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 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.

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 item당 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)

(I-14) $0.25O_2 + H^+ + e^- = 0.5H_2O$ $\Delta G^{0\prime} = -78.72$ kJ/e^- eq

\- (I-5) $0.5H_2 = H^+ + e^-$ $\Delta G^{0\prime} = -39.87$ kJ/e^- eq

= $0.25O_2 + 0.5H_2 = 0.5H_2O$ $\Delta G^{0\prime} = -118.59$ kJ/e^- eq

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, $\Delta G^{0\prime} = \Delta G^0$ 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^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)

Answer)

(Methane COD) = (COD utilized) - (Biomass COD)

$= (COD\ utilized) \times (1 - 1.42 \times Y_n)$

$= 1{,}000\ m^3/d \times 4{,}000\ g\ COD/m^3 \times 0.9 \times (1 - 1.42 \times 0.05)$

$= 3{,}344{,}400\ g\ COD/d$

Therefore, the mass of methane produced is calculated as

$$\frac{3{,}344{,}400\ g\ COD/d}{4.0\ g\ COD/g\ CH_4} = 836{,}100\ g\ CH_4/d = 836\ kg\ CH_4/d$$

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)

Answer)

i) half reaction

Step 1: $C_2HCl_3O = C_2HCl_3$

Step 2: $C_2HCl_3O + H_2O + e^- = C_2HCl_3$

Step 3: $C_2HCl_3O + H_2O + e^- = C_2HCl_3$

Step 4: $C_2HCl_3O + e^- = C_2HCl_3 + H_2O$

Step 5: $C_2HCl_3O + 2H^+ + e^- = C_2HCl_3 + H_2O$

Step 6: $C_2HCl_3O + 2H^+ + 2e^- = C_2HCl_3 + H_2O$

Step 7 (optional): $0.5C_2HCl_3O + H^+ + e^- = 0.5C_2HCl_3 + 0.5H_2O$

ii) overall reaction

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

(I-14) $0.25O_2 + H^+ + e^- = 0.5H_2O$

Combining the two half reactions:

$$0.25O_2 + H^+ + e^- = 0.5H_2O$$

$$+ \quad 0.5C_2HCl_3 + 0.5H_2O = 0.5C_2HCl_3O + H^+ + e^-$$

$$= \quad \underline{0.5C_2HCl_3 + 0.25O_2 = 0.5C_2HCl_3O}$$

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)

Answer)

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

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

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

Answer)

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

To convert the value as BOD,

$1.42\ mg\ COD/mg\ VSS \cdot 0.8\ BOD_L/COD \cdot 79.38\ mg\ VSS/L = 90.2\ mg\ BOD_L/L$

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

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

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

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

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

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

i) N

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

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

ii) P

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

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

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⁻ 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