ type of filter requires large area. (Slow sand / rapid sand / Vaccume / none of these)
4. In case of RSF _____ formula is used for estimation of sand depth. (Hudson's / Chezy's / Manning's / Hardy's)

Theory Questions

Q1. Explain slow sand filter with respect to

i. Enclosure tank
ii. Filter media
iii. Under drainage system
iv. Appurentenances

Q2. Explain slow sand filter with respect to

i. Enclosure tank
ii. Filter media
iii. Gravel Bed (Base material)
iv. Under drainage system

Q3. Explain theory of filtration. OR Discuss mechanisms involved in filtration process

Q4. Write short notes on

i. Backwashing of filter
ii. Head loss and Negative head (Diagram needed)
iii. Filter troubles

Q5. Differentiate between Slow sand and Rapid sand filter

Q6. Give design parameters for rapid sand filter.

Q7. Explain ‘Upflow filter’ with neat sketch.

Q8. Explain with sketch ‘Pressure filter’.

Q9. Explain working of

i. Slow sand filter

ii. Rapid sand filter