Seoul National University

457.621.001

Biological Processes in Environmental Engineering

FINAL EXAMINATION - Solutions

TIME ALLOWED: 80 MINUTES

November 29, 2016

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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 5 questions. Each full question is worth 15 to 30 points. Total points = 100.

Use following values for physical constants and properties, if needed:

Atomic weights: C, 12; H, 1; N, 14; O, 16

Ideal gas constant, R = 8.314×10^{-3} kJ/mole-K

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

Note: This is a bet! +2.5 points for correct answers, -2.5 points for incorrect answers, and 0 point if you choose not to answer.

i) According to the current method of classification based on phylogeny, bacteria and archaea belong to the same domain of life.

Answer) F

ii) The net effect of competitive inhibition is an increase in the Michaelis constant, K_M, while not affecting the maximum rate of an enzyme reaction, v_m.

Answer) T

iii) By irreversible inhibition, v_m will be reduced.

Answer) T

iv) A process of horizontal gene transfer via a plasmid from one bacterial cell to another is called as transformation.

Answer) F

v) Gram positive bacteria possess thicker peptidoglycan layer than the Gram negative ones.

Answer) T

vi) If a reaction is at second order, a PFR (plug flow reactor) shows better performance than a CSTR (continuously stirred tank reactor).

Answer) T

vii) The substrate utilization rate (r_{su}) described by Monod kinetics is not a function of substrate concentration if the substrate concentration is sufficiently higher than the half saturation coefficient K.

Answer) T

viii) Soluble microbial products (SMPs) are generally assumed as biodegradable.

Answer) T

ix) The overall substrate utilization rate of a fully penetrated biofilm is controlled by the diffusion rate of a substrate.

Answer) F

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

Answer) T

xi) Denitrification is an alkalinity consuming process.

Answer) F

xii) Hydrolysis and methanogenesis are two potentially rate-limiting processes for anaerobic digestion.

Answer) T

2. Answer the following questions.

i) Describe why the SRT of an activated sludge process should be higher than the value just good for BOD removal if sufficient nitrification is to be achieved. (5 points)

Answer)

As nitrifiers are less competitive compared to heterotrophs, the BOD level in an aerobic reactor should be maintained quite low for the nitrification to occur at a significant degree. To achieve lower BOD level, the SRT should be longer.

ii) Describe the working principles of an enhanced biological phosphorus removal (EBPR) process including the processes occurring at an anaerobic and aerobic reactors, and the eventual mechanism of P removal from the wastewater treatment stream. (6 points)

Answer)

In an anaerobic reactor: the PAO synthesizes PHAs from VFAs by utilizing energy of polyphosphate, releasing P into the water

In an aerobic reactor: the PAO utilizes PHAs stored in cells as well as wastewater BOD with O_2 *supplied, resulting in cell growth. Phosphate in the wastewater is taken up by PAOs reducing the P concentration in the water.*

Mechanism of P removal: by wasting sludge with PAO cells rich in P.

iii) Among those in the box below, select processes for which sufficient effectiveness for nitrogen removal can be expected. (4 points)

Conventional activated sludge	Modified Ludzak-Ettinger (MLE)
4-stage Bardenpho	A/O
A^2O	

Answer)

MLE, Bardenpho, A^2O

iv) Describe the interspecies hydrogen transfer mechanism for anaerobic fermentation and oxidation. (5 points)

Answer)

The acidogens and acetogens produce H_2 *which are the substrates for methanogens while the methanogens clean up the* H_2 *by utilizing it, preventing the* H_2 *partial pressure build-up so that the acidogens and acetogens can thrive without any inhibition. By this mechanism they form a syntrophic relationship.*

v) Describe the advantages of the membrane bioreactor (MBR) process. (5 points)

Answer)

Can accomplish high biomass concentration in the reactor – can reduce the size

No clarifier needed – can further save space

Can achieve good particulate removal in the secondary treatment process. (as good as granular media filtration following conventional secondary treatment or even better)

3. *Nitrobacter* is a well-known genus of nitrite-oxidizing bacteria. Answer the following questions.

i) Classify *Nitrobacter* based on the carbon source (autotroph or heterotroph) and the energy source (phototroph, chemolithotroph, or chemoorganotroph). (4 points)

Answer)

Autotroph, chemolithotroph

ii) Write the electron donor half reaction (R_d) written as an electron equivalent form for this bacterial genus. (6 points)

Answer)

$$\frac{1}{2}NO_3^- + H^+ + e^- = \frac{1}{2}NO_2^- + \frac{1}{2}H_2O$$

iii) The electron acceptor half reaction (R_a) for *Nitrobacter* is given as follows:

$$\frac{1}{4}O_2 + H^+ + e^- = \frac{1}{2}H_2O$$

Write the energy reaction (R_e) for *Nitrobacter*. (5 points)

Answer)

$$R_e = R_a - R_d$$

$$\frac{1}{2}NO_2^- + \frac{1}{4}O_2 = \frac{1}{2}NO_3^-$$

4. An activated sludge process receives an influent with 150 mg BOD_L/L as soluble organics and 10 mg VSS/L as inert biomass at a flowrate of 4000 m^3/day. Using the following microbial growth parameters, answer the following.

$$\hat{q} = 6.5\ mg\ BOD_L/mg\ VSS-d$$

$$Y = 0.4\ mg\ VSS/mg\ BOD_L$$

$$K = 30\ mg\ BOD_L/L$$

$$b = 0.05/d$$

$$f_d = 0.8$$

Neglect the production of soluble microbial products and hydrolysis of particulate BOD/COD.

i) Calculate the solids retention time (SRT) to achieve the effluent BOD_L standard of 10 mg/L. (8 points)

Answer)

$$S = \frac{K(1+b\theta_c)}{Y\hat{q}\theta_c - (1+b\theta_c)} = \frac{30\ mg\ BOD_L/L \cdot (1+0.05\ day^{-1} \cdot \theta_c)}{0.4\ mg\ VSS/mg\ BOD_L \cdot 6.5\ mg\ BOD_L/mg\ VSS-d \cdot \theta_c - (1+0.05/d \cdot \theta_c)}$$

$$10 = \frac{30+1.5\theta_c}{2.55\theta_c - 1} \qquad (\theta_c\ in\ days)$$

$$24\theta_c = 40$$

$$\theta_c = 1.67\ days$$

ii) Calculate the daily production of sludge as VSS (i.e., $P_{X,VSS}$) in kg VSS/d. (7 points)

Answer)

$$P_{X,VSS} = QY(S^0 - S)\frac{1+(1-f_d)b\theta_x}{1+b\theta_x} + QX_i^0$$

$$= 4\times 10^{6}\ L/day \cdot 0.4\ mg\ VSS/mg\ BOD_L \cdot (150-10)\ mg\ BOD_L/L \cdot \frac{1+(1-0.8)\cdot 0.05/day \cdot 1.67\ day}{1+0.05/day \cdot 1.67\ day}$$

$$+ 4\times 10^{6}\ L/day \cdot 10\ mg\ VSS/L$$

$$= 2.50\times 10^{8}\ mg\ VSS/day = 250\ kg/day$$

5. A wastewater with soluble organic concentration of 200 mg BOD_L/L, dissolved oxygen (DO) concentration of 3.0 mg/L, and a flowrate of 10^4 m^3/day is being treated in an activated sludge process maintained at a solids retention time (SRT) of 6 days. Using the following growth parameters, answer the followings.

$$\hat{q} = 10\ mg\ BOD_L/mg\ VSS-d$$

$$Y = 0.5\ mg\ VSS/mg\ BOD_L$$

$$K = 50\ mg\ BOD_L/L$$

$$b = 0.05/d$$

$$f_d = 0.8$$

Neglect the production of soluble microbial products, hydrolysis of particulate BOD/COD, and any inert VSS in the influent.

i) Calculate the soluble organic concentration of the effluent and the total VSS concentration in the aeration tank of the process. (6 points)

Answer)

$$S = \frac{K(1+b\theta_c)}{Y\hat{q}\theta_c - (1+b\theta_c)} = \frac{50\ mg\ BOD_L/L \cdot (1+0.05\ day^{-1} \cdot 6\ day)}{0.5\ mg\ VSS/mg\ BOD_L \cdot 10\ mg\ BOD_L/mg\ VSS-d \cdot 6\ day - (1+0.05/d \cdot 6\ day)}$$

$$= 2.3\ mg\ BOD_L/L$$

$$X_v = X_i^0 + Y(S^0 - S)\frac{1+(1-f_d)b\theta_x}{1+b\theta_x}$$

$$= 0 + 0.5\ mg\ VSS/mg\ BOD_L \cdot (200 - 2.3)\ mg\ BOD_L/L \cdot \frac{1 + (1 - 0.8) \cdot 0.05/day \cdot 6\ day}{1 + 0.05/day \cdot 6\ day}$$

$$= 80.6\ mg\ VSS/L$$

ii) Calculate the requirement for oxygen supply in kg/day to maintain the DO level in the aeration tank as 2.0 mg/L. Use the cell COD value of 1.42 mg COD/mg VSS. (9 points)

Answer)

$$\gamma_a \left[Q\left(S^0 + 1.42 X_v^0\right) - Q(S + SMP + 1.42 X_v) \right] = Q\left(S_a^0 - S_a\right) + R_a$$

As SMP and inert VSS in the influent is neglected, the equation can be simplified and rearranged to:

$$R_a = Q\left[\gamma_a\left(S^0 - S - 1.42 X_v\right) - \left(S_a^0 - S_a\right)\right]$$

$$= 10^4\ m^3/day\left[1\ mg\ O_2/mg\ COD \cdot (200\ mg\ COD/L - 2.3\ mg\ COD/L - 1.42\ mg\ COD/mg\ VSS \cdot 80.6\ mg\ VSS/L)\right.$$

$$\left. - (3.0 - 2.0)\ mg\ O_2/L\right] \times 10^3\ L/m^3$$

$$= 8.22 \times 10^8\ mg\ O_2/day = 822\ kg/day$$