**1.85 WATER AND WASTEWATER TREATMENT ENGINEERING**
FINAL EXAM
DECEMBER 20, 2005

This is an open-book exam. You are free to use your textbook, lecture notes, homework, and other sources other than the internet.

1.   (12 points)
    Fish generate wastewater too! Aquariums need to be equipped with filters to remove fish wastes and uneaten fish food from the water. One such design is the under-gravel filter, illustrated schematically below.
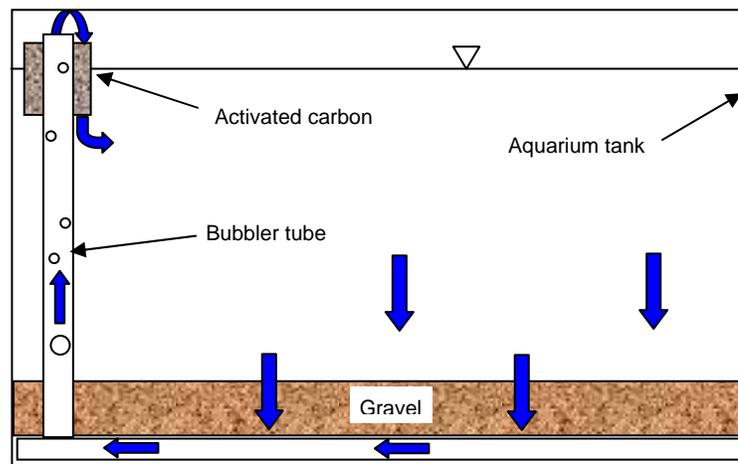
    The filter consists of a plastic plate that covers the floor of the aquarium and creates an open space beneath the gravel for water to flow to the bubbler tube. Air is pumped into the bottom of the bubbler tube, and the rising air bubbles entrain water and pump the water upwards. The water bubbles out of the top of the tube, drops into a plastic container filled with activated carbon, and then flows into the aquarium. The flow of water up and out of the bubbler tube causes water to draw from the main part of the tank into and through the bottom gravel and then along the tank bottom to the bubbler tube.

    Identify two major treatment functions at work in the aquarium water treatment system and briefly describe how they function.

Solution:

   The major unit processes are:

Aerobic biological treatment by biofilms in the gravel. This would treat the BOD created by fish wastes, uneaten food, dead plants, and (depending on the care the aquarium receives) dead fish.

Activated carbon to remove organics and other absorbable chemicals, including ammonia.

*If plants are in the aquarium, they would uptake nbitrogen and phosphorus.*

Air stripping would treat volatile organics if present, but they are unlikely to be present. Unionized ammonia could be stripped. Without specificity as to what was being stripped, I gave only partial credit for this answer.

2.   (12 points)
Filamentous bacteria that cause sludge foaming in activated sludge treatment systems differ from the desirable floc-forming bacteria in several aspects of their metabolism. First, filamentous bacteria have different growth curves than floc-forming bacteria as shown in the figure below. Second, filamentous bacteria use only oxygen as an electron acceptor and cannot use nitrate for that function; floc-forming bacteria can use either oxygen or nitrate as electron acceptors. Third, filamentous bacteria cannot store polyphosphates or use acetate for growth as can some floc-forming bacteria.
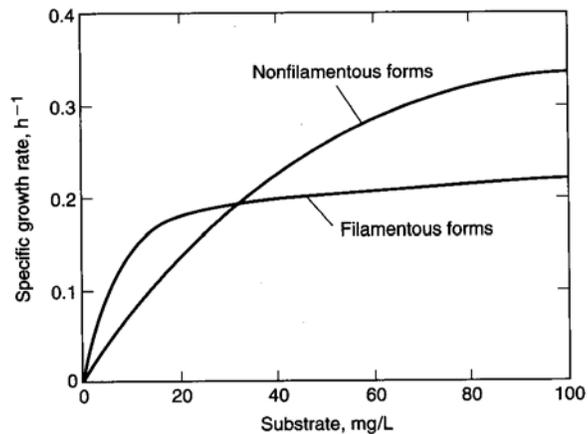
Different designs have used one or more of these characteristics to create "selectors" to favor floc-forming bacteria over filamentous bacteria in AST systems. The selector is typically created in one or more tanks upstream of the aeration tank as shown in the schematic below. The purpose of the selector is to suppress filamentous bacteria growth and thereby control foaming sludge.
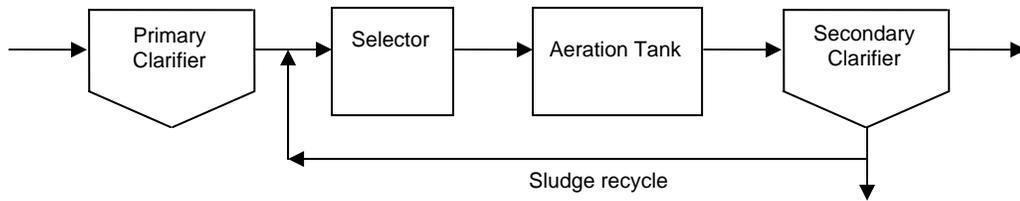
Suggest conditions that could be created in a selector to achieve the design goal of favoring floc-forming bacteria over filamentous bacteria.

Solution:

The three possible selectors are:

A high F/M tank to select nonfilamentous bacteria over filamentous.

An anoxic tank (as used in biological nitrogen removal)

Anaerobic followed by anoxic and aerobic (as used in biological phosphorus removal)

3. (8 points)
Parkin and Owen (1986) report the following parameter values for anaerobic digestion of primary treatment sludge:

K_s = half-saturation constant = 1.8 $(1.112^{(T-35)})$ [g COD/L];
μ_{max} = maximum specific growth rate = 0.27 $(1.035^{(T-35)})$ [day^{-1}];
k = maximum specific substrate use rate = 6.67 $(1.035^{(T-35)})$ [day^{-1}];
k_e = endogenous respiration rate = 0.03 $(1.035^{(T-35)})$ [day^{-1}];
Y = cell yield = 0.04 [g VSS/g COD];
T = temperature [°C]

If the sludge flow rate into the tank were doubled and simultaneously the temperature dropped from 35°C to 20°C, by what ratio would the factor of safety decrease?

Solution:

See attached calculations.

4.   (8 points)
The operations staff at a sewage treatment plant has decided to reduce the SRT of their activated sludge process from 6 days to 3 days by increasing the recycle rate. The goal is to reduce the oxygen requirement. You have been called in as an expert to give a qualitative assessment of this plan.

a. Will the oxygen requirement actually be reduced?
b. Will the MLVSS increase, decrease or stay about the same?
c. Will the sludge settling characteristics improve, stay about the same, or worsen?
d. Will the effluent BOD concentration increase, decrease, or stay about the same?

Solution:

This can be answered at an intuitive level, or mathematically.

The intuitive approach would recognize that there is less time for biological growth and reactions. Thus the bacterial population will be smaller and there will be less biodegradation. This implies:

a. *Less biodegradation implies less oxygen is needed.*

b. *Less time for growth implies a smaller X value.*

c. *Per the graph of settling velocity vs. θ_c from Lecture 19, page 21, sludge will settle most slowly at θ_c = 3 days.*

d. *Less time for biodegradation implies poorer treatment and a higher effluent concentration S.*

A mathematical analysis for parts a, b, and d is attached.

Part II – Short-answer Questions (5 points each, 60 points total)
The following are intended to be answerable with a few sentences or a simple sketch.

5. From the standpoint of the overall waste treatment process, is a sequencing batch reactor more like a plug-flow reactor or a fully-mixed tank, and why?

Solution:

A SBR is a series of fully-mixed tanks. It approximates plug flow in the same way tanks-in-series approximate plug flow.

6. The wastewater treatment plant for a small town is heavy overloaded with respect to both the wastewater flow and the solids load. The plant consists of headworks, a primary clarifier, an aeration tank, and a secondary clarifier. Suggest a measure or measures that could be implemented quickly and which would allow the plant to achieve better treatment.

Solution:

Chemically enhanced primary treatment.

7.   What is the difference between an anaerobic reactor and an anoxic reactor?

Solution:

Anaerobic = essentially zero oxygen, allowing methanogenesis to occur
Anoxic = low in oxygen such that nitrate is also used as an electron acceptor.

8.   Activated sludge systems are often designed with long, narrow aeration tanks to approximate plug flow within the tank. An existing AST tank is proposed to be modified by turning the aerators off along a length of the aeration tank. The operators hope to improve nitrogen removal using this technique. Do you think this will work? Why or why not?

Solution:

This scheme should work. The one caveat is that SRT may need to be increased to allow nitrification.

9.   The concentration of mixed-liquor suspended solids (MLSS) is often taken as the concentration of active biomass (represented by the variable X in the AST modeling equations). What are at least two shortcomings to the assumption that X = MLSS?

Solution:

MLSS contains inert SS, dead bacteria (cell debris), protozoa, non-biodegradable organic matter, none of which are active biomass.

10.   At solids retention times of greater than about 8 days, settling of activated sludge becomes more problematic. Give at least two reasons for this.

Solution:

Long SRT leads to pin floc, dispersed flox, possibly filamentous bulking.

11.   Why is control of turbidity considered important for disinfection of drinking water?

Solution:

Control of turbidity is recognized in EPA regulations as a surrogate for control of cryptosporidium and giardia.
Turbidity may:

  Harbor bacteria, allowing bacteria to avoid full exposure to disinfectants.

  Exert a demand on chlorine or other oxidants, and thus diminish disinfection.

12.   One method to control sludge bulking by filamentous bacteria in activated sludge systems is to segregate the floating sludge ("skimmings") from the secondary clarifier and keep those skimmings from being recycled to the aeration tank as part of the recycled activated sludge. How does this method reduce potential for sludge bulking?

Solution:

Return activated sludge acts as a "seed" for bacteria in the aeration tank. Skimmings will be enriched in filamentous bacteria and would thus seed those undesirable bacteria.

13.   A wastewater sample is being analyzed to determine its BOD content. The sample is diluted in order to perform the test: 295 mL of distilled water are added to 5 mL of sample to fill the 300 mL BOD bottle. The bottle has an initial dissolved oxygen concentration of 7.9 mg/L. After incubating 5 days, the dissolved oxygen concentration is 4.5 mg/L.

    a.   What is the 5-day BOD of the wastewater?
    b.   The deoxygenation rate constant, k_1, is 0.013 day^{-1}. What is the ultimate BOD of the wastewater?

Solution:

a. *ΔDO from Day 0 to Day 5 is 7.9 – 4.5 = 3.4 mg/L*
   Since wastewater was diluted 60-fold, BOD5 = 60 x 3.4 = 204 mg/L

b. $L_t = L_u(1 - e^{k_1 t})$
   204 mg/L = L_u [1 – exp (-0.013 x 5)] = 0.063 BODu
   BODu = 3200 mg/L

14.   An engineer has proposed to add coagulants to improve the Type 1 solids removal in the clarification zone of a sludge thickener and thereby increase the overall solids removal. Is this a good idea? Why or why not?

Solution:

Flux theory indicates that the overall solids flux will be controlled at the solids concentration where the overall flux (Cv + Cu) is least. This is usually at moderate to high C in the thickening zone, not at the low C in the clarification zone. This strategy is therefore unlikely to increase the overall solids flux.

15.   Short-circuiting is a greater concern in disinfection systems when 99.99% removal is the goal than when 90% removal is the goal. Explain why short-circuiting is more problematic when greater removal is sought.

Solution:

Consider 10% short circuiting at "four 9's" versus "one 9".

99.99% treatment – If 10% gets no treatment and 90% gets full (99.99%) treatment, the resulting overall treatment is:

$$C_{total} = 0.9 \times 0.0001 \ C_0 + 0.1 \ C_0 = 0.1001 \ C_0$$

This is about 1000 times worse than the 99.99% treatment desired.

90% treatment – Again, 10% gets no treatment and 90% gets full (90%) treatment.

$$C_{total} = 0.9 \times 0.01 \ C_0 + 0.1 \ C_0 = 0.19 \ C_0$$

This is only about twice as bad as the treatment desired and much easier to fix than the previous case.

16.   An adequate chlorine concentration for disinfection is often achieved prior to the chlorine "breakpoint." Why then is the breakpoint concentration used rather than a lesser concentration?

Solution:

There are several problems.

One is that the form of chlorine created before the breakpoint is not as stable.

Another is that to get the peak disinfection ability before the breakpoint, you have to be accurate in the amount of chlorine you add: too much can be as bad as too little. Chlorinating past the breakpoint is much more forgiving: you can shoot for a high concentration and be confident of adequate disinfection.

3.

$$\frac{1}{\theta_{min}} = \frac{YKS}{K_s + S} - k_e$$

Note $S \gg K_s$ $\therefore$ $\frac{1}{\theta_{min}} \approx YK - k_e$

At $T = 35\,C$ $YK = 0.04 \cdot 6.67 \left(1.035^{35-35}\right) = 0.27 \text{ day}^{-1}$

$k_e = 0.03 \cdot 1.035^{35-35} = 0.03 \text{ day}^{-1}$

$\frac{1}{\theta_{min}} = 0.24 \text{ day}^{-1}$ $\theta_{min_1} = 4.2 \text{ days}$

At $T = 20\,C$ $YK = 0.16 \text{ day}^{-1}$

$k_e = 0.02 \text{ day}^{-1}$

$\frac{1}{\theta_{min}} = 0.14 \text{ day}^{-1}$ $\theta_{min_2} = 7.1 \text{ days}$

$SF = \frac{\theta_{design}}{\theta_{min}}$

$\frac{SF_2}{SF_1} = \frac{\theta_{d_2}/\theta_{min_2}}{\theta_{d_1}/\theta_{min_1}}$

Since residence time is halved, $\theta_{d_2} = \frac{1}{2}\theta_{d_1}$

$\therefore$ $\frac{SF_2}{SF_1} = \frac{\frac{1}{2}\theta_{d_1}/7.1}{\theta_{d_1}/4.2} = 0.3$

4. Mathematical approach:

a. Oxygen uptake rate, $OUR = \dfrac{R_{O_2}}{\forall}$

$$= \frac{S_{in} - S}{t_R} - 1.42 \frac{S_{in} - S}{t_R (1 + k_e \theta_c)}$$

t_R stays the same

If plant is running OK, $S_{in} \gg S$

$$\therefore \quad OUR \approx \frac{S_{in}}{t_R} - 1.42 \frac{S_{in}}{t_R} \frac{1}{(1 + k_e \theta_c)}$$

θ_c is less, so OUR will be somewhat less but not __much__

b. $\underline{MLVSS = X} = \dfrac{\theta_c}{t_R} Y \left[\dfrac{S_{in}}{1 + k_e \theta_c} - \dfrac{k_s}{\mu_{max} \theta_c - (1 - k_e \theta_c)} \right]$

$\mu_{max} \approx 5 \gg k_e \approx 0.06$ (see text, pg. 456)
$\mu_{max} \theta_c = 15$ to $30 \gg 1$
$k_e \theta_c = 0.2$ to 0.4

$$X \approx \frac{\theta_c}{t_R} Y \left[\frac{S_{in}}{1 + k_e \theta_c} - \frac{k_s}{\mu_{max} \theta_c} \right]$$

$$\frac{\theta_c}{1 + k_e \theta_c} \left(\frac{S_{in} Y}{t_R} \right) - \frac{k_s Y}{\mu_{max} t_R}$$

$$\longrightarrow \frac{0.6}{1.4} \rightarrow \frac{0.3}{1.2} \downarrow$$

__Decrease in θ_c implies a decrease in X__

c. Per graph of settling velocity vs. θ_c (Lecture 19, pg 21) sludge will settle slower at $\theta_c = 3$ days. In fact, $\theta_c = 3$ days is the worst for sludge settling!

d.
$$S = \frac{K_s(1 + \Theta_c K_e)}{\Theta_c(\mu_{max} - K_e) - 1}$$

$$\approx \frac{K_s(1 + \Theta_c K_e)}{\Theta_c \mu_{max}}$$

$$\approx \frac{K_s}{\mu_{max}} \frac{1}{\Theta_c} + \frac{K_s K_e}{\mu_{max}}$$

Decrease in Θ_c → increase in S