## Solution: Exercise 1

### Typical Concentrations of Nitrogen in Influent & Effluent

<table>
<thead>
<tr>
<th></th>
<th>Raw Municipal Influent</th>
<th>Primary Effluent (No Nitrification)</th>
<th>Secondary Effluent (Nitrified)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NH₄⁺- N</strong></td>
<td>15</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>SKN</td>
<td>18</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>TKN</td>
<td>30</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td><strong>NO₂⁻- N</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>NO₃⁻- N</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total N</td>
<td>30</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Sol. Organic - N</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Organic - N</td>
<td>15</td>
<td>9</td>
<td>3</td>
</tr>
</tbody>
</table>
Calculation of Required Mean Cell Residence Time for Nitrification
Solution: Exercise 2

Required Input Data

1. Average Temperature in Aeration Tank, \( T \)  
   \[ 20 \ °C \]

2. Average Effluent Ammonia Concentration  
   \[ 1.0 \ \text{mg/L (as N)} \]

3. Average Aeration Tank Dissolved Oxygen Concentration  
   \[ 3.0 \ \text{mg/L} \]

Determine Maximum Specific Growth Rate Corrected For Temperature \( (\mu_{\text{max}, T}) \)

4. \( \mu_{\text{max}, T} = (0.65)(1.055)^{(T - 25)} \)

5. \[ \mu_{\text{max}, 20} = (0.65)(1.055)^{(20 - 25)} = 0.497 \ \text{day}^{-1} \]
   Enter temperature in °C from line (1)

Determine Decay Rate Corrected For Temperature \( (k_d) \)

6. \[ k_d = (0.05)(1.055)^{(T - 25)} \]

7. \[ k_{d, 20} = (0.05)(1.055)^{(20 - 25)} = 0.038 \ \text{day}^{-1} \]
   Enter temperature in °C from line (1)
Determine Growth Rate Correction Factor For Ammonia Concentration

\[
(8) \quad CF_{NH_4^+} = \frac{NH_4^+ - N}{K_N + NH_4^+ - N}
\]

\[
(9) \quad K_N = (1.0)(1.055)^{(T-25)}
\]

\[
(10) \quad K_N = (1.0)(1.055)^{(20 - 25)} = 0.765 \text{ mg/L}
\]

\[
(11) \quad CF_{NH_4^+} = \frac{1.0}{0.765 + 1.0} = 0.567
\]

Determine Growth Rate Correction Factor For Dissolved Oxygen Concentration

\[
(12) \quad CF_{DO} = \frac{DO}{1 + DO}
\]

\[
(13) \quad CF_{DO} = \frac{3.0}{1 + 3.0} = 0.75
\]
Determine Growth Rate Corrected For Temperature, Ammonia and DO

\[ \mu_T = \mu_{\text{max, } T} (\text{CF}_{\text{NH}_4^+} \text{)(CF}_{\text{DO}}) \]  (14)

\[ \mu_T = (0.497)(0.567)(0.75) = 0.211 \text{ day}^{-1} \]  (15)

Enter CFDO from line (13)
Enter CFNH4+ from line (11)
Enter \mu_{\text{max, } T} from line (5)

Determine Required MCRT

\[ \text{MCRT} = \frac{1}{\mu_T - k_d} \]  (16)

\[ \text{MCRT} = \frac{1}{0.211 - 0.038} = 5.77 \text{ days} \]  (17)

Enter kd from line (7)
Enter \mu_T from line (15)
Calculation of Actual Mean Cell Residence Time

Solution: Exercise 3

Required Input Data

Aeration Tank Volume

(1) Aerobic Volume, \( V_{AER} \)  
\[ 7.5 \text{ MGal} \]

(2) Anoxic Volume (if applicable), \( V_{ANOX} \)  
\[ 2.5 \text{ MGal} \]

Average MLSS Concentration

(3) Aerobic Zone, MLSS  
\[ 2500 \text{ mg/L} \]

(4) Anoxic Zone (if applicable), MLSS\(_{ANOX}\)  
\[ 2500 \text{ mg/L} \]

(5) Sludge Wasting Rate, \( Q_W \)  
\[ 0.5 \text{ MGD} \]

(6) Waste Sludge Solids Concentration, \( TSS_W \)  
\[ 7500 \text{ mg/L TSS} \]

(7) Clarifier Effluent Flow, \( Q_E \) (Plant Flow)  
\[ 40 \text{ MGD} \]

(8) Clarifier Effluent TSS, \( TSS_E \)  
\[ 13 \text{ mg/L} \]

Determine Mass of Solids in Anoxic Zone

(9) \[ M_{ANOX} = (V_{ANOX})(8.34)(MLSS_{ANOX}) \]

(10) \[ M_{ANOX} = (2.5)(8.34)(2500) = 52,125 \text{ lb} \]

Enter from line (2)  
Enter from line (4)
Determine Mass of Solids in Aerobic Zone

(11)  \[ M_{AER} = (V_{AER})(8.34)(MLSS_{AER}) \]

(12)  \[ M_{AER} = (7.5)(8.34)(2500) = 156,375 \text{ lb} \]

Enter from line (1)  Enter from line (3)

Determine Mass of Solids Removed from System in Waste Sudge

(13)  \[ M_W = (Q_W)(8.34)(TSS_{W}) \]

(14)  \[ M_W = (0.5)(8.34)(7,500) = 31,275 \text{ lb/day} \]

Enter from line (5)  Enter from line (6)

Determine Mass of Solids Removed from System in Plant Effluent

(15)  \[ M_E = (Q_E)(8.34)(TSS_{E}) \]

(16)  \[ M_E = (40)(8.34)(13) = 4,337 \text{ lb/day} \]

Enter from line (7)  Enter from line (8)

Determine Overall MCRT

(17)  \[ MCRT = \frac{(M_{ANOX} + M_{AER})}{(M_W + M_E)} \]

Enter from line (10)  Enter from line (12)

(18)  \[ MCRT = \frac{(52,125 + 156,375)}{(31,275 + 4,337)} = 5.9 \text{ days} \]

Enter from line (14)  Enter from line (16)
Determine Aerobic MCRT

(19) \[ \text{MCRT}_{\text{AER}} = \frac{(M_{\text{AER}})(\text{MCRT})}{(M_{\text{AER}} + M_{\text{ANOX}})} \]

Enter from line (12) Enter from line (18)

(20) \[ \text{MCRT}_{\text{AER}} = \frac{(156,375)(5.9)}{(156,375 + 52,125)} = 4.4 \text{ days} \]

Enter from line (12) Enter from line (10)

Determine Anoxic MCRT

(21) \[ \text{MCRT}_{\text{ANOX}} = (\text{MCRT}) - (\text{MCRT}_{\text{AER}}) \]

(22) \[ \text{MCRT}_{\text{ANOX}} = (5.9) - (4.4) = 1.5 \text{ days} \]

Enter from line (18) Enter from line (20)
## Nitrogen Balance in a Nitrifying and Denitrifying Plant

**Condition:** 8 day MCRT, nitrification and denitrification

### Required Input Data

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Data</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Secondary effluent flow</td>
<td>40 mgd</td>
<td>(assume equal to primary effluent flow)</td>
</tr>
<tr>
<td>(2) Primary effluent TKN</td>
<td>25 mg/L, 8,340 lbs/day</td>
<td></td>
</tr>
<tr>
<td>(3) Primary effluent NOxN</td>
<td>0 mg/L, 0 lbs/day</td>
<td></td>
</tr>
<tr>
<td>(4) Nitrogen in waste activated sludge</td>
<td>6.7 mg/L, 2,242 lbs/day</td>
<td></td>
</tr>
<tr>
<td>(5) Secondary effluent NH$_4^+$-N</td>
<td>1.0 mg/L, 334 lbs/day</td>
<td></td>
</tr>
<tr>
<td>(6) Secondary effluent soluble org-N</td>
<td>1.0 mg/L, 334 lbs/day</td>
<td></td>
</tr>
<tr>
<td>(7) Nitrogen in secondary effluent SS</td>
<td>1.2 mg/L, 400 lbs/day</td>
<td></td>
</tr>
<tr>
<td>(8) Secondary effluent NOx-N</td>
<td>6 mg/L, 2,002 lbs/day</td>
<td></td>
</tr>
</tbody>
</table>

### Mass Balance Calculations (do in lbs/day first because it is easier)

1. Nitrogen Entering activated sludge system = Nitrogen leaving activated sludge system
2. Nitrogen entering activated sludge system = Primary Effluent (TKN + NOxN)
3. Nitrogen leaving activated sludge system = N in secondary effluent + N in WAS + N denitrified

Combining equations (10) and (11):

4. Primary Eff (TKN+NOxN) = Sec Eff (NH$_4^+$N + Sol org N + N in SS + NOxN) + N in WAS + N denitrified

#### Diagram:

- **Primary Effluent TKN = 8,340 lbs/d**
- **Primary Effluent NOx = 0 lbs/d**
- **Nitrogen Gas Produced = 3,028 lbs/d**
- **Secondary Effluent NH$_4^+$-N = 334 lbs/d**
- **Secondary Effluent Soluble Org N = 334 lbs/d**
- **Secondary Effluent N in Suspended Solids = 400 lbs/d**
- **Secondary Effluent NOx-N = 2,002 lbs/d**
- **Nitrogen in WAS = 2,242 lbs/d**
For operation with nitrification (medium to high MCRT with adequate aeration)

**Nitrification is the difference between the unoxidized-N forms entering and leaving the activated sludge system.**

(12) Nitrification = Primary Effluent TKN - Secondary Effluent(NH₄⁺-N + sol org N + N in TSS) - WAS org N

(13) Nitrification = (8,340) - (334 + 334 + 400) - (2,242) = 5,030 lbs/day or 15.1 mg/L

Denitrification is the difference in unoxidized and oxidized N forms entering and leaving the activated sludge process.

(14) Denitrification = Primary Effluent (TKN + NOₓN) - Secondary Effluent (NH₄⁺-N + sol org N + N in TSS + NOₓN) - N in WAS

(15) Denitrification = (8,340 + 0) - (334 + 334 + 400 + 2,002) - (2,242) = 3,028 lbs/day or 9.1 mg/L

Effluent NH₄⁺-N 1 mg/L
(16) Effluent SKN 2 mg/L
Effluent TKN 3.2 mg/L
Effluent NOₓN 6.0 mg/L
Effluent TN 9.2 mg/L
Attached is a plant data sheet for a BNR plant using a modified A\textsuperscript{2}/O process similar to the schematic shown in Transparency 98. The plant has effluent limits of 5 mg/L TN and 2 mg/L ammonia. The plant has automatic DO control in the first aerobic zone. It also has automatic methanol feed to the second anoxic zone based on feedback from a nitrate probe in the second aerobic zone. This data set indicates that the plant is achieving excellent nitrogen removal. The monthly average effluent total nitrogen of 4.4 mg/L meets the discharge permit limit of 5.0 mg/L. The monthly average effluent ammonia of 0.8 mg/L meets the discharge permit limit of 2.0 mg/L. There are, however, some days when minor problems occurred. Process adjustments during these times could have improved performance.

Can you identify three problems indicated by the data and recommend actions to improve performance?

1. On days 3 and 4 the MLSS concentration in the first anoxic zone dropped dramatically. Also denitrification in the first anoxic zone decreased, indicated by nitrate values of 6.8 and 7.1 in the first aerobic zone. The cause was a shutdown of the mixers in the anoxic zone resulting in settling of solids and decreased denitrification. The event adversely affected total nitrogen removal, with effluent TN values of 7.4 and 7.6. The system should have automatically increased methanol feed to remove more nitrate in the second anoxic zone. The feed system should be checked to be sure it is functioning properly.

2. Days 18, 19 and 20 were rainy resulting in a significant increase in plant flow. During this time, dissolved oxygen levels in the first aerobic zone increased to as high as 5.2 mg/L. Excess DO entering the second anoxic zone appears to have adversely affected denitrification in the second anoxic zone. DO levels may have increased due to higher water surface elevation in the oxidation ditch causing increased rotor aerator submergence. More dilute wastewater caused by inflow and infiltration from the storm event may have also contributed to the elevated DO level.

3. On days 14, 15 and 16 the DO in the first aerobic zone was at its lowest level of the month. This resulted in the highest effluent ammonias of the month (though still acceptable values). An increase in DO in the oxidation ditch may have improved nitrification and resulted in lower effluent ammonia on those days.