

Chapter-V

Filtration

1. Theory of Filtration

2. Types of Filters

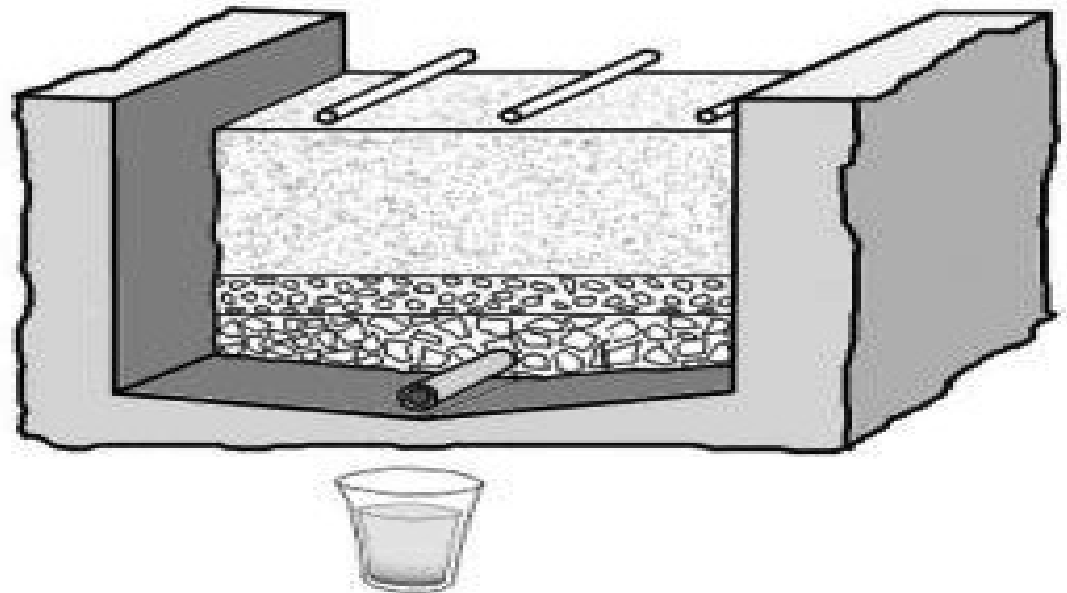
- **Slow Sand Filter**
- **Rapid Sand Filter**

1. Theory of Filtration

- ❑ The effluent obtained after **coagulation-flocculation** process does not satisfy the drinking water standards and is **not safe**. So it requires **further treatment**.
- ❑ **Filtration is one of Purification process** whereby water to be treated is passed through a **porous medium**
- ❑ **Removal of suspended** and colloidal particles from the water by passing it through a **layer or bed** of a porous granular material, such as **sand**
- ❑ Assist significantly by reducing the **load** on the **disinfections process**, increasing disinfection efficiency

Con...

- During the passage of water through sand, the following **effects** take place:-
 - Suspended matter and colloidal matter are removed
 - Chemical characteristic of water get changed
 - Number of bacteria considerably reduced



Mechanism of Filtration

Overall **removal of impurities** which is associated with the process of **filtration** is mostly brought by combination of:-

- **Mechanical straining:**

- Passing the water through a filter in which the pores are smaller than the particles to be removed

- **Floc are captured** and the water is able to flow through



floc particles behind

Con...

- **Sedimentation and Adsorption:**



Adsorption:

- Gathering of gas, liquid, or dissolved solids onto the surface of another
- Soaking up of one substance into the body of another substance
- The particles stick on the grains, gelatinous coating formed on sand grains

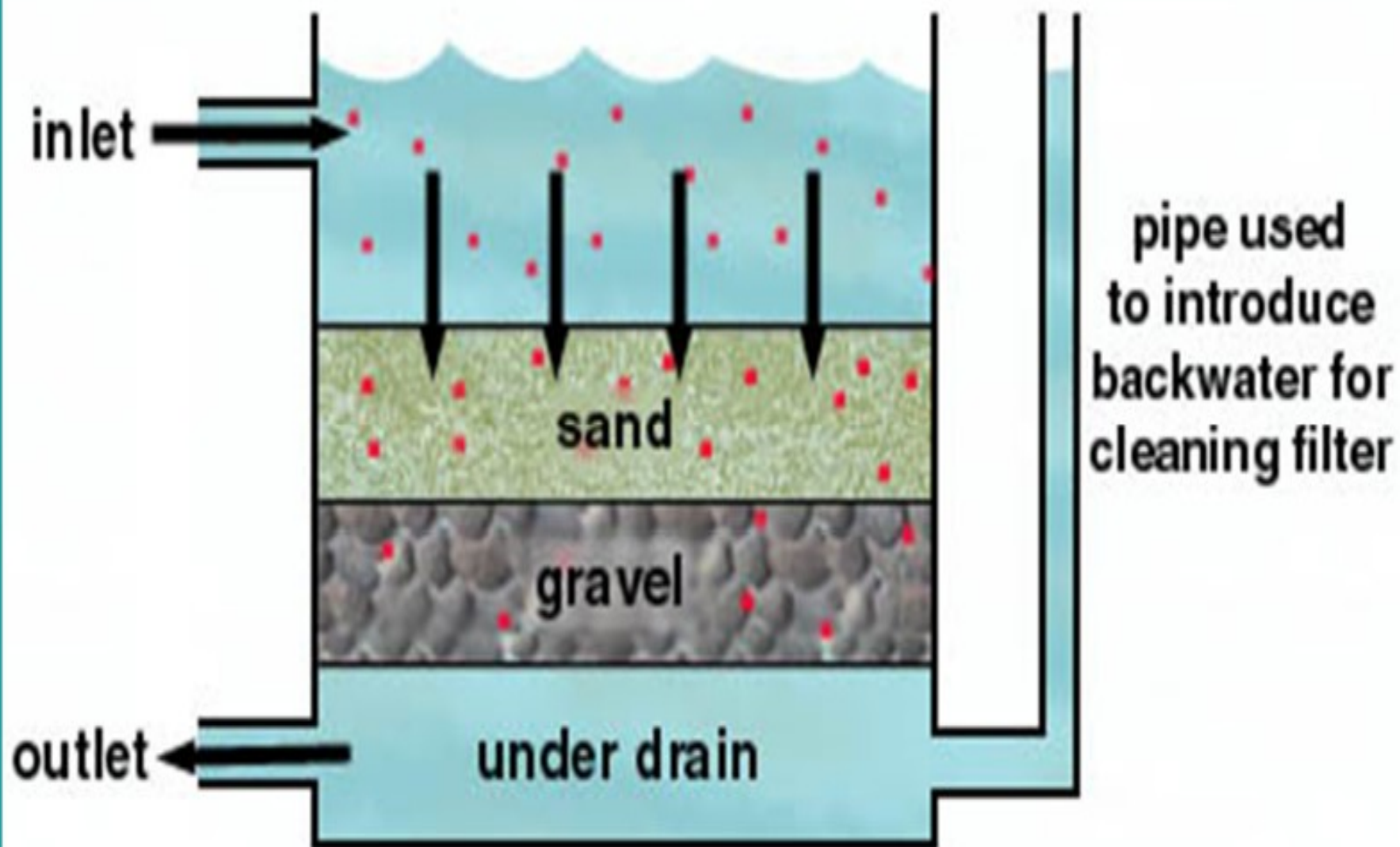
Sedimentation

- Interstices b/n sand grains act as sedimentation basins
- Suspended particles smaller than voids in the filter-bed settle upon the sides of the sand grains

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- **Electrolytic action:** Due to the friction between medium and suspended solids, certain amount of dissolved and suspended matter is ionized. Suspended matter in water is ionized, carries charge of one polarity and the particles of sand in filter which are also ionized, possess electrical charges of opposite polarity. These neutralize each other; change the chemical character of water.
- **Biological Action :** The growth and life process of the living cells, biological metabolism. The surface layer gets coated with a film in which the bacterial activities are the highest and which feed on the organic impurities. The bacteria convert organic impurities by a complex biochemical action into simple, harmless compounds – purification of water

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2. Types of Filters

- **Two** types of filter:

1. **Gravity** filter system

- Slow Sand Filter (SSF)
- Rapid Sand Filter (RSF)

2. **Pressure** filter system

- Water passes through the sand bed under pressure



RATE OF FILTRATION

Rate of filtration (loading rate) is the flow rate of water applied per unit area of the filter. It is the velocity of the water approaching the face of the filter:

$$v_a = \frac{Q}{A_s}$$

where v_a = face velocity, m/d = loading rate, $\text{m}^3/\text{d} \cdot \text{m}^2$

Q = flow rate onto filter surface, m^3/d

A_s = surface area of filter, m^2



A. Slow Sand Filter

- Purification process when water is passed through a porous medium (usually sand) its quality improves by:-
 - Reduction no of **micro-organisms** (bacteria, viruses, cysts)
 - Removal of **suspended and colloidal** matter
 - Change in its **chemical composition**
- Removes particles from water through **adsorption** and **straining**
- Water is allowed at **a slow rate** through a bed of sand, so that coarse suspended solids are **retained on/near surface** of the bed
- **Very effective** for removing flocs containing microorganisms such as **algae, bacteria, virus**, etc

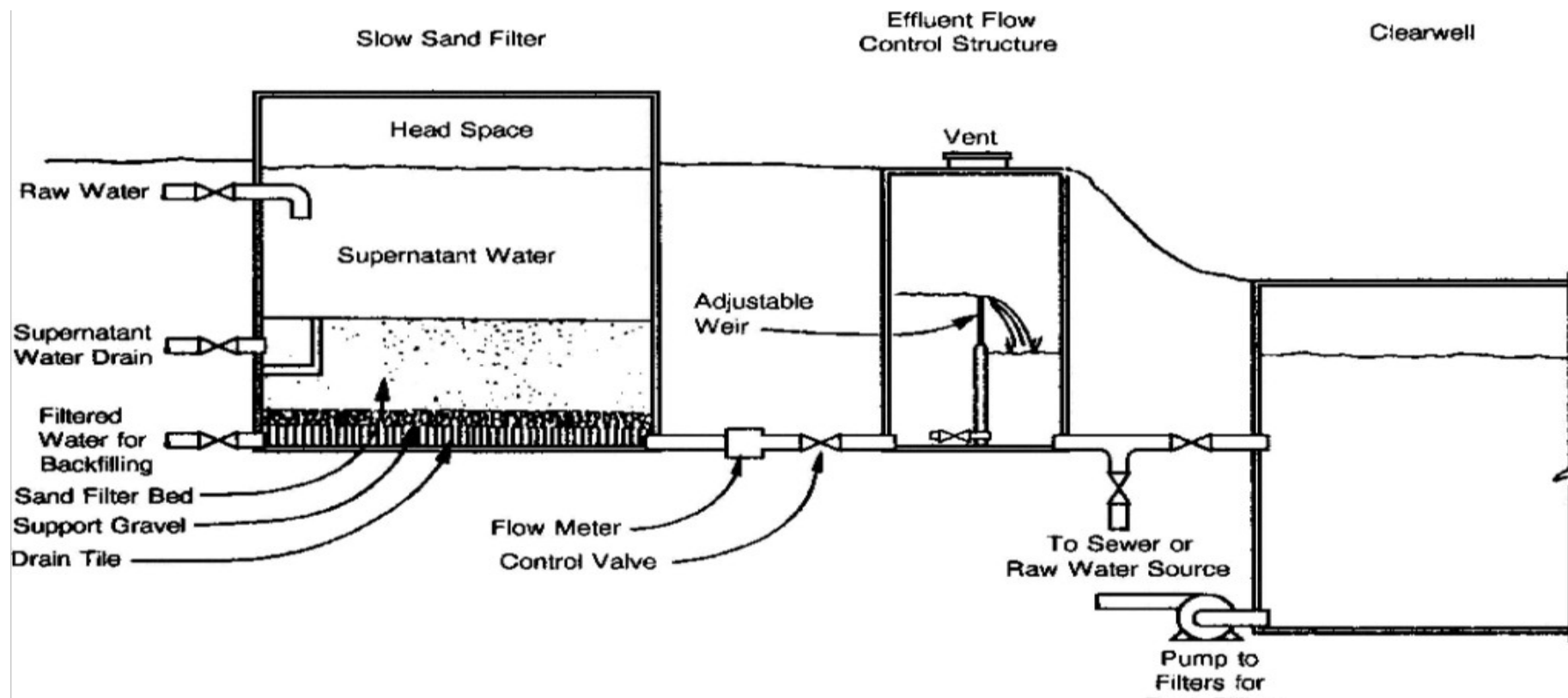
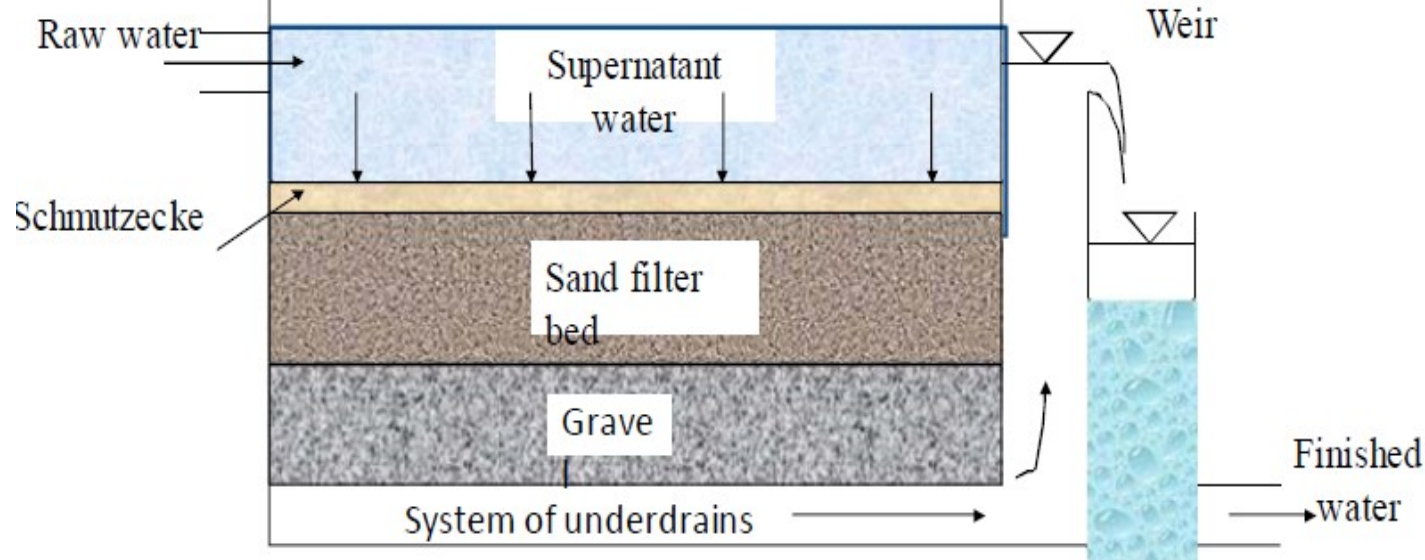
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✓ **Schmutzdecke:**

- **Gelatinous slimes** of bacterial growth on surface in the upper sand layer
- **Layer of dirt, debris, & microorganisms** builds up on top of the sand
- Breaks down organic particles in the water biologically & is also **very effective in straining out** even very small inorganic particles from water
- Underlying sand provides the support medium for this biological treatment layer
- Consumes and adsorbs/absorbs organic contaminants

Basic Elements of SSF

- Consists of a box containing a supernatant water layer, a bed of filter medium, an under draining system and a set of filter regulation and control accessories. The latter includes:-
 - The raw water **inlet valve**
 - The scum and **overflow facility**
 - Supernatant **drainage valve**
 - Filter **drainage valve**
 - The filtration rate regulation valve
 - **Valve for backfilling** clean water in the filter bed
 - Valve which allows the filtrate to go to storage reservoirs /distribution mains
 - Valve which allows wastage of water during the ripening stage of the filter bed
- SSF are best suited for the filtration of water for **small towns**



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Advantages

- Simple to construct and supervise
- Suitable where sand is readily available
- Effective in bacterial removal
- Preferable for uniform quality of treated water

Disadvantages

- Large area is required
- Unsuitable for treating highly turbid waters
- Less flexibility in operation due to seasonal variations in raw water quality

Design Criteria

Parameter	Recommended level (UK experience)
Design life	10-15 year
Period of operation	24 h/day
Filtration rate	0.1 – 0.2 m/h
Filter bed area	5-200 m ² /filter (minimum of two filters)
Height of filter bed	
Initial	0.8-0.9 m
Minimum	0.5-0.6 m
Effective size	0.15-0.3 mm
Uniformity coefficient	< 3
Height of underdrains + gravel layer	0.3-0.5 m
Height of supernatant water	1 m

CLEANING SLOW SAND FILTERS

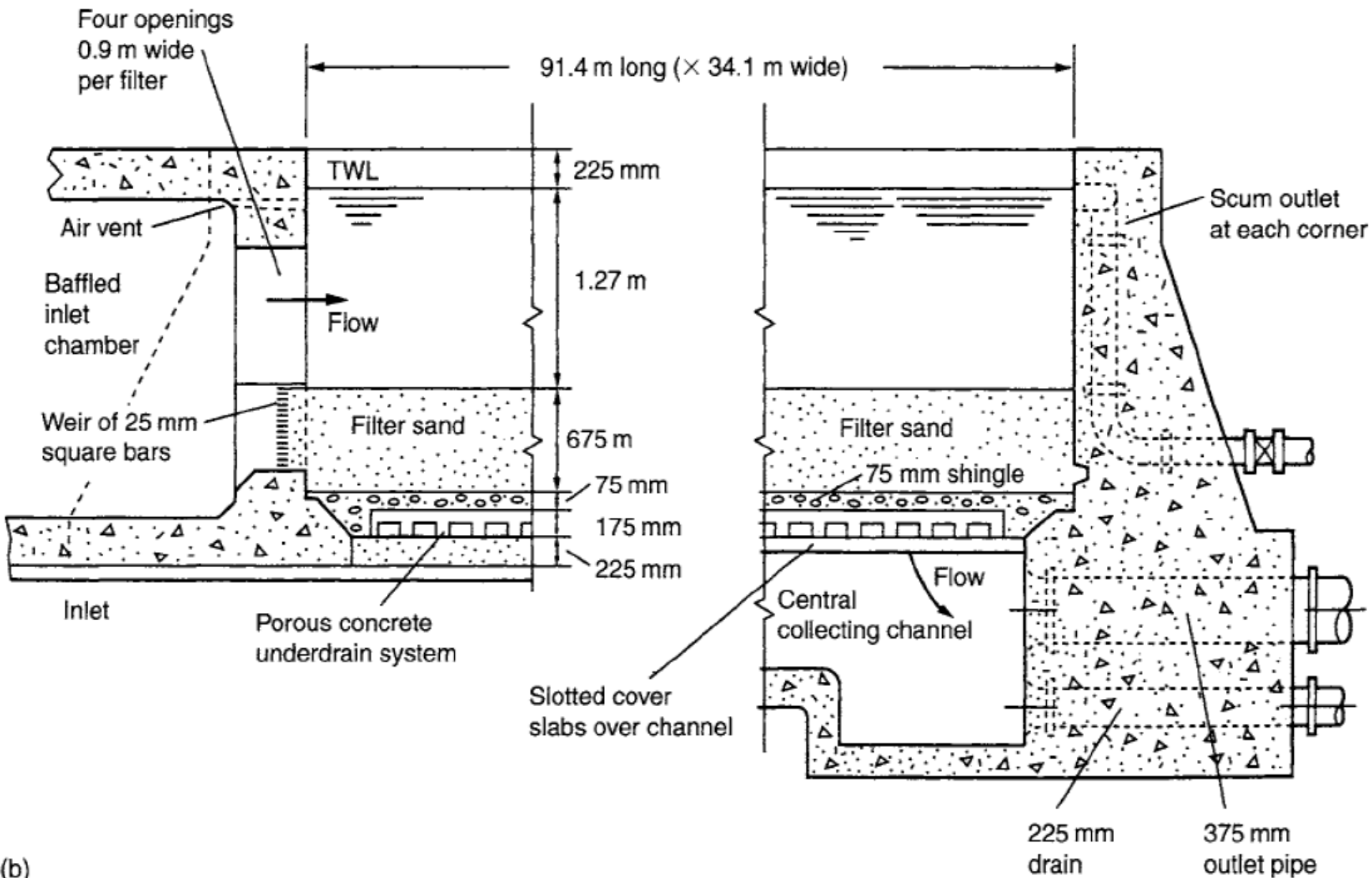
- **Scrapping:**

- The **top few mm of sand** is carefully **scraped off** using mechanical plant
- Water is then **decanted back** into the filter and recirculated for a few hours to allow a new ***Schmutzdecke*** to develop
- The filter is then filled to full depth and brought back into service

- **Wet harrowing:**

- Lower the water level to just above the **Schmutzdecke**, stirring the sand and thereby **suspending any solids** held in that layer and then **running the water to waste**
- The filter is then **filled to full depth** and brought back into service

Construction



B. Rapid Sand Filter

- The most **common type** of filter for treating municipal water supplies
- During filtration, the water flows downward through the bed under the force of **gravity**
- When the **filter is washed, clean water is forced upward**, expanding the filter bed slightly and **carrying away the accumulated impurities** □ **backwashing**

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✓ **RSF as opposed to SSF is usually applicable in circumstances:-**

- In case of **limited space** availability (RSF require about 10-50 time less filter surface area than SSF)
- In case of direct filtration of **high turbidity raw** waters (filter inlets containing greater than 40-50 mg/l suspended solids) since RSF can handle higher particle loads than SSF and hence have shorter filter runtimes (1-2 days)
- Where excessive **algal growth** in the **supernatant** of SSF might be expected to cause serious operating problems
- Where **decomposition** of organics is not required
- Major difference b/n SSF & RSF is the principle of operation – the **speed or rate** at which water passes through the media

ADVANTAGES AND DISADVANTAGES

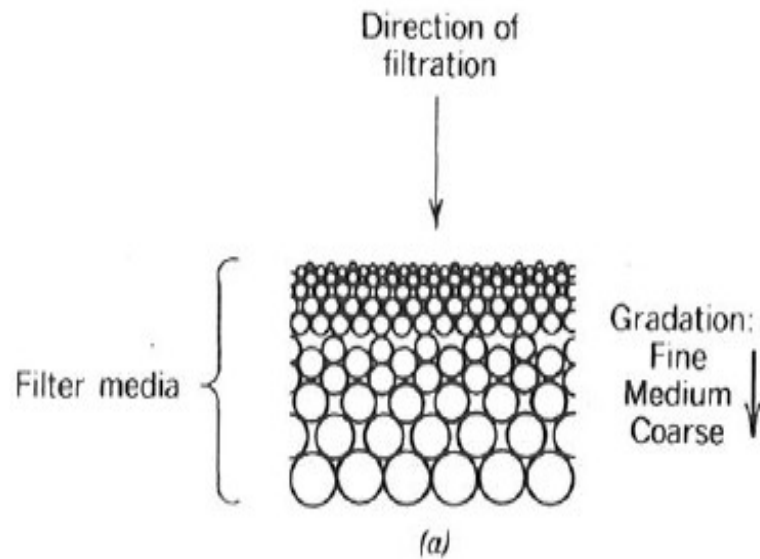
○ *Advantages*

- Turbid water may be treated
- Land required is less compared to slow sand filter
- Operation is continuous.

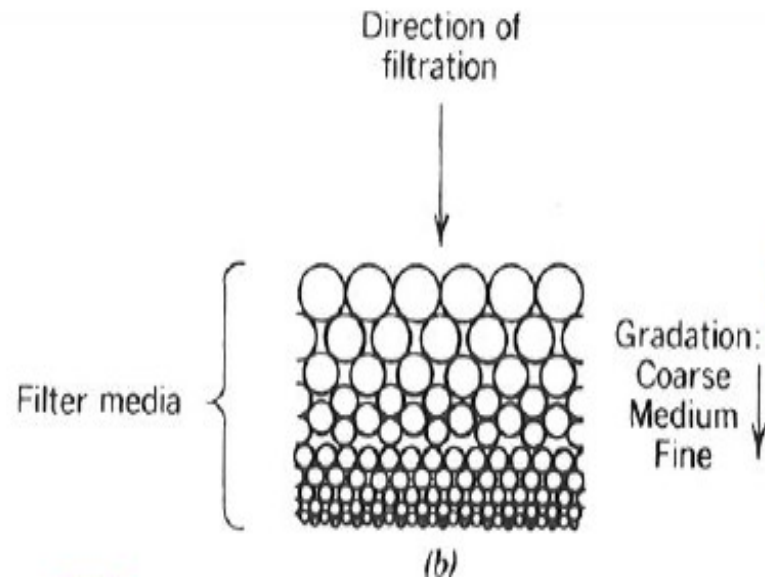
○ *Disadvantages*

- Requires skilled personnel for operation and maintenance
- Less effective in bacteria removal
- Operational troubles

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after backwashing, the larger sand grains settle to the bottom first, leaving the smaller sand grains at the filter surface.



Allows in-depth filtration:
provides more storage space for the solids, offer less resistance to flow, and allows longer filter runs.

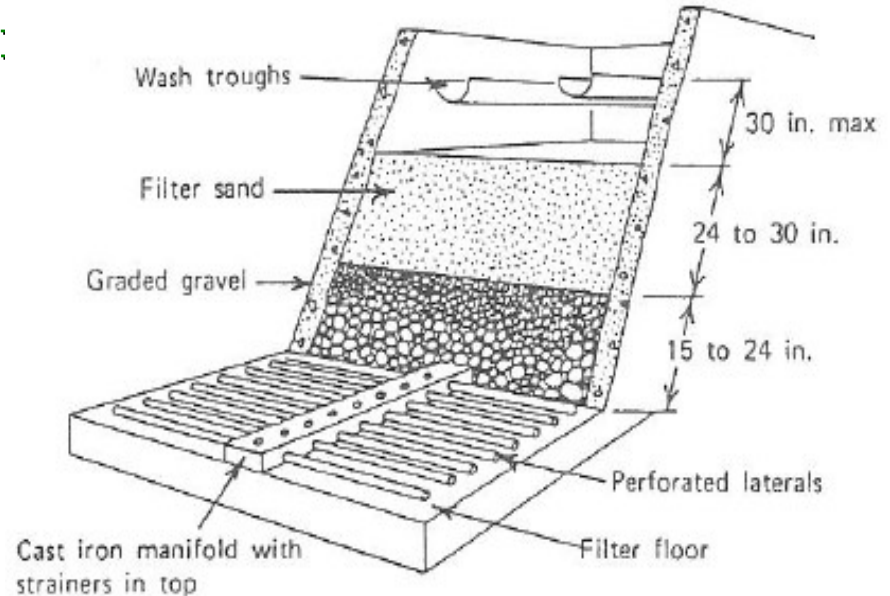
Con...

✓ **RSF based on filter material, three types:**

- **Single-media filters:** these have **one type** of media, usually **sand** or **crushed anthracite coal**
- **Dual-media filters:** these have two types of media, usually crushed anthracite coal and sand
- **Multi-media filters:** these have three types of media, usually crushed anthracite coal, sand, and garnet

Cleaning Rapid sand Filter:

Backwashing: Conditions



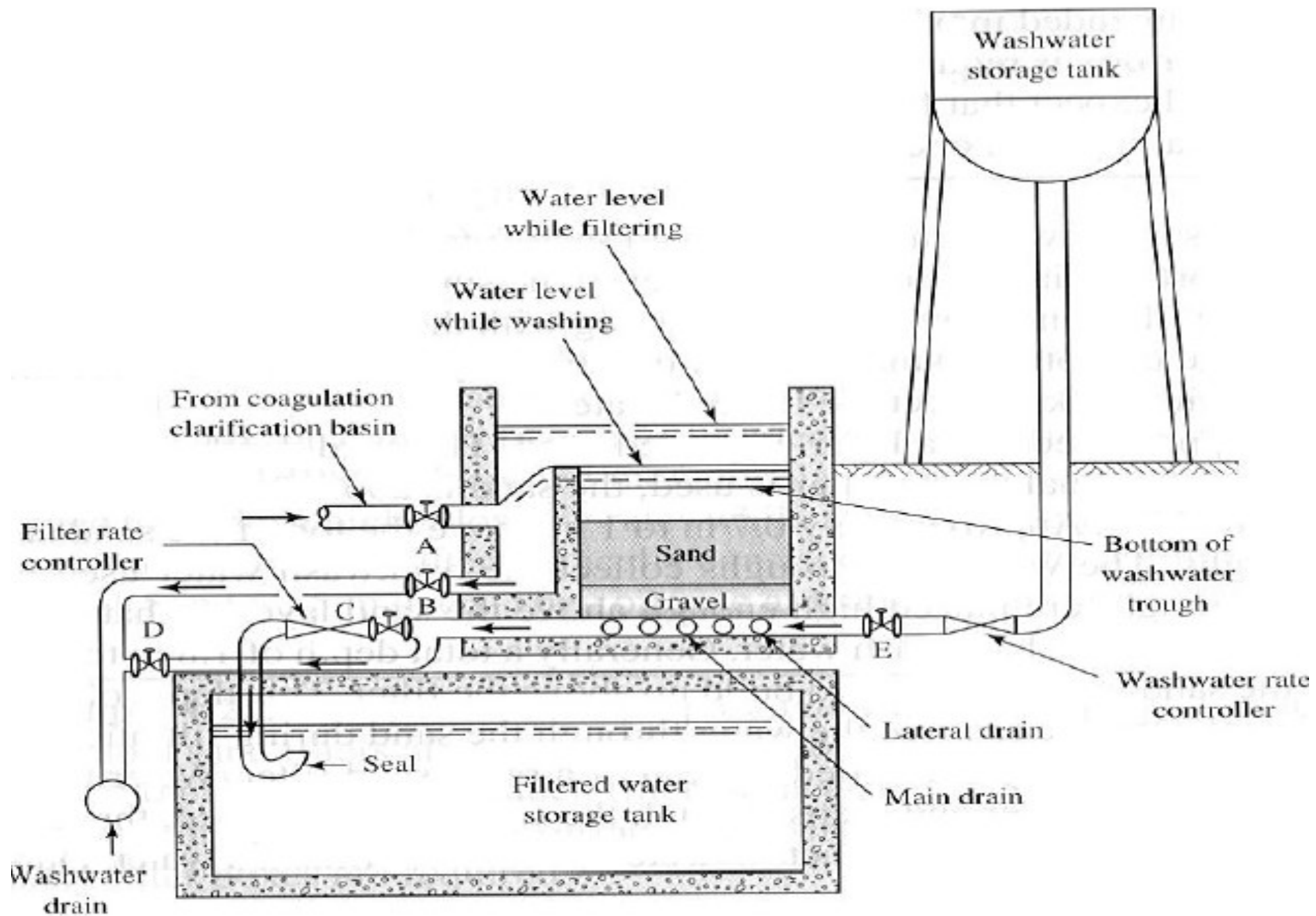
- **Head loss** is so high, filter no longer produces water at the desired rate
- Floc starts to break through the filter & turbidity in the filter effluent increases
- A filter run reaches a given hour of operation
- If a filter is taken out of service for some reason, prior to being put back on-line
- Filter backwash rate has to be great enough to **expand & agitate** the filter media & suspend the flocs in the water for removal
- If the filter backwash rate is too high, media will be washed from the filter into the troughs and out of the filter

Design Criteria

The main features of rapid sand filter are as follows

Effective size of sand	- 0.45 to 0.70mm
Uniformity coefficient of sand	- 1.2 to 1.7
Depth of sand	- 60 to 75cm
Filter gravel	- 2 to 50mm size (Increase size towards bottom)
Depth of gravel	- 45cm
Depth of water over sand during filtration	- 1 to 2m
Overall depth of filter including 0.5m free board	- 2.5m
Area of single filter unit	- 100m ² in two parts of each 50m ²
Loss of head	- Max 1.8 to 2.0m
Turbidity of filtered water	- 1 NTU

Construction



Comparison of SSF and RSF

Sl.No.	ITEM	S.S.F	R.S.F
1.	Area	Need very large area	Needs small area
2.	Raw Water Turbidity	Not more than 30 NTU	Not more than 10NTU hence needs coagulation
3.	Sand Media	Effective size 0.2 to 0.3 mm uniformity coefficient 2 to 3 single layer of uniform size	Effective size 0.45 to 0.7 mm uniformity coefficient 1.3 to 1.7 multiple graded layers of sand.
4.	Rate of Filtration	2.4 to 3.6m ³ /m ² /day	100-150 m ³ /m ² /day
5.	Loss of Head	0.6m to 0.7 m	1.8m to 2.0m
6.	Supervision	No skilled supervision is required	Skilled supervision is required
7.	Cleaning of Filter	Scraping of 21/2cm thick layer washing and replacing. Cleaning interval that is replacement of sand at 1 to 2 months.	Back wash with clean water under pressure to detach the dirt on the sand. Backwashing daily or on alternate days.
8.	Efficiency	Bacterial removal, taste, odour, colour and turbidity removal.	There is no removal of bacteria. Removal colour taste, odour and turbidity is good.

No	Parameter	SSF	RSF
1	Filter loading or filtration rate (m/s)*10 ⁻³	0.03-0.15	5-15
2	Detention time	Several hours	A few minutes
3	Filter material	D10 = 0.15-0.35mm Uc ≤ 2-3 Only relatively fine media used, usually sand	D10= 0.5-2mm Sand, anthracite, coal, magnetite, plastics, coconut fibers.
4	Filter depth	0.6-1.5m	0.5-2.0m
5	Filter run	1-12 months	1-3 days
6	Major impurity removal mechanism	All five mechanisms	Adsorption. Sedimentation and chemical action
7	Method of cleaning filter bed	Skimming off 2-3 cm of sand	Backwashing (water/air) in reverse direction to normal flow
8	Equipment and accessories	Few, simple	Many and sophisticated
9	Construction cost	High	low
10	Land requirement	Large	Small (20% of SSF)
11	Operational cost	Very low	high
12	Level of sophistication	Low, therefore feasible for construction and operation by locally trained manpower	Very high, it requires importation of many equipments and use of high skills in operation
13	Purpose	Sole treatment or final filtration step	Sole treatment. Pre or final filtration step

Example-1

10 MLD of water after secondary sedimentation (average turbidity: 10 NTU) is to be filtered through a battery of rapid sand filters to reduce water turbidity to < 2.5 NTU. Based on pilot plant studies, it was determined that 60 cm filter beds of sand (0.5 mm average sand diameter) were suitable for this purpose. It was further determined that such beds could be operated for 7.5 hours at a filtration rate of $10 \text{ m}^3/\text{m}^2/\text{hr}$ before the terminal head-loss of 3 m was reached. Filter backwashing rate was $1 \text{ m}^3/\text{m}^2/\text{min}$ and the backwash time was 5 minutes. A filter unit will be off-line for 30 minutes during each backwash operation. Based on this information, determine the numbers of filter units to be provided and dimensions of each unit. Determine how much filtered water is required for backwashing each day and hence determine the filtered water production per day.

Example-2

Determine the percentage of filtered water required for wash water based on the following criteria:

- Flow, $Q_f = 250 \text{ L/s}$
- Rate of filtration, $v_{of} = 150 \text{ m}^3/\text{m}^2.\text{day}$
- Time of washing = 10 min/24 hr
- Rate of washing, $v_{oBW} = 15 \text{ mm/s}$