MIDTERM 2

Please sign Honor Code Statement: I have not given or received unauthorized assistance during this exam.

Answer all questions. Test is open book and notes. Always specify your approach to solving a problem (appropriate formulas, steps to be followed, assumptions, etc.) even if you cannot complete it. Partial credit will be given for a correct approach. Indicate your answers clearly by boxing or arrows. Don't forget that dimensions are part of the answer.

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<td>3</td>
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<td>4</td>
<td>/20</td>
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<td>Total</td>
<td>/100</td>
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</table>
1. (40 points total) A tomato cannery discharges $5 \times 10^4$ m$^3$/d of wastewater with BOD$_w$ = 400 g/m$^3$ and 2 g/m$^3$ dissolved oxygen (DO$_w$) to the San Joaquin River during August and September. No wastewater is discharged during the rest of the year. The river flow rate year-round is $2 \times 10^4$ m$^3$/d. Upstream of the cannery discharge, the BOD$_r$ = 3 g/m$^3$ and the DO$_r$ = 7 g/m$^3$.

The 1st-order BOD consumption rate coefficient, $k_b$ = 0.24 d$^{-1}$ during those months, and the reaeration coefficient, $k_r$ = 0.32 d$^{-1}$. The saturation DO concentration for the water is 8.5 g/m$^3$.

San Joaquin River
Q$_r$, BOD$_r$, DO$_r$

wastewater discharge
Q$_w$, BOD$_w$, DO$_w$

The State environmental protection agency wants the cannery to treat their wastewater to BOD$_w$ = 30 g/m$^3$ claiming that this will maintain the minimum DO level in the river downstream of 4.5 g/m$^3$ during August and September.

a) (15 points) Is the State correct? (Show calculations to justify your answer.)

$$\text{BOD}_0 = \frac{5 \times 10^4 (30) + 2 \times 10^4 (3)}{2.5 \times 10^5} = 8.4 \text{ g/m}^3$$

$$D_0 = 8.5 - \left( \frac{5 \times 10^4 (3) + 2 \times 10^4 (7)}{2.5 \times 10^5} \right) = 2.5 \text{ g/m}^3$$

$$t_c = \frac{1}{(0.32-0.24)} \ln \left[ \frac{0.32}{0.24} \left( 1 - \frac{2.5(0.32-0.24)}{8.4(0.24)} \right) \right] = 2.3 \text{ d}$$

$$D_C = \frac{0.24 (8.4)}{0.32} \exp \left( -2.3(0.24) \right) = 3.64 \text{ g/m}^3 \sqrt{\text{ }}$$

$$D_{OC} = 8.5 - 3.64 = \frac{4.86 \text{ g/m}^3}{\text{}} > 4.5 \text{ g/m}^3$$

State is correct.
However, the cannery feels that building a facility to get this level of treatment is too expensive for use only 2 months out of the year. There is lots of land at the cannery site, so they propose instead to build a large storage pond, essentially a facultative lagoon, to hold the August-September flows and discharge at a constant lower flow rate 12 months a year. Their engineer has told them to expect 50% BOD reduction in the holding pond. \( \text{DO}_w \) will still = 2 g/m³.

1b) (5 points) What will the new \( \text{BOD}_w \) and \( Q_w \) into the River be year-round with the storage pond?

\[
\text{new } Q_w = \frac{5 \times 10^4 \text{ m}^3/\text{d}}{365 \text{ d}} = \frac{18,360 \text{ m}^3/\text{yr year round}}{365 \text{ d}}
\]

\[
\text{new } \text{BOD}_w = 0.5 \left( \frac{400 \text{ g}}{\text{m}^3} \right) = \left( \frac{200 \text{ g}}{\text{m}^3} \right)
\]

1c) (15 points) Calculate the minimum \( \text{DO} \) downstream of the discharge under the cannery plan, assuming that all other conditions apply year-round. Based on your calculations, should the State allow the cannery to build the holding pond and discharge stored wastewater all year?

\[
\text{BOD}_0 = \frac{8360 \text{ (200) } + 2 \times 10^5 \text{ (3)}}{208360} = 11 \text{ g/m}^3
\]

\[
D_0 = 8.5 - \left( \frac{8360(2) + 2 \times 10^5(3)}{208360} \right) = 1.7 \text{ g/m}^3
\]

\[
t_c = \frac{1}{0.08} \ln \left( \frac{0.32}{0.24} \left( 1 - \frac{1.7(0.08)}{11(0.24)} \right) \right) = 2.93 \text{ d}
\]

\[
D_c = \frac{0.24(11)}{0.32} \exp\left( -2.93(0.24) \right) = 4.1 \text{ g/m}^3
\]

\[
\text{DO}_c = 8.5 - 4.1 = 4.4 \text{ g/m}^3
\]

This is pretty close to 4.5 - State could go either way.
1d) (5 points) Calculate the pond surface area if the allowable organic loading rate (OLR) is 100 kg/(ha*d) using the 12-month discharge flow rate and influent BOD to the pond = 400 g/m³.

\[
A_s = \frac{Q \text{ (BOD}_m\text{)} = 8360 \text{ m}^3/\text{d} (400 \text{ g/m}^3) \times 10^{-3} \text{ kg/ha.d}}{100 \text{ kg/ha.d}} = 33.4 \text{ ha}
\]

2. (20 points total) The land required for the pond was larger than the cannery operators expected, so they are considering building a Partially Mixed Aerated Lagoon system consisting of two ponds (CMFR's) of equal volume in series.

a) (5 points) The 1st-order BOD consumption rate coefficient for the PMAL = 0.2 d\(^{-1}\) at 20 °C. However, the critical wintertime temperature that the ponds must be designed for = 15 °C. If the temperature correction factor, \(C = 1.04\), what is the applicable BOD rate coefficient?

\[
K_{15} = K_{20} \times (15-20)^{-\frac{-5}{C}} = 0.2 \times (1.04)^{-\frac{-5}{1.04}} = 0.164 \text{ d}^{-1}
\]

b) (10 points) Calculate the residence time in the 2-cell PMAL system for 65% reduction in BOD for the year-round flow rate of 8,360 m³/d.

\[
\frac{\text{BOD}_2}{\text{BOD}_0} = \frac{1}{(1+K_C)^2} = 0.35
\]

\[
\tau = \frac{1}{K} \left( \frac{1}{\left( \frac{\text{BOD}_0}{\text{BOD}_2} \right)^{\frac{1}{2}}} - 1 \right) = \frac{1}{0.164} \left( \left( \frac{1}{0.35} \right)^{\frac{1}{2}} - 1 \right)
\]

\[
\tau = 4.2 \text{ d/cell}
\]

Total residence time = 2 \times 4.2 = 8.4 \text{ d}

c) (5 points) If the depth of the cells is 2.5 m, what is the total surface area for the 2-cell PMAL system?

\[
V = 8,360 \text{ m}^3 \times 8.4 \text{ d} = 70,200 \text{ m}^3
\]

\[
A_s = \frac{70,200 \text{ m}^3}{2.5 \text{ m}} = 28,100 \text{ m}^2 = 2.8 \text{ ha}
\]
3. (20 points total) Drinking water treatment process questions.

a) (10 points) Associate each process with two (2) operations or mechanisms by putting the appropriate letters in the blanks in column 1.

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>OPERATION or MECHANISM</th>
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<tbody>
<tr>
<td>filtration <em>K</em>, <em>M</em></td>
<td>A. slow mixing</td>
</tr>
<tr>
<td>coagulation <em>E</em>, <em>F</em></td>
<td>B. gravity</td>
</tr>
<tr>
<td>flocculation <em>A</em>, <em>C</em></td>
<td>C. particle collisions</td>
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<tr>
<td>sedimentation <em>B</em>, <em>H</em></td>
<td>D. flotation</td>
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<tr>
<td>disinfection <em>G</em>, <em>J</em></td>
<td>E. rapid mixing</td>
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<td></td>
<td>F. alum addition</td>
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<td></td>
<td>G. inactivation</td>
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<td>H. overflow rate</td>
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<td></td>
<td>I. biodegradation</td>
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<td>J. Chick's Law</td>
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<tr>
<td></td>
<td>K. interception</td>
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<td></td>
<td>L. evaporation</td>
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<td>M. backwashing</td>
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b) (10 points) Circle all of the following that are disinfectants:

1. Alum (Al₂(SO₄)₃·14H₂O)
2. Hypochlorous acid (HOCl)  
3. Monochloramine (NH₂Cl)   
4. Chloroform (CHCl₃)       
5. Ozone (O₃)               
6. Oxygen (O₂)              
7. Infrared light (IR)      
8. Ultraviolet light (UV)   
9. Iodine (I₂)              
10. Ammonia (NH₃)
4. (20 points total) A chlorine contact basin for disinfection is to be designed to act as an ideal plug flow reactor. Killing of the target organism, *E. coli*, follows Chick's and Watson's Laws. For a chlorine dose resulting in 1 mg/L of free chlorine, the 1st-order kill coefficient, $k = 0.23 \text{ min}^{-1}$.

a) (10 points) What volume is required for 2-log removal in the PFR contact basin if the water flow rate = 20,000 m$^3$/d?

$$\frac{N}{N_0} = 0.01 = \exp(-kt_c)$$

$$t_c = -\frac{\ln(N/N_0)}{k} = -\frac{\ln(0.01)}{0.23} = 20 \text{ min}$$

$$V = Qt_c = 20,000 \text{ m}^3/\text{d} \times \frac{20 \text{ min}}{1440 \text{ min}} = \frac{278 \text{ m}^3}{1}$$

b) (10 points) During summer, there are more bacteria entering the treatment plant, and 3-log removal will be necessary. If the value of "n" in Watson's Law = 1 ($C \cdot t_c = \alpha$, and $k = k' \cdot C$), what chlorine dose is required for 3-log removal?

3-log removal: $\frac{N}{N_0} = 0.001 = \exp(-k(20))$

$$K = -\frac{\ln(0.001)}{20} = 0.345 \text{ min}^{-1}$$

From a) $K' = \frac{k}{C} = 0.23 = 0.23$

$$C (3\text{-log removal}) = \frac{k}{K'} = \frac{0.345}{0.23} = \frac{1.5 \text{ g}}{\text{m}^3}$$