Seoul National University

457.621.001

Biological Processes in Environmental Engineering

MIDTERM EXAMINATION (In-class)

TIME ALLOWED: 80 MINUTES

November 03, 2014

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1. Students may use two double-sided, A4 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 the cheated student will get 80% of the lowest score in class! There is no tolerance at all.

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 7 questions. Each full question is worth 15 to 35 points. Total points = 160.

Use following values for physical constants and properties, if needed:
Atomic weights: C, 12; Cl, 35.5; H, 1; N, 14; O, 16; P, 31; S, 32.1; Ca, 40
Density of water at 4°C: 1 g/cm^3

1. Takai et al. (2006) isolated a bacterial strain named as *Sulfurimonas paralvinellae*. They found that this strain uses elemental sulfur as the energy source, carbon dioxide as carbon source, and oxygen or nitrate as electron acceptor, with a preference to oxygen. Classify the bacterial strain in the following categories:

    i) By energy source: phototroph, organochemotroph, or lithochemotroph

    ii) By carbon source: autotroph or heterotroph

    iii) By growth in the presence/absence of O_2: obligate anaerobe, aerotolerant anaerobe, obligate aerobe, or facultative aerobe

(15 points)

2. Substrate inhibition is a type of reversible inhibition, occurring less frequently, where the enzyme-substrate complex (*ES*) combines with another substrate (*S*) to form substrate-enzyme-substrate complex (*SES*). The *SES* should be dissociated back to *ES* to produce the product (*P*). The entire enzyme reaction under substrate inhibition can be modeled as follows:

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \overset{k_2}{\longrightarrow} E + P$$

$$ES + S \underset{k_{-3}}{\overset{k_3}{\rightleftharpoons}} SES$$

Using four parameters, v_m, K_M, $[S]$, and K_s', write the velocity of the enzyme reaction (v) under substrate inhibition. You don't have to make the equation in the Michaelis-Menten form. Assume that the concentrations of *ES* and *SES* do not change with time. Note the following definitions of the parameters.

* v_m and K_M: the Michaelis-Menten parameters; v_m is the maximum velocity of the enzyme reaction and K_M is the half-reaction coefficient.
* $[S]$ denotes substrate concentration.
* $K_s' = k_{-3}/k_3$
(30 points)

3. You have a glucose-utilizing aerobe with a known true yield (Y) of 0.5 g VSS/g COD. You grew the microorganism in a bottle with complete mixing and found that the rate of glucose degradation was 100 mg COD/L/d when stationary growth was achieved in the bottle (i.e., Y_n = 0). The active biomass concentration (X_a) at stationary growth was 500 mg VSS/L.

   i) Calculate f_s^0 with an assumption that the cell synthesis reaction (R_s) can be represented as follows:

$$\frac{1}{5}CO_2+\frac{1}{20}HCO_3^-+\frac{1}{20}NH_4^++H^++e^-\rightarrow\frac{1}{20}C_5H_7O_2N+\frac{9}{20}H_2O$$

   (10 points)

   ii) Calculate the decay coefficient (b) of the microorganism. (10 points)

4. You are studying the stoichiometry of glucose ($C_6H_{12}O_6$) oxidation under anoxic condition. Answer the following:

   i) Write half reaction for cell synthesis (R_c) using nitrate (NO_3^-) as a nitrogen source. Use $C_5H_7O_2N$ as the cell formula. (15 points)

   ii) Write overall reaction for glucose oxidation using nitrate as an electron acceptor as well as a nitrogen source. Assume f_s = 0.5. Use following electron donor and acceptor half reactions. (15 points)

$$R_d\text{: } \frac{1}{4}CO_2+H^++e^-\rightarrow\frac{1}{24}C_6H_{12}O_6+\frac{1}{4}H_2O$$

$$R_a\text{: } \frac{1}{5}NO_3^-+\frac{6}{5}H^++e^-\rightarrow\frac{1}{10}N_2+\frac{3}{5}H_2O$$

   iii) Calculate the C/N consumption ratio (in g C/g N) for this reaction. (5 points)

5. Hydrolysis of particulate organic matter is often modeled as a first order reaction:

$$\frac{dS_p}{dt} = -k_{hyd} S_P$$

where k_{hyd} = first-order hydrolysis coefficient

S_p = particulate COD

For an influent particulate COD of 100 mg/L and the k_{hyd} of 0.2 d^{-1}, compute the effluent particulate COD of i) a plug flow reactor (PFR) and a ii) continuously-stirred tank reactor (CSTR) both having the hydraulic retention time (HRT) of 12 hours. (20 points)

6. You are designing laboratory chemostats (i.e., CSTRs) to treat a wastewater containing 100 mg BOD_L/L using suspended microorganisms. You are planningi to set up multiple chemostats with different hydraulic retention times (HRTs). First, you conducted batch experiments to find following parameters: the true yield, $Y = 0.5\, g\ VSS/g\ BOD_L$; the maximum specific substrate utilization rate, $\hat{q} = 20\, g\ BOD_L/g\ VSS/d$; the half-saturation coefficient, $K = 50\, mg\ BOD_L/L$; and the decay coefficient, $b = 0.10\, d^{-1}$. Answer the following:

   i) What is the smallest value of HRT you can try if you want to operate the chemostat at steady state? (10 points)

   ii) You are able to analyze the BOD_L of a water sample down to 0.1 mg BOD_L/L. If you run the chemostat with a very large HRT, will you still be able to analyze the BOD_L in the effluent sample? (10 points)

7. Sketch the substrate concentration profile of a i) deep and ii) shallow biofilm as a function of biofilm depth. Include the effective diffusion layer. Additionally, sketch the dissolved CO_2 concentration profile of the deep biofilm. Assume that the biofilm consists of organochemotrophs, producing CO_2 by the utilization of organic substrates. (20 points)