Q1. Problem # 3-19 (Peavy et al. Text Book). A wastewater treatment plant disposes of its effluent in a surface stream. Characteristics of the stream and effluent are shown below. 

![Table: Parameter comparison]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wastewater</th>
<th>stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>flow (m$^3$/s)</td>
<td>0.2</td>
<td>5</td>
</tr>
<tr>
<td>Dissolved oxygen, mg/L</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>15</td>
<td>20.2</td>
</tr>
<tr>
<td>BOD$_5$ at 20°C, mg/L</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>Oxygen consumption rate (K1 at 20°C) (1/day)</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td>Oxygen reaeration rate (K2 at 20°C) (1/day)</td>
<td>-</td>
<td>0.3</td>
</tr>
</tbody>
</table>

(a) What will be the dissolved oxygen conc. in the stream after 2 days?

(b) What will be the lowest dissolved oxygen concentration as a result of the waste discharge?

(c) Also calculate the maximum BOD$_5$ (20°C) that can be discharged if a minimum of 4.0 mg/L of oxygen must be maintained in the stream?

Answer:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>wastewater (given)</th>
<th>stream (given)</th>
<th>Wastewater and stream water mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>flow (m$^3$/s)</td>
<td>0.2</td>
<td>5</td>
<td>Q$_{mixture}$=5+0.2=5.2 m/s</td>
</tr>
<tr>
<td>Dissolved oxygen, mg/L</td>
<td>1</td>
<td>8</td>
<td>DO$_{mixture}$=(0.2<em>1+8</em>5)/(5+0.2)</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>15</td>
<td>20.2</td>
<td>Temp$_{mixture}$=(0.2<em>15+20.2</em>5)/(5+0.2)</td>
</tr>
<tr>
<td>BOD$_5$ at 20°C, mg/L</td>
<td>100</td>
<td>2</td>
<td>BOD$_{mixture}$=(0.2<em>100+2</em>5)/(5+0.2)</td>
</tr>
<tr>
<td>Oxygen consumption rate (K1 at 20°C) (1/day)</td>
<td>0.2</td>
<td>-</td>
<td>0.23 (No temp. correction required)</td>
</tr>
<tr>
<td>Oxygen reaeration rate (K2 at 20°C) (1/day)</td>
<td>-</td>
<td>0.3</td>
<td>0.3 (No temp. correction required)</td>
</tr>
</tbody>
</table>

Ultimate BOD = Y$_{ultimate}$=L$_0$ = (5-day BOD in mixture water)/[1-exp(-K1$_{mixture}$*5)] = (5.77 mg/L)/[1-exp(-0.23*5)] = 8.44 mg/L

Initial DO deficit (D$_0$)

For 20°C stream water temperature, equilibrium concentration of oxygen = 9.17 mg/L

D$_0$ = 9.17 mg/L - 7.73 mg/L = 1.44 mg/L

To get DO after 2 days in stream water after mixing, we need to calculate DO deficit after 2 days first and then calculate DO (at 2days). DO deficit at 2 days is given by

D (t=2 days) = [K1*L$_0$]*[exp (-K1*t)-exp (-K2*t)]/(K2-K1) + D$_0$ exp (-K2*t)

= [0.2*8.44]*[exp (-0.2*2)-exp (-0.3*2)]/(0.3-0.2) + 1.44 exp (-0.3*2)

= [1.94]*[0.6703-0.5488]/ (0.07) + 0.7903 = 3.07 mg/L

D (t=2 days) = DO$_{saturated}$-DO (2day) = 3.07 mg/L

DO (2day) = 9.17-3.07 = 6.10 mg/L (answer for part i)

Time for critical DO deficit (t$_c$) = 1/ (K2-K1)*(1-D$_0$ *(K2-K1)/(K1L$_0$))

= 1/ (0.3-0.23)*ln [(0.3/0.23)*(0.3-0.23)/ (0.23*8.44)]

= 14.29*ln [1.3*(1-1.44 *0.036)] = 14.29*ln [1.23] = 2.95 days

Critical DO deficit (D$_c$)= (K1/K2)*L$_0$ exp (-K2*t$_c$)
\[ D = \text{DO}_{\text{saturated}} - \text{DO}_{\text{critical}} = 3.28 \text{ mg/L} \]

\[ \text{DO}_{\text{critical}} = 9.17 - 3.28 = 5.89 \text{ mg/L} \text{ (answer for part ii)} \]

Required minimum DO = 4.0 mg/L in stream water. As DO at critical location is 5.89 mg/L, greater than the recommended DO level, no modification in wastewater effluent characteristics is required.

To calculate maximum BOD$_5$ in effluent water, calculate allowable DO deficit (i.e., $D_{\text{allowable}}$)

\[ D_{\text{allowable}} = \text{DO}_{\text{saturated}} - \text{DO}_{\text{minimum}} = 9.17 - 4.0 = 5.17 \text{ mg/L} \text{ [Note that 5.17 mg/L DO deficit is allowable and we are having 5.89 mg/L critical DO deficit.]} \]

Now with calculated allowable DO deficit (this is assumed to be the critical deficit now) and calculated $t_{\text{critical}}$ (assumed to be similar to previous case, i.e., 2.95 days), calculate ultimate BOD in this case. Then calculate 5-day BOD of the mixture stream water and then calculate 5-day BOD of the effluent which will be the desired maximum 5-day BOD value.

\[ D_{\text{allowable}} (t=t_{\text{critical}}) = D_{\text{critical,new}} \]

\[ => 5.17 = (0.23/0.30)^*L_0 [\exp (-0.23*2.95)] = 0.77*0.51L_0=0.3927L_0 \]

\[ => \text{Ultimate BOD of the mixture water} = L_0=5.19 \text{ mg/L} / (0.3927) =13.17 \text{ mg/L} \]

Now 5-day BOD in mixture water is calculated.

\[ 5-\text{day BOD}_{\text{mixture}} = L_0 *[1-\exp (-K1_{\text{mixture}} \cdot 5)] \]

\[ = (13.17 \text{ mg/L} *[1-\exp (-0.23 \cdot 5) ] =9.0 \text{ mg/L} \]

5-day BOD in effluent water is calculated now.

\[ \text{BOD}_{\text{mixture}} = (5-\text{day BOD}_{\text{eff}} Q_{\text{eff}}+5-\text{day BOD}_{\text{stream}} Q_{\text{stream}})/(5+0.2) \]

\[ 9.0 \text{ mg/L} = (5-\text{day BOD}_{\text{eff}})*0.2+2^5)/(5+0.2) \]

5-day BOD$_{\text{eff}}$ *0.2+10 = 9.0*5.2 = 46.8

\[ => 5-\text{day BOD}_{\text{eff}} = (46.8-10)/0.2 = 184 \text{ mg/L} \text{ (answer for part iii). This is maximum value of 5-day BOD in wastewater effluent which can be discharged in the stream water without exceeding the minimum required DO value of 4 mg/L.} \]

**Q2.** For a given effluent-stream combination, say values of BOD reaction rate and stream reaeration rate are 0.26 and 0.42 per day, respectively and given that initial dissolved oxygen (DO) deficit is 2 mg/L with ultimate BOD of the mixture equals to 18 mg/L, discuss the approach for calculating time (say $t'$) since mixing of effluent with stream water after which DO deficit becomes 1% of the initial DO deficit?

**Q3.** The WWTP in the “AA” community discharges 10 million gallons/day of secondary effluent into a stream “Red Cedar” whose minimum flow rate is 100 m$^3$/s.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>WWTP effluent</th>
<th>Stream water</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°C BOD$_5$ (mg/L)</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>Dissolved oxygen (mg/L)</td>
<td>2</td>
<td>80% of saturation level</td>
</tr>
<tr>
<td>Oxygen consumption rate (k1) (1/day)</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Oxygen re-aeration rate (k2) (1/day)</td>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>

Using above information, calculate the following:

1. Temperature, dissolved oxygen (DO) and BOD of the mixture.
2. Initial dissolved oxygen deficit at the place of mixing.
3. Critical oxygen deficit ($D_c$), time for maximum dissolved oxygen deficit ($t_{\text{max}}$) and its location from discharge point ($X_c$).
4. The dissolved oxygen level and 20°C BOD$_5$ of a sample taken at the critical point.

(Saturated oxygen concentration in stream before discharge is 10.07 mg/L at 15°C. Saturated DO at 15.7°C is 9.9 mg/L. Use temperature coefficients of 1.135 for k1 and 1.024 for k2 for applying temperature corrections for these two constants.)
Q4. Look at the BOD patterns of three organic compounds (a, b, and c) (k2=0.42/day; D0 =2 mg/L; ultimate BOD\text{mixture(river and wastewater)} = 18 mg/L). Which organic matter degradation pattern would determine critical location for DO deficit and why? How would you calculate BOD5 at location where DO deficit becomes 1% of the initial DO deficit (list steps)?

\[
D(t) = [K_1 L_0] \cdot [\exp(-K_1 t) - \exp(-K_2 t)] / (K_2 - K_1) + [D_0 \exp(-K_2 t)]
\]

Time for critical DO deficit (t_c) = 1 / (K_2 - K_1) \cdot \ln \left[ \frac{K_2}{K_1} \cdot \frac{1 - D_0 (K_2 - K_1)}{K_1 L_0} \right]

Critical DO deficit (D_c) = (K_2 / K_1) \cdot L_0 \cdot \exp(-K_1 t_c)

Q5. Two industries situated at 1 Km apart are discharging wastewater in a river (BOD effluent =500 mg/L for both cases). Draw a DO sag curve with distance downstream of discharge location? How does DO sag curve change if BOD effluent becomes 200 mg/L? Redraw it.