Seoul National University
457.621.001
Biological Processes in Environmental Engineering

FINAL EXAMINATION

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.

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

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

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

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

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

7) For denitrifying heterotrophs with a half saturation coefficient of 0.08 mg NO_3-N/L, the specific growth rate due to synthesis (μ_{syn}) changes by less than 1% at the NO_3-concentration range of >10 mg NO_3-N/L.

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

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

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

2. Answer the followings.

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

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)

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

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)

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)

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

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)

3) An anaerobic digester receives a wastewater with a flow of 1,000 m^3/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_4/d from the reactor. If needed, use 4.0 g COD/g CH_4 and 1.42 g COD/g VSS as the COD value for methane and for biomass, respectively. (8 points)

4. Trichloroethylene (C_2HCl_3) is oxidized to trichloroethylene epoxide (C_2HCl_3O) 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)

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_L/L
Influent particulate BOD	S_p^0	0 mg BOD_L/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_L/mg VSS-d
Half saturation coefficient	K	10 mg BOD_L/L
Decay coefficient	b	0.10 d^{-1}
Biodegradable fraction of biomass	f_d	0.80
True yield	Y	0.50 mg VSS/mg BOD_L

Notes:

i) Neglect the production of soluble microbial products.

ii) Assume that biomass tank can be represented as $C_5H_7O_2N$.

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

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

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)

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		$\Delta G^{0\prime}$ (kJ/e⁻ 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⁺	$H^+ + e^-$	$= \frac{1}{2}H_2$	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