

**CHBE 373 – Water Pollution Control**  
**Final Exam**  
**December 15, 2012**

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**Duration:** 2 hours & 20 minutes  
**Type:** closed book, closed notes  
**# of Questions:** 6

**FIVE PAGES IN TOTAL**

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1. Sketch a typical batch growth profile (biomass vs. time), label the phases of growth, and briefly describe each. **7 marks.**
2. An ion exchange resin is used to remove Nitrate ( $\text{NO}_3^-$ ) from a water source with the following ionic concentrations:

Ion	meq/L
$\text{Ca}^{+2}$	1.5
$\text{Mg}_{+2}$	0.7
$\text{Na}^+$	2.5
$\text{NO}_3^-$	2
$\text{Cl}^-$	2.7
$\text{SO}_4^{-2}$	0

- a. Do the anions and cations balance? *Support your response quantitatively.* **2 marks**
- b. If the selectivity of the ion exchanger used to remove Nitrate is 4, calculate the fraction of nitrate in the solid phase. **6 Marks**
- c. 1L of the resin above is just sufficient to treat 1000 L of the water, calculate the total exchange capacity of the resin. **5 Marks**

**Answers:**

a)  $\sum \text{anions} = \sum \text{cations} = 4.7 \text{ meq/L}$

b) Equivalent fraction of nitrate in solution:

$$X_{\text{NO}_3^-} = \frac{2}{4.7} = 0.425$$

THEREFORE :

$$Y_{\text{NO}_3^-} = \frac{4 * 0.425}{1 + (4 - 1) * 0.425} = 0.747$$

- c) **MAX USEFUL CAPACITY OF RESIN PER LITRE = 1000 L \* 2 meq/L = 2000 meq/L**  
**RESIN CAPACITY = 2000 (meq/L)/ 0.747 = 2677 meq/L = 2.7 eq/L**

3. Disinfection. *Note that the following parts are completely independent from one another.*
- Name at least 5 characteristics of a good disinfectant? **5 Marks**
  - Comment whether either UV or ozone be good secondary disinfectants? Briefly explain why? **5 Marks**
  - Some US EPA stipulated requirements for “Ct” values associated with Giardia are described below:

Disinfectant	Water Temp at 5 C	
	1 Log	3 Log
Free Chlorine, pH=6.0	35	105
Free Chlorine, pH=8.0	72	216
Chlorine dioxide	8.7	26
Chloramine	735	2200

Why are the “Ct” values for free chlorine much higher at pH=8.0 as compared to pH=6.0? Include chemical species in your explanation (by words or formulas) **6 Marks**

**Answers:**

**a:** any of the followings would be the characteristics of a good disinfectant:

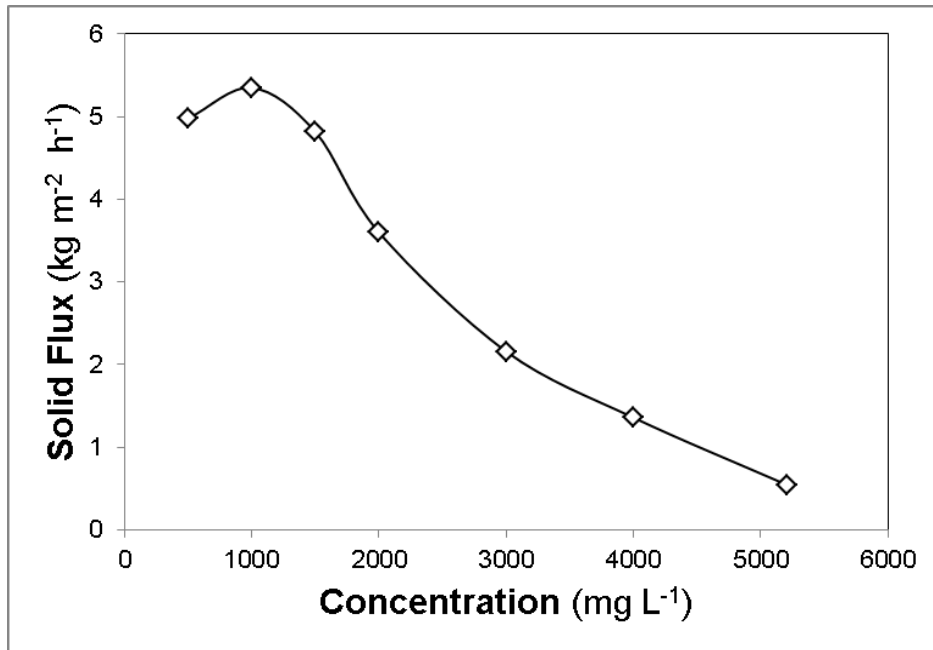
- Broad spectrum: active against all microbes
- Fast acting: produces rapid inactivation
- Effective in the presence of organic matter, suspended solids and other matrix or sample constituents
- Nontoxic; soluble; non-flammable; non-explosive
- Compatible with various materials/surfaces
- Stable or persistent for the intended exposure period
- Provides a residual (sometimes this is undesirable)
- Easy to generate and apply
- Economical

**b:** No, because neither UV nor O<sub>3</sub> does leave any residual in the distribution system, so they would not be a suitable secondary disinfectants

**c:** Chlorine undergoes a conversion from more effective hypochlorous acid (HOCl) to less effective hypochlorite (OCl<sup>-</sup>) as one moves from pH 6 to pH 8.  
*The 50:50 point is at the pKa which is 7.6. Therefore one has to add more chlorine at higher pH to get the same effect.*

4. A suspension containing 1570 mg L<sup>-1</sup> solids (Type 3) enters a 6 meters diameter thickener/clarifier at a flowrate of 0.025 m<sup>3</sup> s<sup>-1</sup>.
- Based on the solid flux curve given bellow, calculate the maximum underflow concentration that is possible to obtain. **6 marks**
  - Calculate the flow rate of the streams leaving the thickener when operating the thickener/clarifier under the conditions of (a). **6 marks**
  - Could you operate the thickener/clarifier with an underflow concentration of 5000 mg L<sup>-1</sup>? Why? **3 marks**

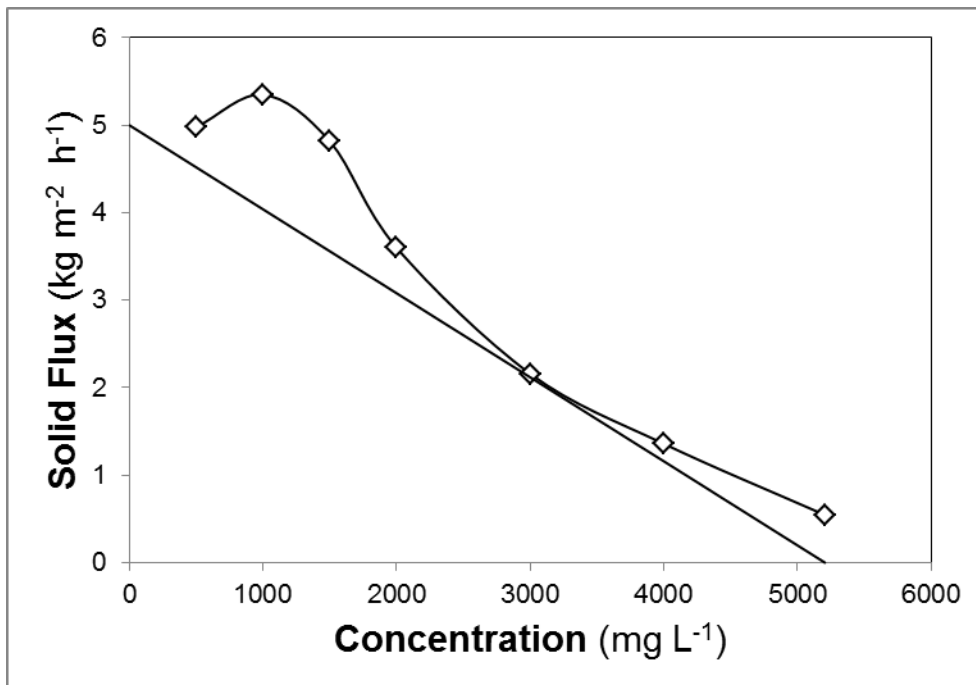
d) Could you operate the thickener/clarifier with an underflow concentration of 6000 mg L<sup>-1</sup>?  
 Why? **3 marks**



**Answers:**

1.

$$G = \frac{1570 \frac{\text{mg}}{\text{L}} \times \frac{1 \text{ kg}}{1000000 \text{ mg}} \times \frac{1000 \text{ L}}{1 \text{ m}^3} \times 0.025 \frac{\text{m}^3}{\text{s}} \times \frac{3600 \text{ s}}{1 \text{ h}}}{3.14 \times (3 \text{ m})^2} = 5 \frac{\text{kg}}{\text{m}^2 \text{ s}}$$



From the graph, the maximum underflow concentration is  $5200 \text{ mg L}^{-1}$

2. Assuming 100% efficiency:

$$Q_u = \frac{Q_f \times C_f}{C_u} = \frac{0.025 \frac{\text{m}^3}{\text{s}} \times 1570 \frac{\text{mg}}{\text{L}}}{5200 \frac{\text{mg}}{\text{L}}} = 0.00755 \frac{\text{m}^3}{\text{s}}$$

$$Q_e = Q_f - Q_u = 0.025 \frac{\text{m}^3}{\text{s}} - 0.00755 \frac{\text{m}^3}{\text{s}} = 0.0175 \frac{\text{m}^3}{\text{s}}$$

3. Yes, because  $5000 \text{ mg/L}$  is lower than the maximum underflow concentration.

4. No, the thickener cannot remove that amount of solids (higher than the  $G_{\text{max}}$ ).

5. An experimenter set a sample for a BOD determination in an incubator at  $20^\circ\text{C}$ . The sample had an ultimate BOD of  $330 \text{ mg/L}$  and the rate constant for this waste was  $0.13 \text{ d}^{-1}$  (base 10) at  $20^\circ\text{C}$ . In the beginning of day 3 another person adjusted the temperature of the incubator to  $25^\circ\text{C}$  for another analysis. The incubator temperature changed to the new temperature within 20 minutes. What were the true 5-day BOD of the sample and the 5-day BOD that was determined? Assume the temperature coefficient  $\alpha=1.047$ . **18 points**

The true  $BOD_5$  can be obtained from:

$$Y_t = BOD_u (1 - 10^{-kt}) = (330 \text{ mg/L}) (1 - 10^{-5 \times 0.13})$$
$$= \boxed{256 \text{ mg/L}}$$

@  $25^\circ\text{C}$ :  $k_{25} = k_{20} \alpha^{(25-20)} = (0.13 \text{ d}^{-1}) (1.047)^5 = \underline{\underline{0.16 \text{ d}^{-1}}}$

After 2 days, the remaining BOD in the sample will be:

$$L = BOD_u \times 10^{-kt} \Rightarrow L_2 = (330 \text{ mg/L}) (10^{-0.13 \times 2}) = 181 \text{ mg/L}$$

Hence, the amount of BOD exerted was:  $330 - 181 = 149 \text{ mg/L}$

The BOD exerted over days 3-5 is:

$$Y_{3-5} = (181 \text{ mg/L}) (1 - 10^{-k_{25} \times t}) = (181 \text{ mg/L}) (1 - 10^{-0.16 \times 3}) = 121 \text{ mg/L}$$

this will be the new ultimate BOD after day 2

→ The five-day BOD determined will be:

$$BOD_2 + BOD_{3-5} = 149 + 121 = \boxed{270 \text{ mg/L}}$$

Hence, we'll find that the determined 5-day BOD will be slightly higher than the true 5-day BOD due to the change in  $T$  of the incubator

6. A completely mixed activated sludge treatment plant is designed to treat a wastewater flow of 5400 m<sup>3</sup>/d with a COD of 375 mg/L. Influent suspended solids are negligible. The nondegradable portion of influent COD is 15 mg/L. The process must attain a removal of 90% of the total COD. A hydraulic retention time of 6 hours will be used. VSS in the return activated sludge line will have a concentration of 8000 mg/L. The following parameters have been determined based on the following substrate removal model.

$$r_s = -\frac{X}{Y} \frac{\mu_{\max} S}{S + K_s}$$

$$\mu_{\max} = 9.78 \text{ d}^{-1}$$

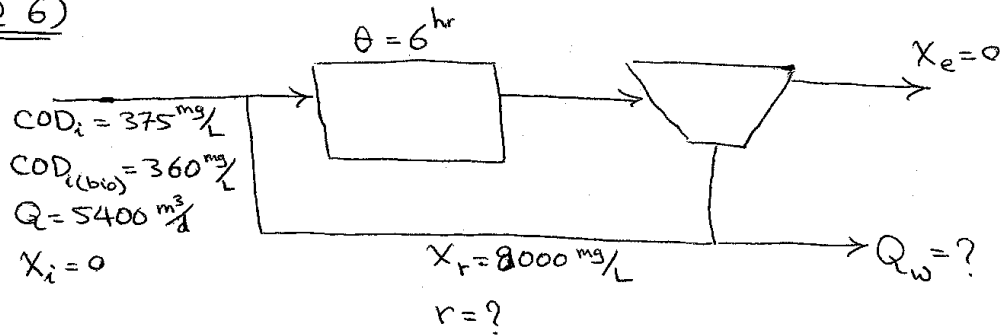
$$K_s = 170 \text{ mg/L}$$

$$Y = 0.45 \text{ g VSS/g COD}$$

$$k_d = 0.05 \text{ d}^{-1}$$

What are the sludge age, MLVSS, waste sludge flow rate, and recycle ratio in this process. Assume there are no solids in the clarifier overflow (ie., final effluent). **28 points**

Q 6)



COD removal efficiency = 90%

∴ The amount of COD in the outlet stream is:

$$\text{COD}_e = 375 \text{ mg/L} \times 10\% = 37.5 \text{ mg/L}$$

biodegradable COD @ outlet stream (effluent) is:

$$37.5 - 15 = 22.5 \text{ mg/L}$$

Note that the non-biodegradable fraction pass through

$$\Rightarrow \begin{cases} S_i = 360 \text{ mg/L} \\ S_e = 22.5 \text{ mg/L} \end{cases}$$

$$\mu = \frac{\mu_{\max} \cdot S_e}{K_s + S_e} = \frac{9.78 \times 22.5}{170 + 22.5} = 1.14 \text{ d}^{-1}$$

From the substrate balance eq.  $\Rightarrow \mu = \frac{Y \cdot Q (S_i - S_e)}{V \cdot X}$  ①

V can be obtained from:  $\theta = \frac{V}{Q}$

$$V = Q \cdot \theta = 5400 \frac{\text{m}^3}{\text{d}} \times \frac{6}{24} = 1350 \text{ m}^3$$

From ①, we can obtain X which is MLVSS

$$X = \frac{Y \cdot Q (S_i - S_e)}{V \cdot \mu} = \frac{0.45 \times 5400 \times (360 - 22.5)}{1350 \times 1.14} = 532.9 \text{ mg/L}$$

$$\frac{F}{M} = \frac{S_i}{\theta \cdot X} = \frac{360}{\frac{6}{24} \times 532.9} = 2.7 \text{ d}^{-1}$$

To obtain recycle ratio, write a mass balance around the aeration tank:

$$Q_r X_r - (1+r)Q X + (\mu - k_d) X \cdot V = 0$$

$$(X_r - X)Q_r = Q X - (\mu - k_d) X \cdot V = X [Q - (\mu - k_d) V]$$

$$r = \frac{X [Q - (\mu - k_d) V]}{(X_r - X) Q} = \frac{532.9 (5400 - 1.09 \times 1350)}{5400 (8000 - 532.9)}$$

$$r = 0.052 = 5.2\%$$

$$Q_r = 0.052 \times 5400 = 280.3 \text{ m}^3/\text{day}$$

write a mass balance around the clarifier:

$$X(1+r)Q = X_r Q_w + Q_r X_r + Q_e X_e$$

$$5400 \times 532.9 \times 1.052 = 8000 (Q_w + 280.3)$$

$$Q_w + 280.3 = 378.05$$

$$Q_w = 97.7 \text{ m}^3/\text{d}$$

$$\theta_e = \frac{V X}{Q_w X_r} = \frac{1350 \times 532.9}{97.7 \times 8000} = 0.92 \text{ days}$$

## Formulas

### BOD calculations:

$$Y_t = BOD_u (1 - 10^{-kt})$$

$$L = BOD_u \times 10^{-kt}$$

$$k_T = k_{20} \alpha^{(T-20)}$$

### Cell growth:

$$r'_g = \frac{dX}{dt} = \frac{\mu_{\max} X S}{S + K_s} - k_d X$$

$$\frac{dS}{dt} = -\frac{x}{Y} \frac{\mu_{\max} S}{S + K_s}$$

$$r'_g = -Y \frac{dS}{dt} - k_d X$$

### Biological reactor with no recycle (e.g. aerated lagoon):

Steady state biomass balance:

$$QX_0 - QX + V \mu X = 0$$

Steady state substrate balance:

$$QS_0 - QS - V \left( \frac{1}{Y} \mu X \right) = 0$$

$$\theta_c = \frac{VX}{QX} = \frac{V}{Q}$$

$$\frac{Q}{V} = \frac{1}{\theta} = \frac{\mu_{\max} S}{S + K_s} - k_d$$

$$\frac{1}{\theta} = \mu - k_d$$

$$X = Y \frac{(S_0 - S_e)}{\mu \theta}$$

### Biological reactor with recycle (e.g. activated sludge):

Biomass balance:

$$QX_0 - QX_e - Q_w X_r + V(\mu - k_d)X = 0$$

Substrate balance:


$$QS_0 - (Q - Q_w)S - Q_w S - V \frac{\mu X}{Y} = 0$$

sludge age ( $\theta_c$ ):

$$\theta_c = \frac{VX}{Q_w X_r}$$

Food to microorganism ratio ( $F/M$ ):

$$\frac{F}{M} = \frac{S_0}{\theta X}$$

See back 

## ***Nomenclature:***

$dX/dt$ :	rate of change in concentration of bacteria
$K_S$ :	substrate conc. at half the maximum growth rate (mg/L)
$X$ :	Concentration of bacteria/biomass in the reactor (mg/L)
$X_0$ :	Concentration of biomass in the inlet stream to the reactor (mg/L)
$X_r$ :	Concentration of return sludge (mg/L)
$S$ :	concentration of limiting substrate (mg/L)
$S_0$ :	Initial concentration of limiting substrate (mg/L)
$Y$ :	Yield coefficient (mg VSS/mg BOD or COD)
$\mu_{max}$ :	maximum specific growth rate ( $d^{-1}$ )
$\alpha$ :	temperature coefficient
$Q$ :	Wastewater flow rate ( $m^3/d$ )
$Q_w$ :	Waste sludge flow rate ( $m^3/d$ )
$V$ :	reactor (lagoon or activated sludge) volume ( $m^3$ )
$k$ :	rate constant for BOD ( $d^{-1}$ )
$t$ :	time (day)
$Y_t$ :	BOD exerted (mg/L)
$L$ :	BOD remaining in the solution (mg/L)
$BOD_u$ :	ultimate BOD (mg/L)
$T$ :	temperature ( $^{\circ}C$ )
$\theta$ :	hydraulic retention time (day)
$\theta_c$ :	cell retention time (day)
$\mu$ :	specific growth rate ( $d^{-1}$ )