Seoul National University

M1586.000300

Water Quality and Water Pollution Control

MIDTERM EXAMINATION

TIME ALLOWED: 75 MINUTES

April 26, 2016

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1. Students may use one double-sided, A4 notes prepared in their own handwriting. Mechanical or electronic reproduction of any notes are not allowed.
(앞뒷면 모두를 사용하여 A4 용지 두 장에 필요한 내용을 적어 시험에 사용할 수 있습니다. 다만, 컴퓨터로 출력하거나 복사한 것은 불가합니다.)
2. Students should bring their own calculator which is not pre-programmed with formulae from the class.
(계산기를 사용하되, 수업과 관련된 공식이 프로그램되어 있으면 안됩니다.)
3. Cheating is NOT allowed. There is not tolerance for cheating.
(부정행위는 절대 용납하지 않습니다.)
4. Make sure your answers includes units if appropriate. Watch your units! Prepare your answers in a logical, easy-to-follow format.
(해당사항이 있을 경우, 꼭 단위를 기입하고, 정확한 단위를 사용하십시오. 답은 논리적이고 이해하기 쉽게 기재하십시오.)
5. This exam contains 7 questions with a total score of 130.
(본 시험은 7 문항으로 구성되어 있으며, 총점은 130점입니다.)

1. Mark O or X for the following statements.

(+2 points for correct answers; -1 points for incorrect answers)

1) Humic substances are easily degraded by microorganisms in water.

Answer) X

2) The equivalent mass for phosphoric acid (H_3PO_4, MW=98 g/mole) is greater than that for sulfuric acid (H_2SO_4, MW=98.1 g/mole).

Answer) X

3) Turbidity is determined as the ratio of light that penetrates a water sample.

(탁도는 물 샘플을 통과하는 빛의 비율로 결정된다)

Answer) X

4) Total Kjeldahl nitrogen (TKN) is the sum of organic and ammonia nitrogen in water.

Answer) O

5) When secondary effluent of wastewater treatment is reused as irrigation water, high sodium content is one of the major concern.

Answer) O

6) The COD/TOC ratio for methane (CH_4) is greater than that for benzene (C_6H_6).

Answer) O

7) If sufficient amount of PCR ingredients (except for the template DNA) is provided, the amount of DNA will be amplified by approximately three orders of magnitude after running 10 PCR cycles.

(Template DNA를 제외한 PCR 재료의 충분한 공급이 이루어졌을 때, PCR cycle을 10회 돌렸을 때 DNA의 양은 약 1000배 증가한다.)

Answer) O

8) Most serotypes of *E. coli* (*Escherichia coli*) are pathogenic.

Answer) X

9) For the same rainfall intensity and drainage area, the stormwater flowrate in an urban area will be generally greater than that in a suburban area.

(강우강도와 배수면적이 같을 때, 도시지역의 우수유출량은 교외지역의 우수유출량보다 일반적으로 크다.)

Answer) O

10) Screenings are usually combined with primary and secondary sludge for subsequent treatment.

Answer) X

2. Answer the following questions.

1) Select the major form of the following acids that will be present in water at given pH conditions:

i) Sulfuric acid (H_2SO_4; pK_{a1}=-3, pK_{a2}=2.0), pH=8.0

ii) Valeric acid (C_4H_9COOH; pK_a=4.8), pH=3.5

iii) Phosphoric acid (H_3PO_4, pK_{a1}=2.15, pK_{a2}=7.20, pK_{a3}=12.32), pH=9.5

(5 points)

Answer)

SO_4^{2-}, C_4H_9COOH, HPO_4^{2-}

2) From the following bacterial enumeration procedures, select one(s) applicable for viable-but-non-culturable (VBNC) bacterial species.

A. Direct count following acridine orange staining
B. Plate counting using pour plate method
C. Plate counting using spread plate method
D. Multiple-tube fermentation

(5 points)

Answer) A

3) Briefly (in one or two sentences) describe how *Cryptosporidium parvum* survive in natural waters.

(5 points)

Answers)

C. parvum is excreted from its host in the form of thick-walled oocyst, which makes it resistant to stimulants and survive without significant metabolism in natural waters.

4) Describe the benefits of flow equalization for the downstream processes of i) biological treatment and ii) media filtration.

(7 points)

Answer)

Biological treatment: enhanced performance and reliability by preventing shock loadings, diluting inhibiting substances, and pH stabilization

Media filtration: reduction in surface area requirement, better filter performance, and uniform filter-backwash cycles

5) Compare the performance of the following reactors at steady state when first-order reaction is occurring:

(a) Single-stage CSTR, reactor volume = 1000 m^3

(b) Two-stage CSTR, volume for the 1st reactor = 700 m^3, volume for the 2nd reactor = 300 m^3

(c) Two-stage CSTR, volume for the 1st reactor = 300 m^3, volume for the 2nd reactor = 700 m^3

(d) Plug flow reactor, reactor volume = 1000 m^3

(8 points)

Answer)

i) Performance is in the order of: single-stage CSTR < CSTR in series < PFR.

For the two CSTRs in series:

(b): 1st CSTR - $\frac{C_1}{C_0}=\frac{1}{1+kV_1/Q}=\frac{1}{1+7kV_{total}/10Q}=\frac{1}{1+7k\tau/10}$

2nd CSTR - $\frac{C_2}{C_1}=\frac{1}{1+3k\tau/10}$

$\therefore \frac{C}{C_0}=\frac{1}{(1+7k\tau/10)(1+3k\tau/10)}$

(c): $\frac{C}{C_0}=\frac{1}{(1+3k\tau/10)(1+7k\tau/10)}$

(a) < (b) = (c) < (d)

3. Using the following data for water sample analysis, estimate the concentrations of CO_3^{2-} and Cl^-. Assume that all significant ionic species in the water are reported in the table. The pH of the water sample is 8.8. Use pK_a=10.3 for carbonic acid and water dissociation constant $K_w=10^{-14}$.

Ions	**Ionic weight**	**Concentration (mg/L)**
Ca^{2+}	40.1	46.2
Mg^{2+}	24.3	16.7
Na^{+}	23.0	2.3
K^{+}	39.1	3.9
Cl^{-}	35.5	?
SO_4^{2-}	96.1	63.5
CO_3^{2-}	60.0	?
HCO_3^{-}	61.0	80.3

(15 points)

Answer)

Ions	*Ionic weight*	*Concentrations*		
		in mg/L	*in mM*	*in meq/L*
Ca^{2+}	*40.1*	*46.2*	*1.152*	*2.304*
Mg^{2+}	*24.3*	*16.7*	*0.687*	*1.374*
Na^{+}	*23.0*	*2.3*	*0.100*	*0.100*
K^{+}	*39.1*	*3.9*	*0.100*	*0.100*
Cl^{-}	*35.5*	*?*		
SO_4^{2-}	*96.1*	*63.5*	*0.661*	*1.322*
CO_3^{2-}	*60.0*	*?*		
HCO_3^{-}	*61.0*	*80.3*	*1.316*	*1.316*

i) CO_3^{2-}

$$K_{a2} = \frac{[CO_3^{2-}][H^+]}{[HCO_3^-]},\ [CO_3^{2-}] = \frac{K_{a2}[HCO_3^-]}{[H^+]}$$

$$[H^+] = 10^{-8.8}\ M$$

$$[CO_3^{2-}] = \frac{10^{-10.3} \cdot 1.316 \times 10^{-3}\ M}{10^{-8.8}\ M} = 4.13 \times 10^{-5}\ M = 2.48\ mg/L$$

ii) Cl^{-}

$$(CO_3^{2-}) = 0.083\ meq/L$$

Use electroneutrality:

$$2.304 + 1.374 + 0.100 + 0.100 = (Cl^-) + 1.322 + 0.083 + 1.316$$

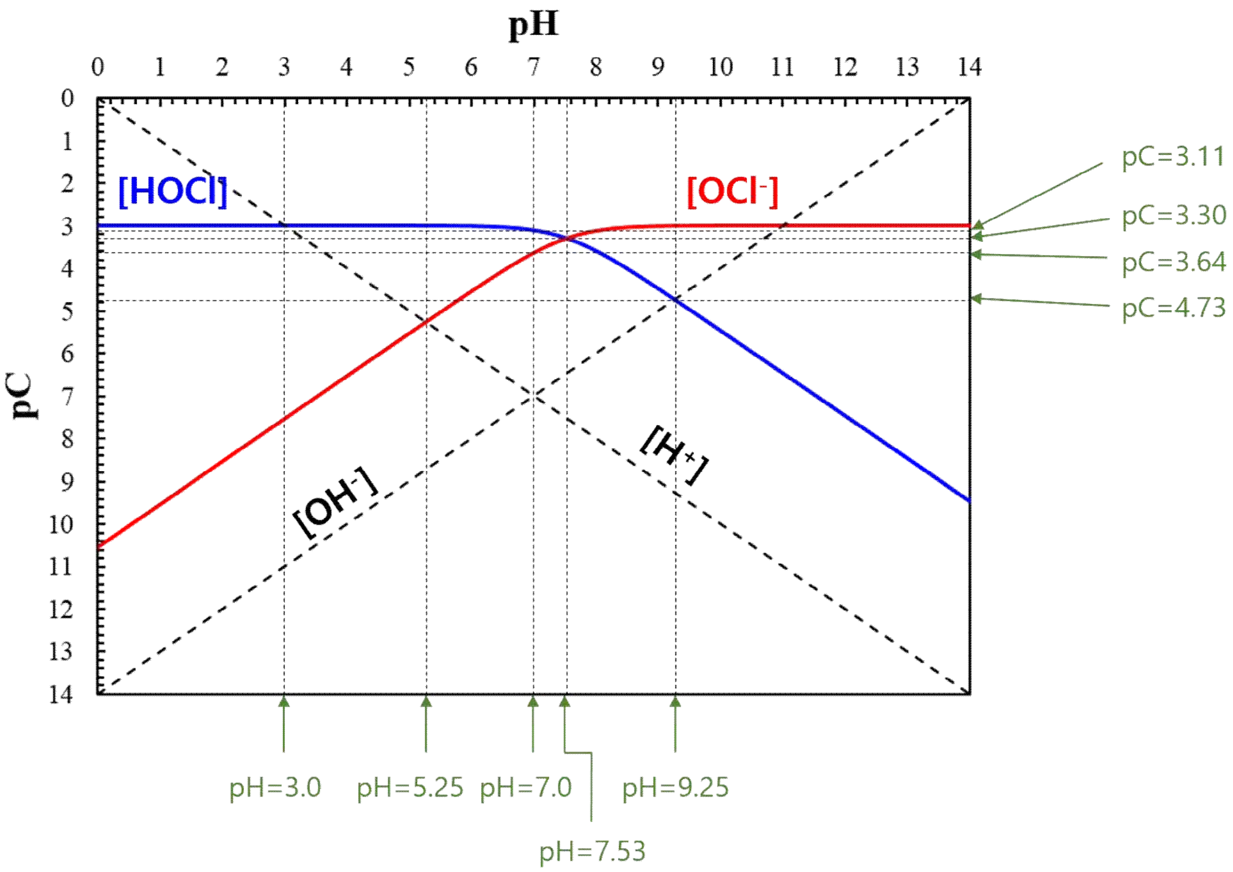
$(Cl^-) = 1.157\ meq/L = 41.1\ mg/L$

4. For disinfection using chlorine (Cl_2) gas, following reactions occur:

$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^- \quad (1)$$

$$HOCl \leftrightarrow H^+ + OCl^-, \quad pK_a = 7.53 \quad (2)$$

10^{-3} M chlorine gas is added to pure water, and in that situation reaction (1) proceeds almost completely to the right. From the pH-pC diagram for 10^{-3} M HOCl as below, estimate the i) pH of water and ii) HOCl and OCl^- concentrations. If concentration is less than 10^{-5} M, just report as "negligible". Show your reasoning.



(15 points)

Answer)

Mass balance: $C_T = [Cl^-] = [HOCl] + [OCl^-]$

Charge balance: $[H^+] = [Cl^-] + [OCl^-] + [OH^-]$

Assuming that $[OCl^-] \ll C_T$ *and* $[OH^-] \ll C_T$,

$\rightarrow [H^+] = [Cl^-] = [HOCl]$

At pH=3.0, the condition is met.

$\therefore$ *pH=3.0, [HOCl] =* 10^{-3} *M, [OCl⁻] negligible*

5. Following information is collected for a wastewater drainage region. Determine the maximum hourly sewage flowrate (in m^3/d), BOD mass loading (in kg/d), and BOD concentration for the drainage region. Consider wastewater from residential sources only - neglect wastewater from any other sources, infiltration/inflow, and stormwater.

   Population = 250,000

   per capita BOD discharge = 85 g/capita/d

   per capita wastewater discharge = 250 L/capita/d

   PF_{season} = 1.4; PF_{day} = 1.6

(15 points)

Answer)

(Average daily sewage flowrate) = 250,000 capita × 250 L/capita/d × 10^{-3} m^3/L

$= 6.25 \times 10^4\ m^3/d$

(Maximum hourly sewage flowrate) = (Average daily sewage flowrate) × PF_{season} × PF_{day}

$= 1.4 \times 10^5\ m^3/d$

(BOD mass loading) = 250,000 capita × 85 g/capita/d × 10-3 kg/g = 2.13×10^4 *kg/d*

(BOD concentration) = (BOD mass loading) / (Average daily sewage flowrate)

= 0.34 kg/m^3 *= 340 mg/L*

6. Compound A undergoes the following two-step reaction to a final product compound C. Both steps can be represented as first-order reactions with rate constants of k_1 and k_2, respectively. For a steady-state CSTR that receives an influent containing compound A only with a concentration of C_{A0}, express the concentrations of compounds A, B, and C in the effluent using HRT (τ), rate constants (k_1 and k_2), and C_{A0}.

$$A \xrightarrow{k_1} B \xrightarrow{k_2} C$$

(20 points)

Answer)

Reactor mass balance for A: $0 = Q(C_{A0} - C_A) - k_1 C_A V$

$$\rightarrow C_A = \frac{C_{A0}}{1 + k_1 \tau}$$

Reactor mass balance for B: $0 = -QC_B + (k_1 C_A - k_2 C_B) V$

$$\rightarrow C_B = \frac{k_1 \tau C_{A0}}{(1 + k_1 \tau)(1 + k_2 \tau)}$$

Reactor mass balance for C: $0 = -QC_C + k_2 C_B V$

$$\rightarrow C_C = \frac{k_1 k_2 \tau^2 C_{A0}}{(1 + k_1 \tau)(1 + k_2 \tau)}$$

7. Determine the overflow rate of a rectangular sedimentation basin to achieve 90% removal of suspended matter (in terms of mass removal) in a wastewater when the settling velocity distribution is as below.

Settling velocity, m/h	**Mass fraction**
0.0-0.5	0.10
0.5-1.0	0.30
1.0-1.5	0.30
1.5-2.0	0.20
2.5-3.0	0.10
total	1.00

(15 points)

Answer)

Settling velocity, m/h	***Mass fraction***
0.25	*0.10*
0.75	*0.30*
⋮	⋮
total	*1.00*

For particles with settling velocity > 1.0 m/h, assume 100% removal ($v_o < 1.0$).

$0.60 + 0.10 \times 0.25/v_o + 0.30 \times 0.75/v_o = 0.90$

$v_o = 0.83\, m/s$