CE 370

Filtration

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).

Uses

- Water Treatment
  - To filter chemically coagulated water
  - Settled water

- Wastewater Treatment
  - Untreated secondary effluent
  - Chemically treated secondary effluent
  - Chemically treated raw wastewater
**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
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 10.2
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
**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
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:

\[
h_L = \frac{1.067 \, C_D \, D \, V_a^2}{\phi \, g \, \varepsilon^4 \, d}
\]

- \(\phi\) = shape factor
- \(C_D\) = coefficient of drag
- \(D\) = bed depth
- \(\varepsilon\) = porosity
- \(V_a\) = approach velocity
- \(d\) = diameter of the particle
Head loss

The coefficient of drag is given by:

\[ C_D = \frac{24}{N_{Re}} \quad \text{for } N_{Re} < 1 \]
\[ C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34 \quad \text{for } N_{Re} > 1 \text{ but } < 10^4 \]

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

\[ h_L = \frac{1.067 \ C_D \ D \ V_a^2}{\phi \ g \ \epsilon \ \sum x} \]

where \( x \) is weight fraction of particle sizes

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

\[ h_L = \frac{1.067 \ D \ V_a^2}{\phi \ g \ \epsilon \ \sum C_D x / d} \]

Study example 10.1 page 300
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-m² of filter bed
- Presently, rates between 1.36 to 3.40 l/s-m² 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

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
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

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-m²
- Backwash continues till the waste washwater is relatively clear
Figure 10.18 Schematic Showing Filler During Backwashing

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

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-ft²
- Common filtration rates are 3-6 gal/min-ft²
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-ft² (3-6 gal/min-ft² 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

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

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Sand medium:</td>
<td></td>
</tr>
<tr>
<td>Depth in. (mm)</td>
<td>24–30</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.35–0.70</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>&lt;1.7</td>
</tr>
<tr>
<td>Anthracite medium:</td>
<td></td>
</tr>
<tr>
<td>Depth in. (mm)</td>
<td>24–30</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.70–0.75</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>&lt;1.75</td>
</tr>
<tr>
<td>Filtration rate:</td>
<td></td>
</tr>
<tr>
<td>gpm/ft² (L/s-m²)</td>
<td>2–5</td>
</tr>
<tr>
<td>([L/s-m²]</td>
<td>(1.36–3.40)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Anthracite:</td>
<td></td>
</tr>
<tr>
<td>Depth in. (mm)</td>
<td>18–24</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.9–1.1</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>1.6–1.8</td>
</tr>
<tr>
<td>Sand:</td>
<td></td>
</tr>
<tr>
<td>Depth in. (mm)</td>
<td>6–8</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.45–0.55</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>1.5–1.7</td>
</tr>
<tr>
<td>Filtration rate:</td>
<td></td>
</tr>
<tr>
<td>gpm/ft² (L/s-m²)</td>
<td>3–8</td>
</tr>
<tr>
<td>([L/s-m²]</td>
<td>(2.04–5.44)</td>
</tr>
</tbody>
</table>
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 desired storage volume for flocculated floc
### TABLE 10.8 Dual-Media Filter Characteristics for Advanced or Tertiary Wastewater Treatment

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Anthracite:</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>12–24</td>
</tr>
<tr>
<td>(in.) (mm)</td>
<td>(305–610)</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.8–2.0</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>1.3–1.8</td>
</tr>
<tr>
<td>Sand:</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>6–12</td>
</tr>
<tr>
<td>(in.) (mm)</td>
<td>(150–305)</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.4–0.8</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>1.2–1.6</td>
</tr>
<tr>
<td>Filtration rate:</td>
<td></td>
</tr>
<tr>
<td>gpm/ft²</td>
<td>2–10</td>
</tr>
<tr>
<td>(1.36–6.79)</td>
<td>(3.40)</td>
</tr>
</tbody>
</table>


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

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
</tr>
<tr>
<td>Anthracite:</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>8–20</td>
</tr>
<tr>
<td>(in.) (mm)</td>
<td>(200–510)</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>1.0–2.0</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>1.4–1.8</td>
</tr>
<tr>
<td>Sand:</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>8–16</td>
</tr>
<tr>
<td>(in.) (mm)</td>
<td>(200–405)</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.4–0.8</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>1.3–1.8</td>
</tr>
<tr>
<td>Garnet:</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>8–16</td>
</tr>
<tr>
<td>(in.) (mm)</td>
<td>(200–405)</td>
</tr>
<tr>
<td>Effective size, mm</td>
<td>0.4–0.8</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>1.3–1.8</td>
</tr>
<tr>
<td>Filtration rate:</td>
<td></td>
</tr>
<tr>
<td>gpm/ft²</td>
<td>2–10</td>
</tr>
<tr>
<td>(1.36–6.79)</td>
<td>(3.40)</td>
</tr>
</tbody>
</table>

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)

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
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-ft²
- Dual- and mixed-media filters were used
- Mixed-media filters gave better results

<table>
<thead>
<tr>
<th>EFFLUENT</th>
<th>EFFLUENT SUSPENDED SOLIDS (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended aeration</td>
<td>1–5</td>
</tr>
<tr>
<td>Conventional activated sludge</td>
<td>3–10</td>
</tr>
<tr>
<td>Contact stabilization</td>
<td>6–15</td>
</tr>
<tr>
<td>Two-stage trickling filter</td>
<td>6–15</td>
</tr>
<tr>
<td>High-rate trickling filter</td>
<td>10–20</td>
</tr>
</tbody>
</table>
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-ft²
- 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-ft²
- 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-ft²
- 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-ft²
  - Filter run of 7 to 150 hours

**FIGURE 10.24 Schematic of the Upflow Filter**