CE 370

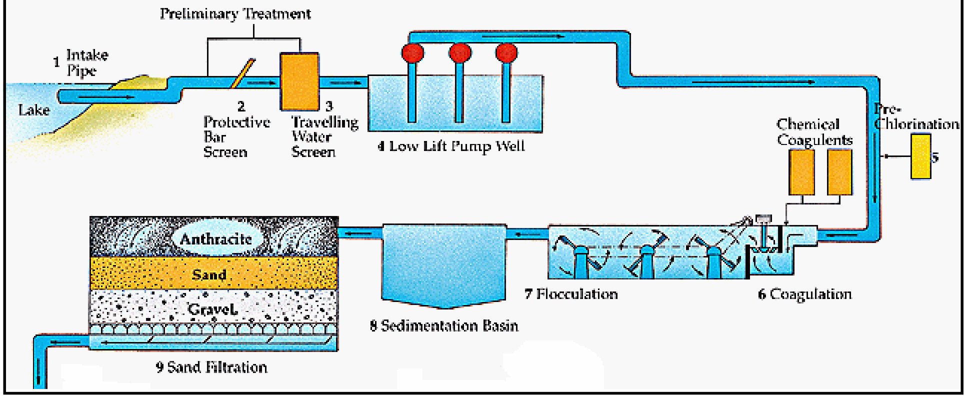
Filtration

1

Overview of the Process

➢Location in the Treatment Plant

- After the water has been settled, some fine solids/flocs may still be in suspension, therefore, removal of these fine solids can be achieved by filtration. Filtration follows sedimentation.



Definition and Objective

Filtration is a solid-liquid separation where the liquid passes through a porous medium to remove fine suspended solids.

The main objective of filtration is to produce high-quality drinking water (surface water) or high-quality effluent (wastewater)

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Uses

- Water Treatment
  - To filter chemically coagulated water
  - Settled water
- Wastewater Treatment
  - Untreated secondary effluent
  - Chemically treated secondary effluent
  - Chemically treated raw wastewater

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Classifications of Filters

- Single-medium filters (used in water)
  - Have one type of medium
  - Medium usually sand or crushed anthracite coal
- Dual-medium filters (used in water and wastewater)
  - Have two types of media
  - Usually crushed anthracite and sand
- Multi-media filters (used in water and wastewater)
  - Have three types of media
  - Usually crushed anthracite, sand, and garnet

Single-Medium Filters

- Types
  - Gravity filters (most common)
  - Vacuum filters
- Medium
  - Sand (water treatment)
  - Anthracite (tertiary treatment)
  - Sand bed is 610 to 760 mm in depth
  - Underlaying anthracite is 380 to 610 mm in depth

Single-Medium Filters

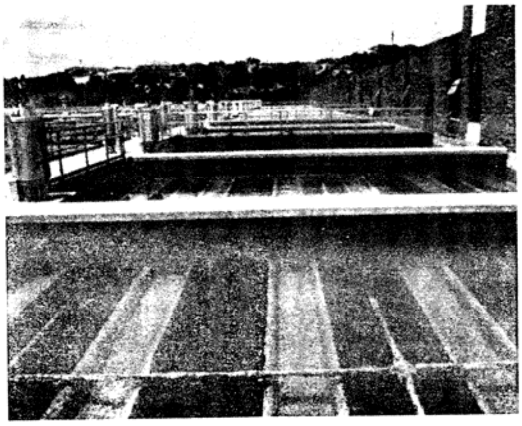

FIGURE 10.1
Row of Rapid Sand Filters at a Water Treatment Plant

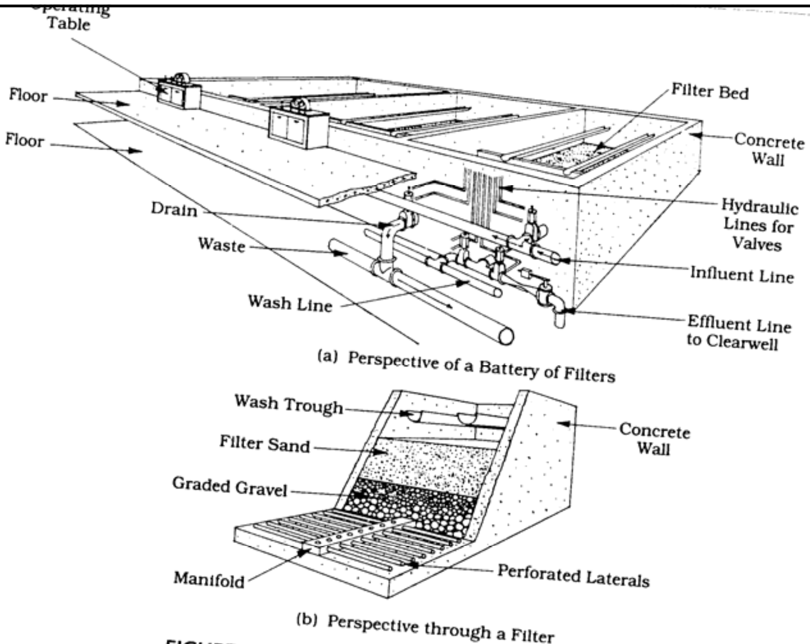

FIGURE 10.2 *Gravity Filters and Accessories*
Courtesy of the National Lime Association.

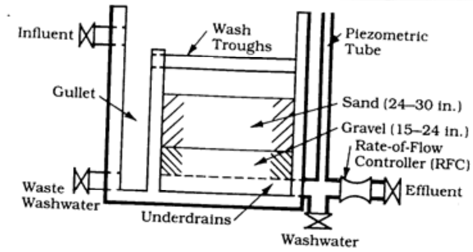

FIGURE 10.3
Section through a Rapid Sand Filter

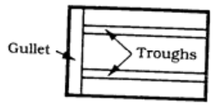

FIGURE 10.4
Wash System Layout

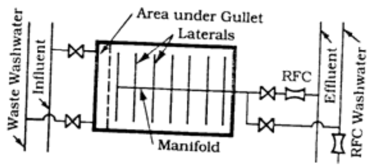

FIGURE 10.5
Filter Piping Layout

Single-Medium Filters

FIGURE 10.15
Layout and Underdrains for a Single Filter

FIGURE 10.16
Layout and Underdrains for a Double Filter

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Single-Medium Filters

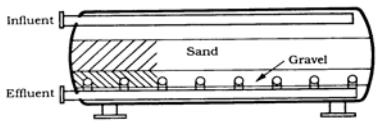

FIGURE 10.7 *Profile through a Horizontal Pressure Filter*

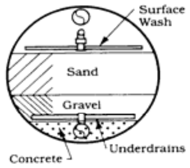

FIGURE 10.8 *Cross Section through a Horizontal Pressure Filter*

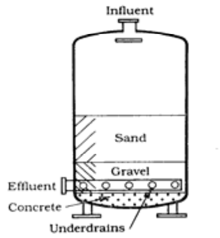

FIGURE 10.9 *Cross Section through a Vertical Pressure Filter*

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Filtration Cycle

- Water level is 0.91 to 1.2 m above sand
- Water passes downward through the media
- Water passes into the underdrain system
- Flow of filtered water flow is controlled by the rate of flow controller (RFC)
- Influent and effluent valves are open
- Washwater and waste washwater valves are closed

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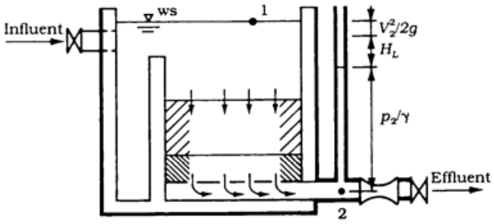

FIGURE 10.11 *Schematic Section Showing a Filter during Filtration*

Mechanisms of Particle Removal

- Surface Removal
  - Particles larger than the pore size of the medium
  - Cake layer is formed
- Depth Removal (most important in water treatment)

Mechanisms of Particle Removal

- Adhesion
  - Particles collide with sand surface and adhere to it
- Flocculation
  - Some particles may be brought together (flocculate) and become bigger
- Sedimentation
  - Flocculated flocs settle on sand particles
- Straining
  - Due to decrease in pore size of the medium

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Head loss

- Head loss is caused by accumulation of particles on top and within the depth of the filter
- Head loss through clean bed of porous media having relatively uniform diameter is given by Rose equation as the following equation:

$$h_L = \frac{1.067}{\phi}\frac{C_D}{g} D \frac{V_a^2}{\varepsilon^4}\frac{1}{d}$$

  - ϕ = shape factor
  - C_D = coefficient of drag
  - D = bed depth
  - ε = porosity
  - V_a = approach velocity
  - d = diameter of the particle

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Head loss

The coefficient of drag is given by:

$$C_D = \frac{24}{N_{\text{Re}}} \qquad \text{For } N_{Re} < 1 \qquad N_{\text{Re}} = \frac{\phi \rho d V_a}{\mu}$$

$$C_D = \frac{24}{N_{\text{Re}}} + \frac{3}{\sqrt{N_{\text{Re}}}} + 0.34 \qquad \text{For } N_{Re} > 1 \text{ but } < 10^4$$

- For beds with varying particle size, the Rose equation is:

$$h_L = \frac{1.067}{\phi} \frac{C_D}{g} D \frac{V_a^2}{\varepsilon^4} \sum \frac{x}{d}$$

where x = weight fraction of particle sizes

- For stratified beds with uniform velocity, the Rose equation is:

$$h_L = \frac{1.067}{\phi} \frac{D}{g} \frac{V_a^2}{\varepsilon^4} \sum \frac{C_D x}{d}$$

Study example 10.1 page 300

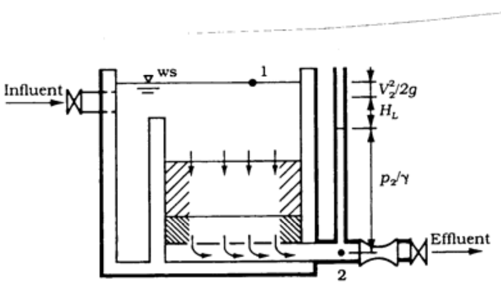

FIGURE 10.11 *Schematic Section Showing a Filter during Filtration*

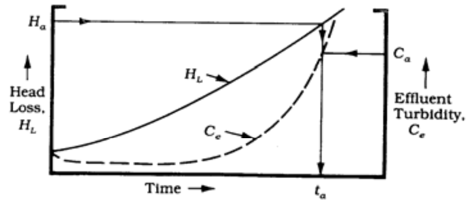

FIGURE 10.17 *Head Loss and Effluent Turbidity versus Filter Run Time for Optimum Performance*

Head loss

- Head loss of clean filter is 0.15 to 0.46 m
- As filtration progresses, head loss increases
- When head loss reaches 1.8 to 2.4 m, the filter is cleaned (backwashed)

Filtration Rate

- Standard filtration rate is 1.36 l/s-m^2 of filter bed
- Presently, rates between 1.36 to 3.40 l/s-m^2 are used
- Filters are run at
  - Constant filtration rate (most common)
  - Declining filtration rate
    - Longer running period
    - Better quality of effluent
    - Limited to medium to large plants

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Filter Dimensions

- Single filter
  - Length to width ratio is 1 : 1.5 to 1 : 2
- Double filter in one concrete basin
  - Almost square with length to width ratio of 1 : 1

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Backwash

- 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

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Backwash

- During backwash, the sand bed expands
- Bed expansion is between 20 to 50%
- Backwash flow is between 10.2 to 13.6 $l/s\text{-}m^2$
- Backwash continues till the waste washwater is relatively clear

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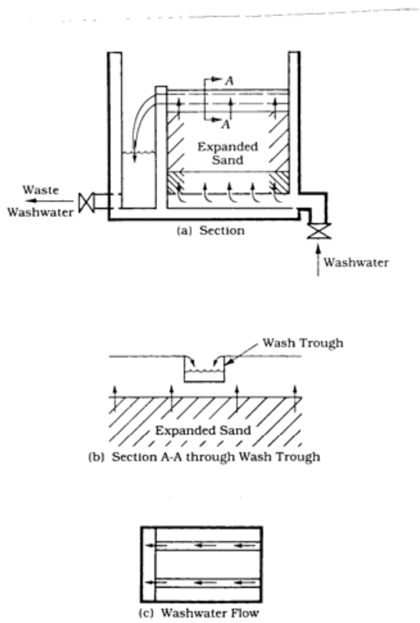

FIGURE 10.18 *Schematic Showing Filter during Backwashing*

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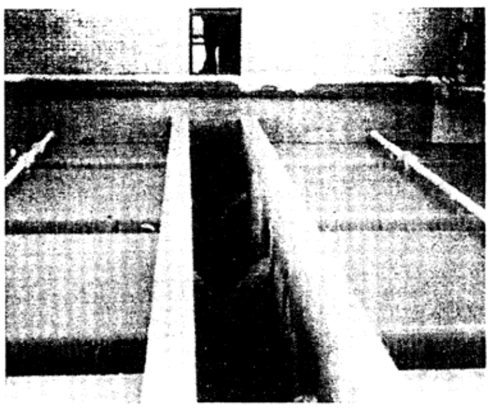

FIGURE 10.19 *Backwashing of Rapid Sand Filters at a Lime-Soda Softening Water Treatment Plant*

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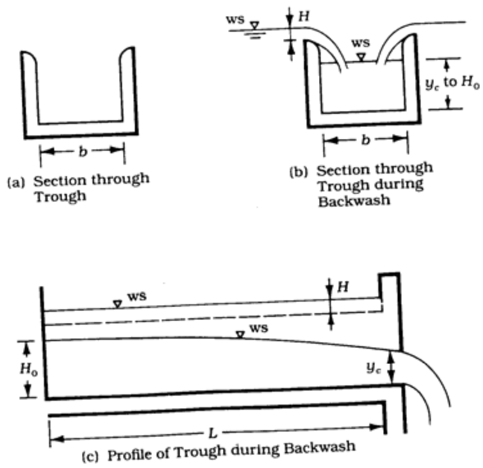

FIGURE 10.23
Wash Trough Details

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Operational Problems

- Mudballs
  - feed contains muddy floc or filter is not adequately backwashed
  - Can be controlled by surface wash
- Bed shrinkage
  - Sand particles are covered with slime coating
  - Can cause cracks of the bed surface and sides
- Air binding
  - Release of dissolved gases in water
  - May cause loss of sand during backwashing
  - Can be controlled by avoiding negative pressure

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Multimedia Filters

- Becoming popular in water treatment
- The main type of filters in tertiary and advanced treatments
- Advantages over single-medium filters:
  - Longer filtration runs
  - Higher filtration rates
  - Ability to filter water with higher turbidity or SS
- Advantages are due to:
  - Media particle size
  - Different specific gravities of the media
  - The media gradation

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Dual-Media Filters

- Consists of a layer of anthracite (18 - 24 inch) above a layer of sand (6 – 12 inch)
- Pore volume is higher than that in single filter
- Specific gravity of coal is 1.2 to 1.6
- Specific gravity of sand is 2.65
- Filtration rate is between 2 – 10 gal/min-ft^2
- Common filtration rates are 3-6 gal/min-ft^2

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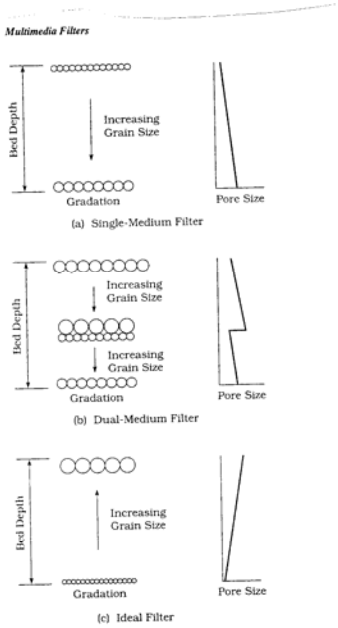

FIGURE 10.22 *Gradation and Pore Size in Various Filters*

Mixed-Media Filters

- Anthracite (1.2-1.6) followed by sand (2.65) followed by garnet (4.5) or ilmenite (4.5)
- During backwashing, there will be intermixing of the media
- There will be no distinct interface between the media layers after backwashing
- The filter approach the ideal filter (decrease in pore volume as depth increase)
- Filtration rate is 2-12 gal/min-ft^2 (3-6 gal/min-ft^2 are common)

Filtration in Water Treatment

- Slow sand filtration
  - Single-medium
  - San size 0.2 to 0.4 mm
  - Filtration rates of 0.05 to 0.15 gal/min-ft^2
  - Cleaned manually (every 4 to 6 weeks)
  - Needs large area and manual labors
  - Has been replaced by rapid sand filter

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Filtration in Water Treatment

- Rapid Sand Filter
  - Preceded by coagulation, flocculation, and sedimentation
  - Filtration rates between 3 to 5 gal/min-ft^2
  - Turbidity removal is 90 to 98%
  - Consist of coarse sand (in-depth filtration)
  - Sand beds are 24 to 30 inch thick
  - Sand effective size 0.35 to 0.70 mm
- Dual-media and mixed-media filters
  - Larger pore volume
  - Higher filtration rates
  - Longer running times
  - Less backwash water per unit volume of filtrate

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TABLE 10.5 *Single-Medium Filter Characteristics for Water Treatment*

CHARACTERISTIC	VALUE	
	Range	Typical
Sand medium:		
Depth		
in.	24–30	27
(mm)	(610–760)	(685)
Effective size, mm	0.35–0.70	0.60
Uniformity coefficient	<1.7	<1.7
Anthracite medium:		
Depth		
in.	24–30	27
(mm)	(610–760)	(685)
Effective size, mm	0.70–0.75	0.75
Uniformity coefficient	<1.75	<1.75
Filtration rate:		
gpm/ft^2	2–5	4
$(\ell/s\text{-}m^2)$	(1.36–3.40)	(2.72)

TABLE 10.6 *Dual-Media Filter Characteristics for Water Treatment*

CHARACTERISTIC	VALUE	
	Range	Typical
Anthracite:		
Depth		
in.	18–24	24
(mm)	(460–610)	(610)
Effective size, mm	0.9–1.1	1.0
Uniformity coefficient	1.6–1.8	1.7
Sand:		
Depth		
in.	6–8	6
(mm)	(150–205)	(150)
Effective size, mm	0.45–0.55	0.5
Uniformity coefficient	1.5–1.7	1.6
Filtration rate:		
gpm/ft^2	3–8	5
$(\ell/s\text{-}m^2)$	(2.04–5.44)	(3.40)

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TABLE 10.7 *Mixed-Media Filter Characteristics for Water Treatment*

CHARACTERISTIC	VALUE Range	VALUE Typical
Anthracite:		
Depth		
in.	16.5–21	18
(mm)	(420–530)	(460)
Effective size, mm	0.95–1.0	1.0
Uniformity coefficient	1.55–1.75	<1.75
Sand:		
Depth		
in.	6–9	9
(mm)	(150–230)	(230)
Effective size, mm	0.45–0.55	0.50
Uniformity coefficient	1.5–1.65	1.60
Garnet:		
Depth		
in.	3–4.5	3
(mm)	(75–115)	(75)
Effective size, mm	0.20–0.35	0.20
Uniformity coefficient	1.6–2.0	<1.6
Filtration rate:		
gpm/ft^2	4–10	6
($\ell/s\text{-}m^2$)	(2.72–6.80)	(4.08)

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Filtration in Wastewater Treatment

- Used in advanced treatment
  - Secondary effluent
  - Chemically treated secondary effluent
  - Chemically treated primary or raw wastewater
  - Usually dual- or mixed media filters
  - Size of media is different from that used in water treatment
  - granules are larger to:
    - To keep the desired flow rate
    - To keep the desires storage volume for flocculated floc

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TABLE 10.8 *Dual-Media Filter Characteristics for Advanced or Tertiary Wastewater Treatment*

CHARACTERISTIC	VALUE Range	Typical
Anthracite:		
Depth		
in.	12–24	18
(mm)	(305–610)	(460)
Effective size, mm	0.8–2.0	1.2
Uniformity coefficient	1.3–1.8	1.6
Sand:		
Depth		
in.	6–12	12
(mm)	(150–305)	(305)
Effective size, mm	0.4–0.8	0.55
Uniformity coefficient	1.2–1.6	1.5
Filtration rate:		
gpm/ft^2	2–10	5
($\ell/s\text{-}m^2$)	(1.36–6.79)	(3.40)

Adapted from *Wastewater Engineering, Treatment, Disposal and Reuse*, 2nd ed., by Metcalf & Eddy, Inc. Copyright © 1979 by McGraw-Hill, Inc. Reprinted by permission.

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TABLE 10.9 *Multimedia or Mixed-Media Filter Characteristics for Advanced or Tertiary Wastewater Treatment*

CHARACTERISTIC	VALUE Range	Typical
Anthracite:		
Depth		
in.	8–20	16
(mm)	(205–510)	(405)
Effective size, mm	1.0–2.0	1.4
Uniformity coefficient	1.4–1.8	1.5
Sand:		
Depth		
in.	8–16	10
(mm)	(205–405)	(255)
Effective size, mm	0.4–0.8	0.5
Uniformity coefficient	1.3–1.8	1.6
Garnet:		
Depth		
in.	2–6	4
(mm)	(50–150)	(100)
Effective size, mm	0.2–0.6	0.3
Uniformity coefficient	1.5–1.8	1.6
Filtration rate:		
gpm/ft^2	2–10	5
($\ell/s\text{-}m^2$)	(1.36–6.79)	(3.40)

Adapted from *Wastewater Engineering: Treatment, Disposal and Reuse*, 2nd ed., by Metcalf & Eddy, Inc. Copyright © 1979 by McGraw-Hill, Inc. Reprinted by permission.

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Filtration in Wastewater Treatment

- Filter performance is affected by:
  - Concentration of suspended solids
  - Floc strength (the ability to withstand shear force)
    - Biological flocs are stronger than chemical ones
- Untreated secondary effluent
  - Surface removal (primary filter action)
  - Excessive headloss terminates the run (not turbidity deterioration)
- Coagulated-flocculated secondary effluent
  - Depth removal (main filter action)
  - Turbidity deterioration terminates the run
  - Low headloss (3 to 6 ft)

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Filtration in Wastewater Treatment

- Filter aids are added to:
  - Strengthen the chemical floc
    - Allow higher filtration rates
    - Longer filter runs
- Operational problems
  - Buildup of microbial slime
    - Can be prevented by surface wash or air scouring
  - Encrustation of calcium carbonate
    - Occurs when high pH coagulation is used
    - Can be prevented by carbonation

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Filtration of Secondary Effluents

- Previous studies showed that:
  - Feed SS is 18.3 mg/l
  - SS removal is 66.2%
  - Filter run is 15.6 hours
  - Filtration rate is 3.7 gal/min-ft^2
  - Dual- and mixed-media filters were used
  - Mixed-media filters gave better results

TABLE 10.10 *Expected Effluent Suspended Solids versus Type of Secondary Treatment*

EFFLUENT	EFFLUENT SUSPENDED SOLIDS (mg/ℓ)
Extended aeration	1–5
Conventional activated sludge	3–10
Contact stabilization	6–15
Two-stage trickling filter	6–15
High-rate trickling filter	10–20

Filtration of Chemically Coagulated Effluents

- Previous studies showed that:
  - SS is 9.3 mg/l
  - SS removal of 74.2%
  - Filter run of 33.7 hours
  - Filtration rate of 3 gal/min-ft^2
  - Mixed-media filters gave better results

Filtration of Chemically Treated Primary or Raw Wastewater

- Previous studies showed that:
  - SS is 122 to 133 mg/l
  - SS removal of 73.0%
  - Filter run of 24 to 31 hours
  - Filtration rate of 3.3 gal/min-ft^2
  - Mixed-media filters gave better results

Upflow Filtration

- Flow is upward (from coarse to fine)
- Single-medium (sand)
- Bed fluidization can be avoided by:
  - Using deeper bed
  - Placing restraining grid on the top of the bed
- Air scouring is used during backwashing
- Mainly used in industrial and municipal wastewater treatment
- Filtration rate is 2 to 3 gal/min-ft^2
- Terminal headloss is 6 to 20 ft
- Design values are:
  - Bed depth is 60 inches (sand 2-3 mm) and 4 inches (sand of 10-15 mm)
  - Average feed SS of 17 mg/l
  - SS removal of 64.6%
  - Filtration rate of 2 to 5 gal/min-ft^2
  - Filter run of 7 to 150 hours

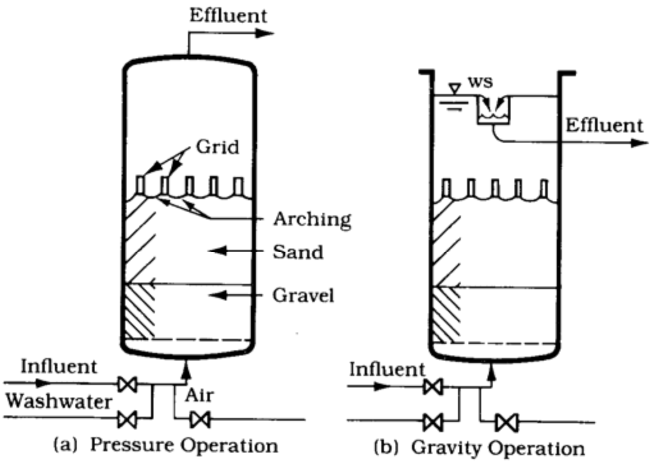

FIGURE 10.24 *Schematic of the Upflow Filter*