**Seoul National University**

**457.621.001**

**Biological Processes in Environmental Engineering**

# *FINAL EXAMINATION*

## TIME ALLOWED: 90 MINUTES

**December 03, 2020**

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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 6 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) Classifying bacterial species into Gram positive and Gram negative bacteria is a way of taxonomic classification.

2) Under a sufficiently high substrate concentration, the enzyme reaction is not significantly affected by a competitive inhibitor.

3) Bacterial cells are generally assumed to be 100% biodegradable.

4) Fermentation of glucose to produce ethanol results in more than 50% loss in COD.

5) Pyruvate ($CH_3COCOO^-$) is the major energy storage material in bacterial cells.

6) At the same hydraulic retention time (HRT) value, a PFR (plug flow reactor) will show higher removal efficiency than a CSTR (continuously stirred tank reactor) for a chemical that undergoes first-order degradation reaction in the reactors.

7) A/O process is generally applied for the biological treatment of nitrogen and phosphorus.

8) Denitrification mediated by heterotrophs is an alkalinity-producing process.

9) Filamentous organisms generally show better settleability than phosphate accumulating organisms (PAOs).

10) Moving bed biofilm reactors (MBBRs) are generally operated at a higher volumetric organic loading rate (OLR) than conventional activated sludge.

2. Define the following biological processes.

1) Bacterial conjugation (5 points)

2) Simultaneous nitrification and denitrification (5 points)

3) Reductive dechlorination (5 points)

4) Cometabolism (5 points)

3. Answer the following questions.

1) Briefly describe strategies to form microbial granules that can be used to operate an aerobic granular sludge process. (6 points)

2) Discuss the opportunities and challenges of adopting anaerobic biological processes for mainstream domestic wastewater treatment. (6 points)

3) Describe the fate of a highly recalcitrant, non-volatile, and water-insoluble compound during a typical domestic wastewater treatment process. (6 points)

4. Write a balanced cell formation half reaction ($R_c$) using $CO_2$ as a carbon source and $NO_3^-$ as a nitrogen source. Use $C_5H_7O_2N$ as cell formula. Provide your final answer in an electron-equivalent form. (12 points)

5. Write up balanced energy reactions for the following biological processes. Pick up half reactions provided in Appendix to build up the reactions. Show which half reactions you select and how the half reactions are combined. Provide your final answer in an electron-equivalent form.

1) Glucose fermentation to lactate (5 points)

2) Anammox (5 points)

3) Hydrogenotrophic methanogenesis (5 points)

6. 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 | $S^0$ | 150 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) | $X_i^0$ | 20 mg VSS/L |
| Influent dissolved oxygen (DO) concentration | $S_{O_2}^0$ | 1.5 mg $O_2$/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 $BOD_L$ |
| First-order hydrolysis rate constant | $k_{hyd}$ | 0.20 $d^{-1}$ |
| Effluent dissolved oxygen (DO) concentration | $S_{O_2}$ | 1.5 mg $O_2$/L |

Notes:

i) Neglect the production of soluble microbial products.

ii) Assume that all forms of VSS in the aeration tank can be represented as $C_5H_7O_2N$.

1) The soluble $BOD_L$ value of the effluent (3 points)

2) Safety factor (SF), which is defined as

$$SF = \frac{\theta_x}{\theta_x^{\min}}$$

where $\theta_x$ = solids retention time (SRT) of the system

$\theta_x^{\min}$ = the SRT value above which value should be maintained to prevent washout

(4 points)

3) The total $BOD_L$ value of the effluent (7 points)

4) The amount of oxygen that should be provided into the chemostat (in g $O_2$/d) (6 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 |

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

Textbook Table 2.2

| Reaction Number | Reduced Compounds | Half-reaction | | $\Delta G^{0'}$ (kJ/e⁻ eq) |
|---|---|---|---|---|
| O-1 | Acetate | $\frac{1}{8}CO_2 + \frac{1}{8}HCO_3^- + H^+ + e^-$ | $= \frac{1}{8}CH_3COO^- + \frac{3}{8}H_2O$ | 27.40 |
| O-2 | Alanine | $\frac{1}{6}CO_2 + \frac{1}{12}HCO_3^- + \frac{1}{12}NH_4^+ + \frac{11}{12}H^+ + e^-$ | $= \frac{1}{12}CH_3CHNH_2COO^- + \frac{5}{12}H_2O$ | 31.37 |
| O-3 | Benzoate | $\frac{1}{5}CO_2 + \frac{1}{30}HCO_3^- + H^+ + e^-$ | $= \frac{1}{30}C_6H_5COO^- + \frac{13}{30}H_2O$ | 27.34 |
| O-4 | Citrate | $\frac{1}{6}CO_2 + \frac{1}{6}HCO_3^- + H^+ + e^-$ | $= \frac{1}{18}(COO^-)CH_2COH(COO^-)CH_2COO^- + \frac{4}{9}H_2O$ | 33.08 |
| O-5 | Ethanol | $\frac{1}{6}CO_2 + H^+ + e^-$ | $= \frac{1}{12}CH_3CH_2OH + \frac{1}{4}H_2O$ | 31.18 |
| O-6 | Formate | $\frac{1}{2}HCO_3^- + H^+ + e^-$ | $= \frac{1}{2}HCOO^- + \frac{1}{2}H_2O$ | 39.19 |
| O-7 | Glucose | $\frac{1}{4}CO_2 + H^+ + e^-$ | $= \frac{1}{24}C_6H_{12}O_6 + \frac{1}{4}H_2O$ | 41.35 |
| O-8 | Glutamate | $\frac{1}{6}CO_2 + \frac{1}{9}HCO_3^- + \frac{1}{18}NH_4^+ + H^+ + e^-$ | $= \frac{1}{18}COOHCH_2CH_2CHNH_2COO^- + \frac{4}{9}H_2O$ | 30.93 |
| O-9 | Glycerol | $\frac{3}{14}CO_2 + H^+ + e^-$ | $= \frac{1}{14}CH_2OHCHOHCH_2OH + \frac{3}{14}H_2O$ | 38.88 |
| O-10 | Glycine | $\frac{1}{6}CO_2 + \frac{1}{6}HCO_3^- + \frac{1}{6}NH_4^+ + H^+ + e^-$ | $= \frac{1}{6}CH_2NH_2COOH + \frac{1}{2}H_2O$ | 39.80 |
| O-11 | Lactate | $\frac{1}{6}CO_2 + \frac{1}{12}HCO_3^- + H^+ + e^-$ | $= \frac{1}{12}CH_3CHOHCOO^- + \frac{1}{3}H_2O$ | 32.29 |
| O-12 | Methane | $\frac{1}{8}CO_2 + H^+ + e^-$ | $= \frac{1}{8}CH_4 + \frac{1}{4}H_2O$ | 23.53 |
| O-13 | Methanol | $\frac{1}{6}CO_2 + H^+ + e^-$ | $= \frac{1}{6}CH_3OH + \frac{1}{6}H_2O$ | 36.84 |
| O-14 | Palmitate | $\frac{15}{19}CO_2 + \frac{1}{92}HCO_3^- + H^+ + e^-$ | $= \frac{1}{92}CH_3(CH_2)_{14}COO^- + \frac{31}{92}H_2O$ | 27.26 |
| O-15 | Propionate | $\frac{1}{7}CO_2 + \frac{1}{14}HCO_3^- + H^+ + e^-$ | $= \frac{1}{14}CH_3CH_2COO^- + \frac{5}{14}H_2O$ | 27.63 |
| O-16 | Pyruvate | $\frac{1}{5}CO_2 + \frac{1}{10}HCO_3^- + H^+ + e^-$ | $= \frac{1}{10}CH_3COCOO^- + \frac{2}{5}H_2O$ | 35.09 |
| O-17 | Succinate | $\frac{1}{7}CO_2 + \frac{1}{7}HCO_3^- + H^+ + e^-$ | $= \frac{1}{14}(CH_2)_2(COO^-)_2 + \frac{3}{7}H_2O$ | 29.09 |
| O-18 | Domestic Wastewater | $\frac{9}{50}CO_2 + \frac{1}{50}HCO_3^- + \frac{1}{50}NH_4^+ + H^+ + e^-$ | $= \frac{1}{50}C_{10}H_{19}O_3N + \frac{9}{25}H_2O$ | * |
| O-19 | Custom Organic | $\frac{(n-c)}{d}CO_2 + \frac{c}{d}HCO_3^- + \frac{c}{d}NH_4^+ + H^+ + e^-$ | $= \frac{1}{d}C_nH_aO_bN_c + \frac{2n-b+c}{d}H_2O$ where, $d = 4n + a - 2b - 3c$ | * |
| O-20 | Cell Synthesis | $\frac{1}{5}CO_2 + \frac{1}{20}HCO_3^- + \frac{1}{20}NH_4^+ + H^+ + e^-$ | $= \frac{1}{20}C_5H_7O_2N + \frac{9}{20}H_2O$ | * |

* Equations O-18 to O-20 do not have $\Delta G^{0'}$ values because the reduced species is not chemically defined.