1. Draw a schematic diagram of a water treatment plant that uses a river as the source. Briefly discuss the purpose of each unit operation or unit process shown on the schematic.

**Bar racks** removes large objects such as tree limbs, debris, etc.

**Screens** remove smaller objects such as leaves, fish, etc.

**Flow measurement** is necessary for record keeping and pacing chemical dosages.

**Mixing** is required for dispersion of coagulant such as alum for removing colloidal particles and other turbidity.

**Flocculation** allows the coagulant time to react with coagulant and for the agglomeration of larger particles to be removed during settling.

**Sedimentation** is required for removing the coagulated particles and suspended solids in the water.

**Filtration** is required for removing any remaining particles not removed during sedimentation.

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**Solutions Chapter 9 Exercises**

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Disinfectant is added to the filtered water to kill pathogens before entering the clear well. Cear well provides the detention time necessary for the disinfectant to kill pathogens. High service pumps are used for conveying treated water throughout the distribution system.

2. Draw a schematic diagram of a water treatment plant that uses a ground water as the source. Briefly discuss the purpose of each unit operation or unit process shown on the schematic.

Pumps are used for pumping the water from the well to the water treatment plant. A flow meter such as magnetic meter or ultrasonic meter is used to measure the volumetric flow rate.

The first major unit process is aeration because it involves the oxidation of hydrogen sulfide and the stripping of carbon dioxide that most likely is found in groundwater. Some oxidation of iron and manganese will occur.

The next series of unit processes would include a solids contact basin or traditional lime-soda ash chemical softening. If a solids contact basin is used, lime and soda ash are added to the mixing zone of the contact basin, flocculation, and settling occur followed by recarbonation (carbon dioxide addition) in a separate basin to lower the pH
of the water. This would be followed by filtration, and a disinfectant being added before storage in the clear well. Filtration removes suspended solids remaining after sedimentation and those produced during recarbonation. The final unit operation is high service pumping that is used for distributing the water throughout the water distribution system. Lime and soda ash are used for removing hardness from groundwater.

Traditional lime- soda ash treatment involves lime and soda ash being added to a rapid mixing basin followed by slow stirring in a flocculation basin to promote agglomeration of flocs. Settling follows flocculation for separating the solids from the liquid. Filtration, disinfection, storage in the clear well followed by high service pumping would be used.

3. A circular rapid mix basin with stator blades is to be designed to treat 2.0 million gallons of water per day. The detention time should be 60 seconds with a velocity gradient of 900 s\(^{-1}\). The minimum temperature anticipated is 60\(^\circ\)F and the absolute viscosity (\(\mu\)) is \(2.359 \times 10^{-5}\) lb⋅s/ft\(^2\). Determine the diameter (ft) if two rapid mix basins are operating in parallel with a depth of 10 feet. Also calculate the power input to the basin (HP).  

\[
\theta = \frac{V}{Q}
\]

\[
V = \theta \times Q = 60 \text{s} \times \left( \frac{1 \text{min}}{60 \text{s}} \right) \times \left( \frac{1 \text{h}}{60 \text{min}} \right) \times \left( \frac{1 \text{d}}{24 \text{h}} \right) \times \left( 1 \times 10^6 \frac{\text{gal}}{\text{d}} \right) \times \left( \frac{1 \text{ft}^3}{7.48 \text{gal}} \right) = 92.84 \text{ ft}^3
\]

Area of rapid mix basin = \(92.84 \text{ ft}^3 / 10 \text{ ft} = 9.284 \text{ ft}^2\). Area of circular basin = \(\frac{\pi D^2}{4}\)

Therefore, \(A = \frac{\pi D^2}{4} = 9.284 \text{ ft}^2\) \(\Rightarrow\) \(D = 3.4 \text{ ft}\) Use a diameter of 3.5 feet.

Volume of rapid mix basin = \(A \times \text{depth} = \frac{\pi (3.5 \text{ ft})^2}{4} \times 10 \text{ ft} = 96.21 \text{ ft}^3\)

\(G = \sqrt{\frac{P}{\mu \times V}}\) or

\[
P = \mu \times V \times G^2 = 2.359 \times 10^{-5} \frac{\text{lb} \cdot \text{s}}{\text{ft}^2} \times (96.21 \text{ ft}^3) \times (900 \text{ s}^{-1})^2 = 1838 \frac{\text{ft} \cdot \text{lb}}{\text{s}}
\]

\[
P = 1838 \frac{\text{ft} \cdot \text{lb}}{\text{s}} \times \left( \frac{1 \text{ HP}}{550 \text{ ft} \cdot \text{lb/s}} \right) = 3.3 \text{ HP}
\]
4. A flocculation basin is to be designed with a 30 minute detention time and a mean velocity gradient of 40 s\(^{-1}\). Determine the power (W) required if the average design flow to the flocculation basin is 30,000 m\(^3\)/d. \(\mu = 1.002 \times 10^{-3} \text{ N} \cdot \text{s/m}^2\)

\[
V = 0 \times Q = 30 \text{ min} \left( \frac{1 \text{ h}}{60 \text{ min}} \right) \left( \frac{1 \text{ d}}{24 \text{ h}} \right) \left( \frac{30,000 \text{ m}^3}{\text{d}} \right) = 625 \text{ m}^3
\]

\[
P = G^2 \mu V = \left( 40 \text{ s}^{-1} \right)^2 \left( 1.002 \times 10^{-3} \text{ N} \cdot \text{s/m}^2 \right) \left( 625 \text{ m}^3 \right) = 1002 \frac{\text{N} \cdot \text{m}}{\text{s}}
\]

\[
P = 1002 \frac{\text{N} \cdot \text{m}}{\text{s}} \left( \frac{1 \text{ W}}{1 \text{ N} \cdot \text{m/s}} \right) \left( \frac{1 \text{kW}}{1000 \text{ W}} \right) = 1.00 \text{ kW}
\]

5. A flocculation basin with dimensions of 60 feet long, 45 feet wide, and 14 feet deep treats a coagulated water flow of 10 million gallons per day (MGD) at a temperature of 50°F (absolute viscosity, \(\mu = 2.735 \times 10^{-5} \text{ lb} \cdot \text{sec/ft}^2\)). The power (P) input to the paddle wheel is 930 \(\text{ft} \cdot \text{lb/sec}\) resulting in a paddle blade tip velocities of 1.4 and 1.0 feet per second (fps) for the outer and inner blades, respectively.

a. Determine the detention time in hours.

\[
V = 60 \text{ ft} \times 45 \text{ ft} \times 14 \text{ ft} = 37,800 \text{ ft}^3
\]

\[
V = 37,800 \text{ ft}^3 \times \left( \frac{7.48 \text{ gal}}{\text{ft}^3} \right) = 283,000 \text{ gal}
\]

\[
\theta = \frac{V}{Q} = \frac{283,000 \text{ gal}}{10 \times 10^6 \text{ gal/d}} \left( \frac{24 \text{ h}}{\text{d}} \right) = 0.68 \text{ h}
\]

b. The horizontal flow through velocity (\(V_h\)) in feet per minute.

\[
Q = A \times V \quad \text{or} \quad V_h = \frac{Q}{A_x} = \frac{10 \times 10^6 \text{ gal/d}}{45 \text{ ft} \times 14 \text{ ft}} \left( \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \right) \left( \frac{1 \text{ d}}{24 \text{ h}} \right) \left( \frac{1 \text{ h}}{60 \text{ min}} \right) = 1.47 \text{ ft/min}
\]

c. The mean velocity gradient (\(G\)) in s\(^{-1}\).
\[ G = \left( \frac{P}{\mu V} \right)^{0.5} = \left( \frac{930 \text{ ft} \cdot \text{lb/s}}{9.8 \times 10^{-5} \text{ lb} \cdot \text{s}^{-1} \cdot \text{ft}^{-1} \cdot (37,800 \text{ ft}^3)} \right)^{0.5} = 30 \text{s}^{-1} \]

d. The Gt value (dimensionless).

\[ Gt = 30 \text{s}^{-1} \times (0.68 \text{ h}) \times \left( \frac{60 \text{ min}}{\text{h}} \right) \times \left( \frac{60 \text{ s}}{1 \text{min}} \right) = 7.34 \times 10^4 \quad \text{OK between } 10^4 \text{ and } 10^5 \]

6. A groundwater was analyzed with the following ionic constituents:

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (mg/L)</th>
<th>Equivalent Weight</th>
<th>Concentration (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2)</td>
<td>17</td>
<td>44/2 = 22</td>
<td>17/22 = 0.8</td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td>80</td>
<td>40/2 = 20</td>
<td>80/20 = 4.0</td>
</tr>
<tr>
<td>Mg(^{2+})</td>
<td>29</td>
<td>24.3/2 = 12.15</td>
<td>29/12.15 = 2.4</td>
</tr>
<tr>
<td>HCO(_3)</td>
<td>180</td>
<td>50</td>
<td>180/50 = 3.6</td>
</tr>
<tr>
<td>Na(^+)</td>
<td>25.3</td>
<td>23/1=23</td>
<td>25.3/23 = 1.1</td>
</tr>
<tr>
<td>Cl(^-)</td>
<td>138.5</td>
<td>35.3/1=35.3</td>
<td>138.5/35.3 = 3.9</td>
</tr>
</tbody>
</table>

a. Draw a bar graph in milliequivalents per liter (meq/L) for determining lime and soda ash requirements for softening the water to the practical limits of hardness removal (40 mg/L as CaCO\(_3\) and 10 mg/L magnesium hardness as CaCO\(_3\)).
### Component Concentration (meq/L)

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (meq/L)</th>
<th>Lime (meq/L)</th>
<th>Soda Ash (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.8</td>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td>Ca(HCO₃)₂</td>
<td>3.6</td>
<td>3.6</td>
<td>-</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>0.4</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>MgCl₂</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>NaCl</td>
<td>1.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Excess Lime</td>
<td>1.25</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8.05</strong></td>
<td><strong>2.8</strong></td>
<td></td>
</tr>
</tbody>
</table>

b. Calculate the quantity of lime in kilograms per day as calcium oxide (CaO) with a 95% purity to treat 18,000 m³/day of flow using excess lime treatment (1.25 meq/L).

\[
\frac{18,000 \text{ m}^3}{\text{d}} \left( \frac{1000 \text{ L}}{\text{m}^3} \right) \left( 8.05 \text{ meq} \right) \left( \frac{28 \text{ mg}}{\text{meq}} \right) \left( \frac{1 \text{ g}}{1000 \text{ mg}} \right) \left( \frac{1 \text{ kg}}{1000 \text{ g}} \right) \left( \frac{1}{0.95} \right) = 4270 \text{ kg/d}
\]

c. Calculate the quantity of soda ash (Na₂CO₃) in kilograms per day with a 90% purity to treat 18,000 m³/day of flow.

\[
\frac{18,000 \text{ m}^3}{\text{d}} \left( \frac{1000 \text{ L}}{\text{m}^3} \right) \left( 2.8 \text{ meq} \right) \left( \frac{53 \text{ mg}}{\text{meq}} \right) \left( \frac{1 \text{ g}}{1000 \text{ mg}} \right) \left( \frac{1 \text{ kg}}{1000 \text{ g}} \right) \left( \frac{1}{0.90} \right) = 2970 \text{ kg/d}
\]

7. A water analysis yielded the following results:

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (mg/L)</th>
<th>Equivalent Weight</th>
<th>Concentration (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>8.8</td>
<td>44/2 = 22</td>
<td>8.8/22 = 0.4</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>70</td>
<td>40/2 = 20</td>
<td>70/20 = 3.5</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>9.7</td>
<td>24.3/2 = 12.15</td>
<td>9.7/12.15 = 0.8</td>
</tr>
<tr>
<td>Na⁺</td>
<td>6.9</td>
<td>23/1 = 23</td>
<td>6.9/23 = 0.3</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>115</td>
<td>50</td>
<td>115/50 = 2.3</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>96</td>
<td>96/2 = 48</td>
<td>96/48 = 2.0</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>10.6</td>
<td>35.3/1=35.3</td>
<td>10.6/35.3 = 0.3</td>
</tr>
</tbody>
</table>

a. Draw a bar graph in milliequivalents per liter (meq/L) for determining lime and soda ash requirements for softening the water to the practical limits of hardness removal (40 mg/L as CaCO₃ and 10 mg/L magnesium hardness as CaCO₃).
Component Concentration (meq/L) Lime (meq/L) Soda Ash (meq/L)

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (meq/L)</th>
<th>Lime (meq/L)</th>
<th>Soda Ash (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.4</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>Ca(HCO₃)₂</td>
<td>2.3</td>
<td>2.3</td>
<td>-</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>1.2</td>
<td>-</td>
<td>1.2</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Excess Lime</td>
<td>1.25</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4.75</strong></td>
<td><strong>2.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

b. Calculate the quantity of lime in pounds per day as calcium oxide (CaO) with a 98% purity to treat 5.0 million gallons per day (MGD) of flow using excess lime treatment (1.25 meq/L).

\[
\left( \frac{4.75 \text{ meq}}{\text{L}} \right) \left( \frac{28 \text{ mg}}{\text{meq}} \right) \left( \frac{5 \text{ MG}}{\text{d}} \right) \left( \frac{8.34 \text{ lb/MG}}{\text{mg/L}} \right) \left( \frac{1}{0.98} \right) = 5660 \frac{\text{lb}}{\text{d}}
\]

c. Calculate the quantity of soda ash (Na₂CO₃) in pounds per day with a 95% purity to treat 5.0 million gallons per day (MGD) of flow.

\[
\left( \frac{2.0 \text{ meq}}{\text{L}} \right) \left( \frac{53 \text{ mg}}{\text{meq}} \right) \left( \frac{5 \text{ MG}}{\text{d}} \right) \left( \frac{8.34 \text{ lb/MG}}{\text{mg/L}} \right) \left( \frac{1}{0.95} \right) = 4650 \frac{\text{lb}}{\text{d}}
\]

8. Use Stokes’ Law (Equation 9.23 or 9.24) to calculate the settling velocity (meters per second) of a spherical particle with a diameter of 1.0 mm and a specific gravity (S.G.) of 3.0 in water at a temperature of 30°C. The absolute and
The kinematic viscosity of water at 30°C is \(0.798 \times 10^{-3} \text{ N}\cdot\text{s/m}^2\) and \(0.8 \times 10^{-6} \text{ m}^2/\text{s}\). The water density \(\rho\) is 995.7 kg/m\(^3\).

Substituting into Equation (9.24).

\[
d = 1\text{mm} \left(\frac{1\text{m}}{1000\text{mm}}\right) = 0.001\text{m}
\]

\[
V_s = \frac{g(SG_p - 1)d^2}{18 \nu} = \frac{9.81\text{m/s}^2 (3 - 1)(0.001\text{m})^2}{18(0.8 \times 10^{-6} \text{ m}^2/\text{s})} = 1.36 \text{m/s}
\]

9. A spherical particle with a diameter of 0.02 mm and a specific gravity (S.G.) of 2.8 settles in water having a temperature of 20°C. Use Stokes’ Law (Equation 9.23 or 9.24) for calculating the settling velocity in meters per second. The absolute and kinematic viscosities of water at 20°C are \(1.002 \times 10^{-3} \text{ N}\cdot\text{s/m}^2\) and \(1.003 \times 10^{-6} \text{ m}^2/\text{s}\), respectively. The water density \(\rho\) at 20°C is 998.2 kg/m\(^3\). Convert the settling velocity from meters per second to gallons per day per square foot (gpd/ft\(^2\)) which represents the units commonly used for expressing the overflow rate in English units.

Substituting into Equation (9.24).

\[
d = 0.02\text{mm} \left(\frac{1\text{m}}{1000\text{mm}}\right) = 0.00002\text{m}
\]

\[
V_s = \frac{g(SG_p - 1)d^2}{18 \nu} = \frac{9.81\text{m/s}^2 (2.8 - 1)(0.00002\text{m})^2}{18(1.003 \times 10^{-6} \text{ m}^2/\text{s})} = 3.91 \times 10^{-4} \text{m/s}
\]

In English units the overflow rate is calculated as follows:

\[
V_s = 3.91 \times 10^{-4} \text{ m/s} \left(\frac{1000\text{L}}{\text{m}^3}\right) \left(\frac{3600\text{s}}{\text{h}}\right) \left(\frac{24\text{h}}{\text{d}}\right) \left(\frac{1\text{gal}}{3.785\text{L}}\right) \left(\frac{1\text{m}^2}{3.281^2\text{ft}^2}\right) = 830 \text{gpd/ft}^2
\]

10. Two long rectangular settling basin are operating in parallel to treat 5 million gallons per day (MGD) of coagulated water. A length-to-width (L:W) ratio of 4:1 and length to depth (L: D) ratio of 10:1 will be used in design. Overflow rate = 1000 gpd/ft\(^2\).

a. Determine the dimensions of the settling basin in feet.

b. Calculate the detention time of each basin in hours.
c. Determine the length of the effluent weir in each basin if the weir loading rate is not to exceed 12,000 gpd/ft.

Determine the surface area of the settling basins using Equation (9.35).

\[ V_o = \frac{Q}{A_s} \]

\[ A_s = \frac{Q}{V_o} = \frac{2.5 \times 10^6 \text{ gal/d}}{1000 \text{ gpd/ft}^2} = 2500 \text{ ft}^2 \]

\[ A_s = L \times W = 2500 \text{ ft}^2 \]

Since \( L = 4W \), then \( A_s = 4W \times W = 2500 \text{ ft}^2 \)

\( W = 25 \text{ ft} \) and \( L = 4 \times 25 = 100 \text{ ft} \)

Since \( L:D = 10:1 \), then \( D = L/10 = 100 \text{ ft}/10 = 10 \text{ ft} \)

Determine the detention time of the settling basins using Equation (9.36).

\[ \theta = \frac{V}{Q} = \frac{100 \text{ ft} \times 25 \text{ ft} \times 10 \text{ ft}}{2.5 \times 10^6 \text{ gal/d}} \left( \frac{7.48 \text{ gal}}{\text{ ft}^3} \right) \left( \frac{24 \text{ h}}{\text{ d}} \right) = 1.8 \text{ h} \]

Finally, calculate the weir length as follows by rearranging Equation (9.37).

\[ \text{Weir Loading Rate} = \frac{Q}{\text{Weir Length}} \]

\[ \text{Weir Length} = \frac{Q}{\text{Weir Loading Rate}} = \frac{2.5 \times 10^6 \text{ gpd}}{12,000 \text{ gpd/ft}} = 208 \text{ ft/basin} \]

11. Two circular settling basins operating in parallel are to be designed for treating 40,000 m\(^3\)/d of coagulated water. Each basin is 2.3 meters deep and has a single peripheral weir attached to the outside wall of the settling basin. \( V_o = 0.6 \text{ m/h} \)

a. Determine the diameter of each basin in meters.

b. Calculate the detention time of each basin in hours.

c. Calculate the weir loading rate (m\(^3\)/d-m).

Determine the surface area of the settling basins using Equation (9.45).
\[ V_o = \frac{Q}{A_s} \]

\[ A_s = \frac{Q}{V_o} = \frac{20,000 \text{ m}^3/\text{d}}{0.6 \text{ m/h} \times (24 \text{ h/d})} = 1,390 \text{ m}^2 \]

\[ A_s = \frac{\pi D^2}{4} = 1,390 \text{ m}^2 \]

Therefore, diameter \( D = 42.07 \text{ m} \), use 42.1 meter

Determine the detention time of the settling basins using Equation (9.36).

First calculate the actual volume using a diameter of 42.1 m and a depth of 2.3 meters.

\[ A_s = \frac{\pi (42.1 \text{ m})^2}{4} = 1,392 \text{ m}^2 \]

\[ V = A_s \times \text{Depth} = 1,392 \text{ m}^2 \times 2.3 \text{ m} = 3,202 \text{ m}^3 \]

\[ \theta = \frac{V}{Q} = \frac{3,202 \text{ m}^3}{20,000 \text{ m}^3/\text{d}} = 0.16 \text{ d} \quad \theta = 0.16 \left( \frac{24 \text{ h}}{\text{d}} \right) = 3.8 \text{ h} \]

Finally, calculate the weir loading rate using Equation (9.37).

\[ \text{Weir Loading Rate} = \frac{Q}{\text{Weir Length}} \]

\[ \text{Weir length} = \pi D = \pi \times 42.1 \text{ m} = 132 \text{ m} \]

\[ \text{Weir Loading Rate} = \frac{20,000 \text{ m}^3/\text{d}}{132 \text{ m}} = 152 \text{ m}^3/\text{d} \cdot \text{m} \]

12. A rapid sand filter has a sand bed depth of 762 mm. Other pertinent data include: sand specific gravity =2.65, porosity (\( \varepsilon \)) =0.41, filtration rate of 1.53 lps/m², shape factor (\( \phi \)) = 0.80, and temperature of 15°C. A sieve analysis is presented below. Determine the head loss for a clean filter using the Carman-Kozeny Equation (Equation 9.65) for a stratified bed. \( \mu = 1.139 \times 10^{-3} \text{kg/m} \cdot \text{s} \quad \rho = 999.1 \text{ kg/m}^3 \)
<table>
<thead>
<tr>
<th>SIEVE #</th>
<th>% Sand Retained</th>
<th>d&lt;sub&gt;ij&lt;/sub&gt;</th>
<th>N&lt;sub&gt;R&lt;/sub&gt;</th>
<th>f&lt;sub&gt;'ij&lt;/sub&gt;</th>
<th>f&lt;sub&gt;'ij&lt;/sub&gt;X&lt;sub&gt;ij&lt;/sub&gt;/d&lt;sub&gt;ij&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-20</td>
<td>0.87</td>
<td>10.006</td>
<td>1.08E+00</td>
<td>8.41E+01</td>
<td>731</td>
</tr>
<tr>
<td>20-28</td>
<td>8.63</td>
<td>7.111</td>
<td>7.64E-01</td>
<td>1.18E+02</td>
<td>14268</td>
</tr>
<tr>
<td>28-32</td>
<td>26.30</td>
<td>5.422</td>
<td>5.83E-01</td>
<td>1.54E+02</td>
<td>74524</td>
</tr>
<tr>
<td>32-35</td>
<td>30.10</td>
<td>4.572</td>
<td>4.91E-01</td>
<td>1.82E+02</td>
<td>119740</td>
</tr>
<tr>
<td>35-42</td>
<td>20.64</td>
<td>3.834</td>
<td>4.12E-01</td>
<td>2.17E+02</td>
<td>116578</td>
</tr>
<tr>
<td>42-48</td>
<td>7.09</td>
<td>3.225</td>
<td>3.47E-01</td>
<td>2.57E+02</td>
<td>56525</td>
</tr>
<tr>
<td>48-60</td>
<td>3.19</td>
<td>2.707</td>
<td>2.91E-01</td>
<td>3.06E+02</td>
<td>36057</td>
</tr>
<tr>
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<td>2.274</td>
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<td>3.64E+02</td>
<td>34566</td>
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<td>1.777</td>
<td>1.91E-01</td>
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<td>26702</td>
</tr>
<tr>
<td></td>
<td><strong>100</strong></td>
<td></td>
<td><strong>479690</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CARMAN-KOZENY  \( h = 0.93 \, m \)

Sample calculations are presented for the first row of the table.

Filtration rate = \( \frac{1.53 \, L/s}{m^2} \left( \frac{1 \, m^3}{1000 \, L} \right) = 1.53 \times 10^{-3} \, m/s \)

Calculate the Reynolds Number using Equation (9.20).

\[
N_R = \frac{\phi \, V \, d}{\nu} = \frac{0.80 \left(1.53 \times 10^{-3} \, m/s\right) \left(10.006 \times 10^{-4} \, m\right)}{1.139 \times 10^{-6} \, m^2/s} = 1.075
\]

Calculate the friction factor using Equation (9.39).

\[
f' = 150 \left( \frac{1 - \varepsilon}{N_R} \right) + 1.75 \quad \quad f' = 150 \left( \frac{1 - 0.41}{1.075} \right) + 1.75 = 84.1
\]

\[
f' \frac{X_{ij}}{d_{ij}} = \frac{84.1 \left(0.0087\right)}{10.006 \times 10^{-4}} = 731
\]
Calculate the head loss using Equation (9.38).

\[ h_L = \frac{L(1 - \varepsilon) V_i^2}{\varphi \, \varepsilon^3 \, g} \sum f_{ij} \frac{X_{ij}}{d_{ij}} \]

\[ h_L = \frac{0.762 \, m \, (1 - 0.41) \left(1.53 \times 10^{-3} \, \text{mps} \right)^2}{\left(0.80 \right) \, 0.41^3 \left(9.81 \, \text{m/s}^2\right)} \times (479,690) = 0.93 \, \text{m} \]

13. A new water treatment plant is to be constructed for treating 30 million gallons of water each day (MGD). Estimate the number of filters required and calculate the area of each filter (ft²) assuming a length-to-width ratio (L:W) of 4:1 is used in constructing the rapid sand filters and use a filtration rate of 6 gpm/ft².

Calculate the number of filters using Equation (9.40).

\[ N = 1.2 \, Q^{0.5} = 1.2 \left(30 \, \text{MGD} \right)^{0.5} = 6.6 \, \text{filters} \]

Go with a total of 8 filters with one of the eight as a stand-by filter.

Determine the surface area of the filters using the following equation.

\[ A_s = \frac{Q}{\text{Filtration Rate}} = \frac{30 \times 10^6 \, \text{gpd}}{6 \, \text{gpm/ft}^2 \left( \frac{1 \, \text{d}}{24 \, \text{h}} \right) \left( \frac{1 \, \text{h}}{60 \, \text{min}} \right)} = 3472 \, \text{ft}^2 \]

\[ \frac{A_s}{\text{Filter}} = \frac{3472 \, \text{ft}^2}{7} = 496 \, \text{ft}^2 \quad A_s = LW = 4 \, W^2 \]

W = 11.1 ft and L = 4 \times 11.1 ft = 44.4 ft

Therefore, go with 8 filters that are 11.1 ft by 44.4 ft.

14. Chlorine gas, 70% granular calcium hypochlorite [Ca(OCl)₂], and 12% sodium hypochlorite solution are being considered as the primary disinfectants for a 6,000 m³/d water treatment plant. The anticipated chlorine dose is 2.5 mg/L. Calculate the quantity of each disinfectant required in kilograms per month (30 days) to supply the dosage of 2.5 mg/L. Which disinfectant is the most cost effective if chlorine gas, Ca(OCl)₂, and NaOCl costs $0.50/kg, $1.50/kg, and $0.95/kg, respectively?

First calculate the quantity of chlorine required per month as follows:
\[
6,000 \frac{m^3}{d} \left( \frac{2.5 \ g}{m^3} \right) \left( \frac{1 \ kg}{1000 \ g} \right) \left( 30 \frac{d}{mon} \right) = 450 \frac{kg}{mon}
\]

Calculate cost of using chlorine gas as follows:

\[
450 \frac{kg}{mon} \times \left( \frac{$0.50}{kg} \right) = $225 \text{ per month}
\]

Calculate cost of using calcium hypochlorite @ 70% available chlorine as follows:

\[
450 \frac{kg}{mon} \times \left( \frac{$1.50}{kg} \right) \left( \frac{1}{0.70} \right) = $964.29 \text{ per month}
\]

Calculate cost of using sodium hypochlorite @ 12% available chlorine as follows:

\[
450 \frac{kg}{mon} \times \left( \frac{$0.95}{kg} \right) \left( \frac{1}{0.12} \right) = $3,562.50 \text{ per month}
\]

Use chlorine gas since it is the most economical.