

**Seoul National University**

**457.621.001**

**Biological Processes in Environmental Engineering**

***FINAL EXAMINATION - Solutions***

**TIME ALLOWED: 80 MINUTES**

**May 31, 2023**

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1. Students may use two sheets of double-sided, A4-sized notes prepared in their own handwriting. Mechanical or electronic reproduction of any notes are not allowed.
  2. Students should bring their own calculator which is not pre-programmed with formulae from the class.
  3. Be aware that a student who cheated during the exam will get no credits.
  4. Make sure your answers include units if appropriate. Watch your units! Prepare your answers in a logical, easy-to-follow format.
  5. This exam contains 5 questions. The total points is 100.

1. Mark true or false (T/F) for the following statements.

Note: +1.5 points for correct answers, -1.5 points for incorrect answers, and 0 point if you choose not to answer.

1) Plasmid DNA replicates only when chromosomal DNA replicates.

Answer) *F*

2) Gram-positive bacteria have thicker peptidoglycan layer in their cell walls than Gram-negative bacteria do.

Answer) *T*

3) Competitive inhibitors permanently inactivates the reactivity of an enzyme.

Answer) *F*

4) Energy is released when adenosine triphosphate (ATP) is hydrolyzed to form adenosine diphosphate (ADP) and a phosphate ion ( $P_i$ ).

Answer) *T*

5) At the stationary growth state of bacteria, the cell synthesis rate by substrate utilization approximately equals to the cell decay rate.

Answer) *T*

6) Sulfate-reducing bacteria are activated in the presence of dissolved oxygen.

Answer) *F*

7) For denitrifying heterotrophs with a half saturation coefficient of 0.08 mg  $\text{NO}_3\text{-N/L}$ , the specific growth rate due to synthesis ( $\mu_{syn}$ ) changes by less than 1% at the  $\text{NO}_3\text{-}$  concentration range of  $>10$  mg  $\text{NO}_3\text{-N/L}$ .

Answer) *T*

8) Soluble microbial products (SMPs) are generally assumed to be biodegradable.

Answer) *T*

- 9) Settling of biomass is one of the major operational problems in the practical application of secondary treatment.

*Answer) T*

- 10) Membrane bioreactors (MBRs) are generally operated at higher volumetric organic loading rate (OLR) than conventional activated sludge.

*Answer) T*

2. Answer the followings.

- 1) Describe the i) structural and ii) functional difference between DNA and RNA. (7.5 points)

*Answer)*

*i) structural difference*

*DNA: deoxyribose as sugar, double-stranded, A, T, G, C as bases (1 item 당 1.5)*

*RNA: ribose as sugar, single-stranded, A, U, G, C as bases*

*ii) functional difference*

*DNA: long-term storage of genetic information, transmission of genetic information to other cells*

*RNA: transferring the genetic code from the DNA to ribosomes to produce proteins*

- 2) Classify the i) ammonia-oxidizing bacteria, ii) nitrite-oxidizing bacteria, and iii) heterotrophic denitrifiers in terms of energy source. Choose from: phototrophs, chemoorganotrophs, and chemolithotrophs. (4.5 points)

*Answer)*

*i) and ii): chemolithotrophs*

iii) *chemoorganotrophs*

3) Briefly describe the typical metabolic pathway for degradation of butyrate ( $C_3H_7COO^-$ ) in bacterial cells. (6 points)

*Answer)*

i) *combined with HS-CoA to form butyryl-CoA*

ii) *butyryl-CoA goes through beta oxidation to form two acetyl-CoA*

iii) *the two acetyl-CoAs go through citric acid cycle to be mineralized*

4) Describe key processes occurring in an anaerobic tank of an anaerobic/aerobic (A/O) process in terms of enhanced biological phosphorus removal. (6 points)

*Answer)*

- *Uptake and conversion of volatile fatty acids to accumulate PHA into cells of PAOs*
- *Hydrolysis of polyphosphates stored in PAOs to produce energy needed for PHA synthesis, which results in the release of phosphate to the aqueous phase*

5) Describe how i) methyl tert-butyl ether (MTBE) and ii) 2,3,7,8-tetrachlorodibenzodioxin (dioxin) is removed from wastewater in a wastewater treatment plant with primary sedimentation and secondary biological treatment (conventional activated sludge).

Note that: MTBE and dioxin are highly resistant to biodegradation; MTBE is highly volatile whereas dioxin is non-volatile; and the logarithm of organic carbon distribution coefficient ( $\log K_{oc}$ ) is 1.1 for MTBE and 7.4 for dioxin.

(4 points)

*Answer)*

*MTBE: volatilized to the air during the whole course of treatment with intensive*

*volatilization in the secondary treatment*

*dioxin: enters WWTP mainly in the particulate-associated form; precipitates with the particulates in the primary treatment and with the biological sludge in the secondary treatment*

3. Answer the followings.

1) Calculate the standard\* Gibb's free energy change for the reaction of hydrogen ( $H_2$ ) and oxygen ( $O_2$ ) to form water ( $H_2O$ ). Use half reactions given in the appendix. (8 points)

\* Standard condition: 25 °C, 1 atm, and unit activity for any chemicals involved (if  $H^+$  is involved, standard condition should include  $\{H^+\} = 1$  or  $pH = 0$ )

*Answer)*



*Because  $H^+$  is cancelled out in the overall reaction, the Gibb's free energy change for the overall reaction is not a function of  $\{H^+\}$ . Therefore,  $\Delta G^{0'} = \Delta G^0$  for the overall reaction.*

$$\underline{\Delta G^0 = -118.59 \text{ kJ/e}^- \text{ eq}}$$

2) A plug flow reactor (PFR) with a length of 40 m is treating a chemical that degrades following a 1st-order reaction. The concentration of the chemical at the inlet is 10 mg/L and the concentration at the halfway (i.e., 20 m away from the inlet) of the PFR is measured to be 2.5 mg/L. Predict the concentration of the chemical i) 30 m away from the inlet and ii) at the outlet. (6 points)

*Answer)*

*For PFR, all fluid elements at a specific distance are given the same time for reaction.*

Therefore, the fluid elements 20 m away from the inlet should have spent twice the half life of the chemical. Because the fluid elements 30 m away from the inlet spend three times the half life and those at the outlet four times the half life,

i) 30 m away = 1.25 mg/L

ii) outlet = 0.625 mg/L

- 3) An anaerobic digester receives a wastewater with a flow of 1,000 m<sup>3</sup>/d and a biodegradable COD (bCOD) value of 4,000 mg/L. At 90% bCOD removal and a net biomass yield of 0.05 g VSS/g COD, calculate the amount of methane produced in g CH<sub>4</sub>/d from the reactor. If needed, use 4.0 g COD/g CH<sub>4</sub> and 1.42 g COD/g VSS as the COD value for methane and for biomass, respectively. (8 points)

Answer)

$$\begin{aligned}
 (\text{Methane COD}) &= (\text{COD utilized}) - (\text{Biomass COD}) \\
 &= (\text{COD utilized}) \times (1 - 1.42 \times Y_n) \\
 &= 1,000 \text{ m}^3/\text{d} \times 4,000 \text{ g COD}/\text{m}^3 \times 0.9 \times (1 - 1.42 \times 0.05) \\
 &= 3,344,400 \text{ g COD}/\text{d}
 \end{aligned}$$

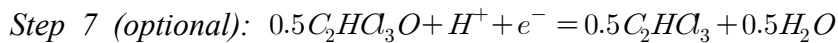
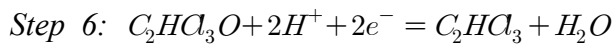
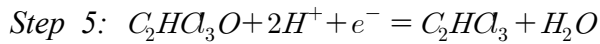
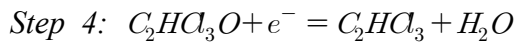
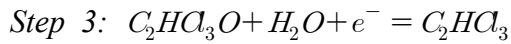
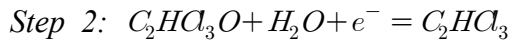
Therefore, the mass of methane produced is calculated as

$$\frac{3,344,400 \text{ g COD}/\text{d}}{4.0 \text{ g COD}/\text{g CH}_4} = 836,100 \text{ g CH}_4/\text{d} = 836 \text{ kg CH}_4/\text{d}$$

4. Trichloroethylene (C<sub>2</sub>HCl<sub>3</sub>) is oxidized to trichloroethylene epoxide (C<sub>2</sub>HCl<sub>3</sub>O) by methane or toluene monooxygenase via cometabolism. For this process, write the balanced i) half reaction (for the trichloroethylene oxidation only; in the direction of reduction) and the ii) overall reaction. (15 points)

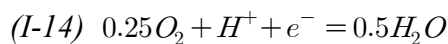
Answer)

i) half reaction

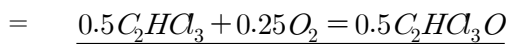
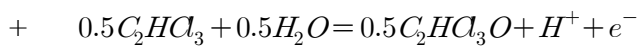
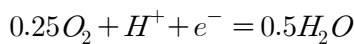


ii) overall reaction

The half reaction that is paired with the one above should be:



Combining the two half reactions:



5. Following table lists parameters for a laboratory chemostat (CSTR) in operation for aerobic treatment of wastewater. Using the parameter values, answer the questions below.

Item	Symbol	Value
Flowrate	$Q^0$	20 L/d
Influent soluble BOD	$S^0$	200 mg BOD <sub>L</sub> /L
Influent particulate BOD	$S_p^0$	0 mg BOD <sub>L</sub> /L
Influent active biomass	$X_a^0$	0 mg VSS/L
Influent nonbiodegradable VSS (nbVSS)	$X_i^0$	0 mg VSS/L
Chemostat volume	$V$	50 L
Maximum specific substrate utilization rate	$\hat{q}$	7.5 mg BOD <sub>L</sub> /mg VSS-d
Half saturation coefficient	$K$	10 mg BOD <sub>L</sub> /L
Decay coefficient	$b$	0.10 d <sup>-1</sup>
Biodegradable fraction of biomass	$f_d$	0.80
True yield	$Y$	0.50 mg VSS/mg BOD <sub>L</sub>

Notes:

- i) Neglect the production of soluble microbial products.
- ii) Assume that biomass tank can be represented as C<sub>5</sub>H<sub>7</sub>O<sub>2</sub>N.

1) Calculate the effluent soluble BOD. (4 points)

Answer)

$$\theta = \frac{V}{Q} = \frac{50 \text{ L}}{20 \text{ L/d}} = 2.5 \text{ d}$$

$$S = K \frac{1 + b\theta}{Y\hat{q}\theta - (1 + b\theta)} = 10 \cdot \frac{1 + 0.1 \cdot 2.5}{0.5 \cdot 7.5 \cdot 2.5 - (1 + 0.1 \cdot 2.5)} = 1.54 \text{ mg BOD}_L/\text{L}$$

2) Calculate the effluent particulate BOD. (6 points)

Answer)

$$X_a = Y \frac{S^0 - S}{1 + b\theta} = 0.5 \cdot \frac{200 - 1.54}{1 + 0.1 \cdot 2.5} = 79.38 \text{ mg VSS/L}$$

To convert the value as BOD,



$$1.42 \text{ mg COD/mg VSS} \cdot 0.8 \text{ BOD}_L/\text{COD} \cdot 79.38 \text{ mg VSS/L} = 90.2 \text{ mg BOD}_L/\text{L}$$

- 3) Calculate the (minimum) daily amount of i) nitrogen and ii) phosphorus that should be provided to the chemostat. Use mg/d as the unit. Assume that the influent does not contain any nitrogen or phosphorus. (10 points)

*Answer)*

*Amount of nutrient supply needed in daily basis*

$$-r_n V = -\gamma_n \cdot Y_{obs} \cdot r_{ut} \cdot V$$

$$Y_{obs} = Y \frac{1 + (1 - f_d)b\theta}{1 + b\theta} = 0.5 \cdot \frac{1 + (1 - 0.8) \cdot 0.1 \cdot 2.5}{1 + 0.1 \cdot 2.5} = 0.42 \text{ mg VSS/mg BOD}_L$$

$$r_{ut} = -\frac{S^0 - S}{\theta} = -\frac{200 - 1.54}{2.5} = -79.4 \text{ mg BOD}_L/\text{L} - d$$

$$\text{or } r_{ut} = -\frac{\hat{q}S}{K + S}X_a = -\frac{7.5 \cdot 1.54}{10 + 1.54} \cdot 79.38 = -79.4 \text{ mg BOD}_L/\text{L} - d$$

$$Y_{obs} \cdot r_{ut} \cdot V = 0.42 \text{ mg VSS/mg BOD}_L \cdot 79.4 \text{ mg BOD}_L/\text{L} - d \cdot 50 \text{ L} = -1667.4 \text{ mg VSS/d}$$

i) N

$$-\gamma_N \cdot Y_{obs} \cdot r_{ut} \cdot V = 0.124 \text{ g N/g VSS} \cdot 1667.4 \text{ mg VSS/d}$$

$$= 207 \text{ mg N/d}$$

ii) P

$$-\gamma_P \cdot Y_{obs} \cdot r_{ut} \cdot V = 0.025 \text{ g P/g VSS} \cdot 1667.4 \text{ mg VSS/d}$$

$$= 41.7 \text{ mg P/d}$$

## Appendix. List of half reactions

## Inorganic half-reactions and their Gibb's free energy at pH = 7.0

Textbook Table 2.1

Reaction Number	Reduced-oxidized Compounds	Half-reaction	$\Delta G^{0'}$ (kJ/e <sup>-</sup> eq)
I-1	Ammonium-nitrate	$\frac{1}{8}NO_3^- + \frac{5}{4}H^+ + e^- = \frac{1}{8}NH_4^+ + \frac{3}{8}H_2O$	-35.11
I-2	Ammonium-nitrite	$\frac{1}{6}NO_2^- + \frac{4}{3}H^+ + e^- = \frac{1}{6}NH_4^+ + \frac{1}{3}H_2O$	-32.93
I-3	Ammonium-Nitrogen	$\frac{1}{6}N_2 + \frac{4}{3}H^+ + e^- = \frac{1}{3}NH_4^+$	26.70
I-4	Ferrous-Ferric	$Fe^{3+} + e^- = Fe^{2+}$	-74.27
I-5	Hydrogen-H <sup>+</sup>	$H^+ + e^- = \frac{1}{2}H_2$	39.87
I-6	Nitrite-Nitrate	$\frac{1}{2}NO_3^- + H^+ + e^- = \frac{1}{2}NO_2^- + \frac{1}{2}H_2O$	-41.65
I-7	Nitrogen-Nitrate	$\frac{1}{5}NO_3^- + \frac{6}{5}H^+ + e^- = \frac{1}{10}N_2 + \frac{3}{5}H_2O$	-72.20
I-8	Nitrogen-Nitrite	$\frac{1}{3}NO_2^- + \frac{4}{3}H^+ + e^- = \frac{1}{6}N_2 + \frac{2}{3}H_2O$	-92.56
I-9	Sulfide-Sulfate	$\frac{1}{8}SO_4^{2-} + \frac{19}{16}H^+ + e^- = \frac{1}{16}H_2S + \frac{1}{16}HS^- + \frac{1}{2}H_2O$	20.85
I-10	Sulfide-Sulfite	$\frac{1}{6}SO_3^{2-} + \frac{5}{4}H^+ + e^- = \frac{1}{12}H_2S + \frac{1}{12}HS^- + \frac{1}{2}H_2O$	11.03
I-11	Sulfite-Sulfate	$\frac{1}{2}SO_4^{2-} + H^+ + e^- = \frac{1}{2}SO_3^{2-} + \frac{1}{2}H_2O$	50.30
I-12	Sulfur-Sulfate	$\frac{1}{6}SO_4^{2-} + \frac{4}{3}H^+ + e^- = \frac{1}{6}S + \frac{3}{2}H_2O$	19.15
I-13	Thiosulfate-Sulfate	$\frac{1}{4}SO_4^{2-} + \frac{5}{4}H^+ + e^- = \frac{1}{8}S_2O_3^{2-} + \frac{5}{8}H_2O$	23.58
I-14	Water-Oxygen	$\frac{1}{4}O_2 + H^+ + e^- = \frac{1}{2}H_2O$	-78.72