SOLUTIONS

1) Suppose some wastewater had a BOD$_5$ equal to 180 mg/L and a reaction rate $k$ equal to 0.22/day. It also has total Kjedahl nitrogen content (TKN) of 30 mg/L.
   a. Find the ultimate carbonaceous oxygen demand (CBOD).
   b. Find the ultimate nitrogenous oxygen demand (NBOD).
   c. Find the remaining BOD (nitrogenous plus carbonaceous) after five days have elapsed.

2) A wastewater treatment plant discharges 1.0 m$^3$/s of effluent having an ultimate BOD of 40 mg/L into a stream flowing at 10.0 m$^3$/s. Just upstream from the discharge point, the stream has an ultimate BOD of 3.0 mg/L. The deoxygenation constant $k_d$ is estimated at 0.22/day.
   a. Assuming complete and instantaneous mixing, find the ultimate BOD of the mixture of waste and river just downstream from the outfall.
   b. Assuming a constant cross-sectional area for the stream equal to 55 m$^2$, what BOD would you expect to find at a point 10,000 m downstream.

3) The wastewater in Problem 1 has DO equal to 4.0 mg/L when it is discharged. The river has its own DO, just upstream from the outfall, equal to 8.0 mg/L. Find the initial oxygen deficit of the mixture just downstream from the discharge point. The temperatures of sewage and river are both 15° C.

4) Two point sources of BOD along a river (A and B) cause the oxygen sag curve shown in the following image.

   a. Sketch the rate of reaeration vs. distance downriver.
   b. Sketch $L_t$ (that is, the BOD remaining) as a function of distance downriver.
5) Untreated sewage with a BOD of 240 mg/L is sent to a wastewater treatment plant where 50 percent of the BOD is removed. The river receiving the effluent has the oxygen sag curve as shown in the following figure (the river has no other sources of BOD). Notice that downstream is expressed in both miles and days.

![Oxygen Sag Curve](image)

a. Suppose the treatment plant breaks down and it no longer removes any BOD. Sketch the new oxygen sag curve starting just after the breakdown. Label the point which represents the critical distance downriver.

b. Sketch the oxygen sag curve, as it would have appeared four day after the breakdown of the treatment plant.

6) The ultimate BOD of a river just below a sewage outfall is 50.0 mg/L and the DO is at the saturation value of 10.0 mg/L. The deoxygenation rate coefficient \( k_d \) is 0.30/day and the reaeration rate coefficient \( k_r \) is 0.90/day. The river is flowing at the speed of 48.0 miles per day. The only source of BOD in this river is the single outfall.

a. Find the critical distance downstream at which DO is minimum.

b. Find the minimum DO.

c. If a wastewater treatment plant is to be build, what fraction of the BOD would have to be removed from the sewage to assure a minimum DO concentration of 5.0 mg/L everywhere downstream?

7) A city of 200,000 people deposits 37 cubic feet per second (cfs) of sewage having a BOD of 28.0 mg/L and 1.8 mg/L of DO into a river that has a flow rate of 250 cfs and a flow speed of 1.2 ft/s. Just upstream of the release point, the river has a BOD of 3.6 mg/L and a DO of 7.6 mg/L. The saturation value of DO is 8.5 mg/L. The deoxygenation coefficient \( k_d \) is 0.61/day and the reaeration coefficient \( k_r \) is 0.76/day. Assuming complete and instantaneous mixing of the sewage and river find

a. The initial oxygen deficit and ultimate BOD just downstream of the outfall

b. The time and distance to reach the minimum DO

c. The minimum DO

d. The DO that could be expected 10 miles downstream
8) The town of Martins Creek, PA, has filed a complaint with the Department of Environmental Protection (DEP) citing the town of Portland, PA, for the discharge of raw sewage into the Delaware River. The raw sewage is considered to be the cause of high fecal coliform counts and reduced levels of dissolved oxygen (DO), which have lead to foul odors along the river between Portland and Martins Creek. The coliform counts and reduced DO levels have lead to restrictions of recreational areas within the Portland/Martins Creek reach of the Delaware River.

The DEP water quality criterion for the Delaware River is 5 mg/L of DO (i.e. at no point shall the DO concentration drop below 5 mg/L). Martins Creek is 15.55 km down stream of Portland.

The following data pertain to the 7-year, 10-day low flow at Portland:

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<td>11.40</td>
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<tr>
<td>DO (mg/L)</td>
<td>1.00</td>
<td>7.95</td>
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<tr>
<td>k at 20°C (day$^{-1}$)</td>
<td>0.4375</td>
<td>k of BOD in river is based on WW</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>16.00</td>
<td>28.00</td>
</tr>
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</table>

Data of river after WWTP:

- Average Speed (m/sec): N/A
- Average Depth (m): N/A
- Bed-activity coefficient: N/A

A) What is the DO concentration as mg/L at Martins Creek?

**WWTP**

BOD$_5$ = 128 mg/L at 16°C

Flow = 0.1507 m$^3$/sec

DO = 1.0 mg/L

T = 16°C

k = 0.4375

**River before Portland**

BOD$_u$ = 11.40 mg/L

Flow = 1.08 m$^3$/sec

DO = 7.95 mg/L

T = 28°C

**Distance between Portland and Martins Creek is 15.55 km**

B) Does your answer make sense based on the complaint received?
Problem Statement: Suppose some waste water has a BOD_5 equal to 180 mg/L and a reaction rate k of 0.22/day. It also has a TKN of 30 mg/L. Find (A) ultimate carbonaceous oxygen demand (CBOD), (B) ultimate nitrogenous oxygen demand (NBOD), and (C) the remaining BOD (nitrogenous plus carbonaceous) after 5 days.

Givens: BOD_5 = 180 mg/L
k = 0.22/day
TKN = 30 mg/L

Assumptions: First order kinetics
constant temp
4.57 mg O_2/mg N

A) Find: CBOD ultimate

BOD_5 = L_0 \left(1 - e^{-k(t)}\right)
180 mg/L = L_0 \left(1 - e^{-0.22(5)}\right)

\[
180 mg/L = L_0 \left(0.667\right)
\]

\[
L_0 = 269.8 mg/L O_2
\]

B) Find: NBOD ultimate

\[
NBOD_u = (4.57 mg O_2/mg N)(TKN)
\]

\[
NBOD_u = (4.57 mg O_2/mg N)(30 mg/L N)
\]

\[
NBOD_u = 137.1 mg/L O_2
\]
C) Find: BOD remaining @ day 5 (RBOD₅)

\[ \text{BOD}_{\text{total}} = \text{CBOD}_{\text{a}} + \text{NBOD}_{\text{a}} \]
\[ \text{BOD}_{\text{total}} = 2.698 \text{ mg/L O}_2 + 137.1 \text{ mg/L O}_2 \]
\[ \text{BOD}_{\text{total}} = 406.9 \text{ mg/L O}_2 \]

\[ \text{RBOD}_{\text{₅}} = \text{BOD}_{\text{total}} - \text{BOD}_{\text{₅}} \]
\[ \text{RBOD}_{\text{₅}} = 406.9 \text{ mg/L O}_2 - 180 \text{ mg/L O}_2 \]
\[ \text{RBOD}_{\text{₅}} = 226.9 \text{ mg/L O}_2 \]
Problem Statement: A WWTP discharges 1.0 m³/s of effluent having an $BOD_u$ of 40 mg/L into a stream flowing at 10.0 m³/sec. Just upstream from the discharge point, the stream has a $BOD_u$ of 3.0 mg/L. $K_s$ is estimated at 0.22/day. Find A) $BOD_u$ of mixture of river and waste just downstream of outfall and B) $BOD_10$ 1,000 m downstream.

Assumptions: First order kinetics
- complete and instantaneous mixing
- constant temp.

Given and FRD:

$Q_{wtrp} = 1.0 \text{ m}^3/\text{sec}$
$BOD_{wtrp} = 40 \text{ mg/L}$

$Q_s = 10 \text{ m}^3/\text{sec}$
$BOD_s = 3 \text{ mg/L}$

A) Find: $BOD_u$ after mixing ($L_a$)

$$L_a = \frac{Q_{wtrp} (L_{wtrp}) + (Q_s)(L_s)}{Q_{wtrp} + Q_s}$$

$$L_a = \frac{(1.0 \text{ m}^3/\text{sec})(40 \text{ mg/L}) + (10 \text{ m}^3/\text{sec})(3 \text{ mg/L})}{1.0 \text{ m}^3/\text{sec} + 10 \text{ m}^3/\text{sec}}$$

$$L_a = 6.36 \text{ mg/L}$$
8) Find: BOD, 10,000 m downstream

\[ v = \frac{11 \text{ m}^3/\text{sec}}{55 \text{ m}^2} = 0.2 \text{ m/sec} \]

\[ \frac{10,000 \text{ m}}{0.2 \text{ m}} = 50,000 \text{ sec} \]

\[ \frac{50,000 \text{ sec}}{60 \text{ sec}} = \frac{500 \text{ min}}{60 \text{ min}} = \frac{10 \text{ hr}}{24 \text{ hr}} = 0.417 \text{ days} \]

\[ L(t) = L_0 e^{-k_d t} \]

\[ L_{0.579} = (6.36 \text{ mg/L} \cdot L_0) e^{(-0.22\text{/day})(0.579)} \]

\[ L_{0.579} = 5.60 \text{ mg/L} \cdot L_0 \]
3) **Problem Statement:** The waste water in Problem 1 has a DO equal to 4.0 mg/L when it is discharged. The river has a DO just upstream from the outfall equal to 8.0 mg/L. Find the initial oxygen deficit of the mixture just downstream from the discharge point. The temp of the sewage and river are both 15°C.

**Given and FBD:**
- BOD<sub>r</sub> = 150 mg/L O<sub>2</sub>
- TN = 30 mg/L O<sub>2</sub>
- DO<sub>r</sub> = 4.0 mg/L O<sub>2</sub>
- T = 15°C
- Q<sub>WWTP</sub> = ?

- DO<sub>5</sub> = 8.0 mg/L O<sub>2</sub>
- T = 15°C
- Q = ?

**Assumptions:**
- Complete and instantaneous mixing
- Constant temp of 15°C
- DO<sub>5</sub> = 10.15 mg/L O<sub>2</sub> (from textbook)

**Find:** Initial oxygen deficit just after mixing (D<sub>a</sub>)

\[
D_a = D_0 - \left( \frac{Q_{WWTP}}{Q_{WWTP} + Q_c} \right) D_0 + Q_c (DO) \]

\[
D_a = 10.15 mg/L O_2 - \left( \frac{Q_{WWTP}}{Q_{WWTP} + Q_c} \right) 4.0 mg/L O_2 + Q_c (8.0 mg/L) \]

\[
Q_{WWTP} + Q_c \]

**Sorry, not sure how to solve for D<sub>a</sub> without Q for the stream or WWTP effluent.**
4. Problem Statement: Two point sources of BOD along a river (A and B) cause the oxygen sag curve shown in the following image. Sketch the rate of regeneration and BOD as a function of distance down river.
Problem Statement: Untreated sewage with a BOD of 240 mg/l is sent to a WWTP where 50% of BOD is removed. Find A) the new oxygen sag curve if the WWTP broke down and B) the oxygen sag curve as it would have appeared four days after the breakdown.

Assumptions: The river has no other sources of BOD

\[ \text{BOD} = 240 \text{ mg/l} \]

\[ \text{WWTP} \rightarrow \text{BOD} = 120 \text{ mg/l} \]

\[ \text{stream} \rightarrow v = 30 \text{ miles/day} \]

---

A) After WWTP broke down =

B) 4 days after breakdown =

Operating WWTP =
The ultimate BOD of a river just below a sewage outfall is 50 mg/L and the DO is at the saturation value of 10 mg/L. The deoxygenation rate coefficient, $k_d$, is 0.30/day and the reoxygenation rate constant, $k_r$, is 0.90/day. The river is flowing at the speed of 48 miles/day. The only source of BOD in this river is the single outfall.

Assumptions:
- Complete and instantaneous mixing
- Steady state non-conservative
- Constant temp.
- $k$ is constant ($k_r$ and $k_d$)
- No additions/removals

Known:
- Ult BOD$_{end}$ = $L_o$ = 50 mg/L
- Speed = 48 miles/day
- $k_r$ = 0.9/day & $k_d$ = 0.3
(a) Find the critical distance downstream at which DO is minimum.

\[ t_c = \frac{1}{k_r - k_d} \ln \left\{ \frac{1 - D_0 (k_r - k_d)}{k_d L_0} \right\} \]

\[ t_c = \frac{1}{0.1/day - 0.3/day} \ln \left\{ \frac{0.9/day}{0.3/day} \right\} = 1.83 \text{ days} \]

\[ \text{speed} \left( v \right) = \frac{\text{distance} \left( x \right)}{\text{time} \left( t \right)} \rightarrow x = vt = \left( 4.8 \text{ miles/day} \right) (1.83 \text{ days}) = 87.84 \text{ miles} \]

(b) Find the minimum DO.

\[ D_0 = \frac{k_d L_0 \left( e^{-k_d t} - e^{-k_r t} \right)}{k_r - k_d} + D_{ao} e^{-k_r t} \]

\[ D_{max} = \left( \frac{0.3/day (50 \text{ mg/L})}{0.9/day - 0.3/day} \right) \left( e^{-0.3/day (1.83)} - e^{-0.9/day (1.83)} \right) = 9.62 \text{ mg/L} \]

\[ D_{min} = D_0 - D_{max} \]

\[ = 10 \text{ mg/L} - 9.62 \text{ mg/L} = 0.38 \text{ mg/L} \]

(c) If a WWTP is to be built, what fraction of the BOD would have to be removed from the sewage to assure a minimum DO concentration of 5.0 mg/L everywhere downstream?

\[ \text{It's a ratio:} \frac{\text{DO desired}}{\text{DO have (max amount)}} = \frac{10 \text{ mg/L} - 5 \text{ mg/L}}{9.62 \text{ mg/L}} = 0.52 \]

\[ 1.0 - 0.52 = 0.48 = 48\% \]

2) A city of 200,000 people deposits 37 cfs of sewage, having a BOD of 28 mg/L and 1.8 mg/L of DO into a river that has a flow rate of 250 cfs and a flow speed of 1.2 ft/s. Just upstream of the release point, the river has a BOD of 3.6 mg/L and a DO of 7.6 mg/L. The saturation value of DO is 8.5 mg/L. The deoxygenation coefficient \( k_d \) is 0.6/day and the reaeration coefficient \( k_r \) is 0.76/day. Assume complete and instantaneous mixing.
**Assumptions:**
- $k$ is constant ($k_r$ and $k_d$)
- Constant temp.
- No additions/removals
- Complete and instantaneous mixing
- Steady state conservative

**Knowns:**
- DO at beginning of river = $D_0 = 7.6 \text{ mg/L}$
- DO at end of river = $D_{o_w} = 1.8 \text{ mg/L}$
- $k_r = 0.76 / \text{day}$ and $k_d = 0.61 / \text{day}$
- Flow rate at beginning = $Q_R = 250 \text{ cfs}$
- Flow rate at end = $Q_w = 37 \text{ cfs}$
- Flow rate of river = $v = 1.24 \text{ ft/s}$
- BOD beginning = $L_R = 3.6 \text{ mg/L}$
- BOD end = $L_{o_w} = 28 \text{ mg/L}$
- $D_{o sat} = 8.5 \text{ mg/L}$

(a) Find the initial oxygen deficit and ultimate BOD just downstream of the outfall.

$$D_a = D_{o sat} - \left[ \frac{Q_w D_{o_w} + Q_R D_R}{Q_w + Q_R} \right]$$

$$= 8.5 \text{ mg/L} - \left[ \frac{(37 \text{ cfs})(1.8 \text{ mg/L}) + (250 \text{ cfs})(7.6 \text{ mg/L})}{(37 \text{ cfs}) + (250 \text{ cfs})} \right] = 1.65 \text{ mg/L} \quad \text{(initial deficit)}$$

$$L_o = \frac{Q_w L_{o_w} + Q_R L_R}{Q_w + Q_R}$$

$$= \frac{(37 \text{ cfs})(28 \text{ mg/L}) + (250 \text{ cfs})(3.6 \text{ mg/L})}{(37 \text{ cfs}) + (250 \text{ cfs})} = 6.75 \text{ mg/L} \quad \text{(initial BOD)}$$

(b) The time and distance to reach the minimum DO

$$t_c = \frac{1}{k_r - k_d} \ln \left\{ \frac{k_r}{k_d} \left[ 1 - \frac{D_a(k_r - k_d)}{k_d L_o} \right] \right\}$$

$$= \frac{1}{(0.76 / \text{day}) - (0.61 / \text{day})} \ln \left[ \frac{0.76 / \text{day}}{0.61 / \text{day}} \left[ 1 - \frac{1.65 \text{ mg/L}(0.76 / \text{day}) - (0.61 / \text{day})}{(0.61 / \text{day})(6.75 \text{ mg/L})} \right] \right]$$

$$= 1.05 \text{ days}$$
\[
x = \sqrt{\frac{1.2 \text{ ft} \times 3600 \text{ s} \times 24 \text{ hours}}{1 \text{ s} \times 1 \text{ hour} \times 1 \text{ day}}} = \frac{108,864 \text{ ft}}{1 \text{ day}}
\]

Usually in terms of miles: \[
\frac{108,864 \text{ ft}}{5,280 \text{ ft/mile}} = 20.6 \text{ miles}
\]

(c) Find the minimum DO
\[
D_{O_{\text{min}}} = D_{O_{\text{saturation}}} - D_{O_{\text{max}}}
\]
\[
D_{O_{\text{max}}} = \frac{k_d h_o}{k_r - k_d} \left( e^{-k_d t} - e^{-k_r t} \right) + D_o e^{-k_r t}
\]
\[
= \frac{(0.61/\text{day})(6.75 \text{ mg/L})}{(0.76/\text{day}) - (0.61/\text{day})} \left( e^{-(0.61/\text{day})(1.05 \text{ days})} - e^{-(0.76/\text{day})(1.05 \text{ days})} \right) + 1.65 e^{-0.76/\text{day}(0.1 \text{ mg/L})}
\]
\[
= 2.85 \text{ mg/L}
\]
\[
D_{O_{\text{min}}} = D_o - D_{O_{\text{max}}}
\]
\[
= 8.5 \text{ mg/L} - 2.85 \text{ mg/L} = 5.65 \text{ mg/L}
\]

(d) Find the DO that could be expected 10 miles downstream

Time in terms of days:
\[
10 \text{ miles} \times \frac{5,280 \text{ ft}}{1 \text{ mile}} = 52,800 \text{ ft}
\]
\[
\frac{1.2 \text{ ft}}{1 \text{ s}} \times \frac{3600 \text{ s}}{1 \text{ hour}} \times \frac{24 \text{ hours}}{1 \text{ day}} = 103,680 \text{ ft/day}
\]
\[
D_{O_{\text{min}}} = D_o - D_{O_{\text{max}}}
\]
\[
D_{O_{\text{max}}} = \frac{(0.61/\text{day})(6.75 \text{ mg/L})}{(0.76/\text{day}) - (0.61/\text{day})} \left( e^{-(0.61/\text{day})(0.5 \text{ days})} - e^{-(0.76/\text{day})(0.5 \text{ days})} \right) + 1.65 e^{-0.76/\text{day}(0.1 \text{ mg/L})}
\]
\[
= 2.6 \text{ mg/L}
\]
\[
D_{O_{\text{min}}} = 8.5 \text{ mg/L} - 2.6 \text{ mg/L} = 5.9 \text{ mg/L}
\]
The town of Martins Creek, PA, has filed a complaint with the Department of Environmental Protection (DEP) citing the town of Portland, PA, for the discharge of raw sewage into the Delaware River. The raw sewage is considered to be the cause of high fecal coliform counts and reduced levels of dissolved oxygen (DO), which have lead to foul odors along the river between Portland and Martins Creek. The coliform counts and reduced DO levels have lead to restrictions of recreational areas within the Portland/Martins Creek reach of the Delaware River.

The DEP water quality criterion for the Delaware River is 5 mg/L of DO (i.e. at no point shall the DO concentration drop below 5 mg/L).

Martins Creek is 15.55 km down stream of Portland.

The following data pertain to the 7-year, 10-day low flow at Portland

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Data of river after WWTP

| Average Speed (m/sec) | N/A | 0.390 |
| Average Depth (m)     | N/A | 2.80  |
| Bed-activity coefficient | N/A | 0.200 |

A) What is the DO concentration as mg/L at Martins Creek?

**WWTP**

$BOD_5 = 128 \text{ mg/L at 16°C}$

Flow = 0.1507 m/sec

$DO = 1.0 \text{ mg/L}$

$T = 16 \degree C$

$k = 0.4375$

**River before Portland**

$BOD_u = 11.40 \text{ mg/L}$

Flow = 1.08 m/sec

$DO = 7.95 \text{ mg/L}$

$T = 28 \degree C$

**River after Portland**

Speed = 0.390 m/s

Depth = 2.8 m

Bed Activity = 0.20

**Martins Creek**

$DO = ?$

Distance between Portland and Martins Creek is 15.55 km

B) Does your answer make sense based on the complaint received?
(a) What is the DO concentration as mg/L at Martin’s Creek?

\[
\text{speed} = \frac{\text{distance}}{\text{time}} \rightarrow t = \frac{d}{s}
\]

\[
t = \frac{15.5 \text{ km}}{1 \text{ km}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ s}}{0.390 \text{ m}} \times \frac{1 \text{ hour}}{3600 \text{ s}} \times \frac{1 \text{ day}}{24 \text{ hours}} = 0.461 \text{ days (time to travel)}
\]

Temp. downstream: 
\[
\frac{Q_w T_w + Q_{R} T_{R}}{Q_w + Q_R} = \left( \frac{0.1507 \text{ m}^3/\text{s}}{0.1507 \text{ m}^3/\text{s}} \right) (16^\circ \text{C}) + \left( 1.08 \text{ m}^3/\text{s} \right) (28^\circ \text{C}) = 26.5
\]

Use ratio to solve for DO_{sat} @ 26.5^\circ \text{C}: * using Table 5.11 values *

\[
\frac{30^\circ \text{C}-35^\circ \text{C}}{7.5^\circ \text{C}-8.26^\circ \text{C}} \rightarrow x = \frac{-8.26}{-0.7}
\]

\[
x = 8.05 \text{ mg/L}
\]

\[
D_o = D_{o_{sat}} - \left[ \frac{Q_w D_{o_{sat}} + Q_{R} D_{o_{R}}}{Q_w + Q_R} \right]
\]

\[
D_o = 8.05 \text{ mg/L} - \left[ \left( \frac{0.1507 \text{ m}^3/\text{s}}{0.1507 \text{ m}^3/\text{s}} \right) (1.0 \text{ mg/L}) + \left( 1.08 \text{ m}^3/\text{s} \right) (19.5 \text{ mg/L}) \right] = 0.95 \text{ mg/L}
\]

\[
L_o @ 28^\circ \text{C} = L_o @ 20^\circ \text{C} = 11.40 \text{ mg/L}
\]

\[
k @ 16^\circ \text{C}:
\]

\[
k_T = k_{20} \theta (r-20) \rightarrow k_{16} = (0.4735/\text{day})(1.135)(16-20) = 0.264/\text{day}
\]

now solve for \( L_o @ 16^\circ \text{C}:
\]

\[
BOD_5 = L_o (1 - e^{-kt}) \rightarrow L_o = \frac{BOD_5}{1 - e^{-k_{16} \theta (5 \text{ days})}} = 174.66 \text{ mg/L}
\]

\[
L_a = \frac{Q_w L_w + Q_{R} L_{R}}{Q_w + Q_R} = \left( \frac{0.1507 \text{ m}^3/\text{s}}{0.1507 \text{ m}^3/\text{s}} \right) (174.66 \text{ mg/L}) + \left( 1.08 \text{ m}^3/\text{s} \right) (11.40 \text{ mg/L})
\]

\[
= 31.39 \text{ mg/L}
\]
solve for $k_d$ and $k_r$:

$$k_r(20^\circ C) = k_r = \frac{3.9 \eta^{1/2}}{h^{3/2}} = \frac{3.9 (0.390 \text{m/l})^{1/2}}{(2.8 \text{m})^{3/2}} = 0.5198 / \text{day}$$

$$k_{26.5} = 0.5198 (1.024)(26.5 - 20) = 0.6064 / \text{day}$$

$$k_d(20^\circ C) = k_d = k + \frac{\mu}{h} \eta = 0.4375 / \text{day} + (\frac{0.390 \text{m/l}}{2.8 \text{m}})(0.2) = 0.4654 / \text{day}$$

$$k_d(26.5^\circ C) = k_{26.5} = 0.4654 / \text{day} (1.056)(26.5 - 20) = 0.6632 / \text{day}$$

$$D_l = \frac{k_dL_o}{k_i - k_d}(e^{-k_dL_o} - e^{-k_it}) + D_o e^{-k_rt}$$

$$= \frac{(0.6632 / \text{day})(31.39 \text{mg/L})}{(0.6064 / \text{day}) - (0.6632 / \text{day})}(e^{-0.6632 / \text{day} \times 0.461 / \text{day}} - e^{-0.6064 / \text{day} \times 0.461 / \text{day}}) - 0.95 \text{mg/L}(e^{-0.6064 / \text{day} \times 0.461 / \text{day}})$$

$$= 7.88 \text{mg/L} \rightarrow DO = DO_o - D_l = 8.05 \text{mg/L} - 7.88 \text{mg/L} = 0.17 \text{mg/L}$$

(b) does your answer make sense based on the complaint?

Yes. DO close to zero = odor.