ENV 4001: ENVIRONMENTAL SYSTEMS ENGINEERING

Fall 2021 | University of South Florida
Problem set #7 | Civil & Environmental Eng.
Complete by Wednesday, November 10 | Prof. J. A. Cunningham

This problem set will not be collected or graded. Your reward for completing this problem set is that it is essential for learning the course material and passing the quizzes and final exam.

1. This problem set deals with wastewater treatment, i.e., sanitation. Proper sanitation is important for protecting public health and preventing diseases such as cholera, typhoid, hepatitis A, adenovirus, and others. For Sustainable Development Goal #6, find two *targets* that are specifically aimed at improving sanitation around the world, and write them down. Also write down the *indicators* associated with those targets. (SDG 6 deals with both drinking water and sanitation, but for this assignment, focus on the sanitation part only.)

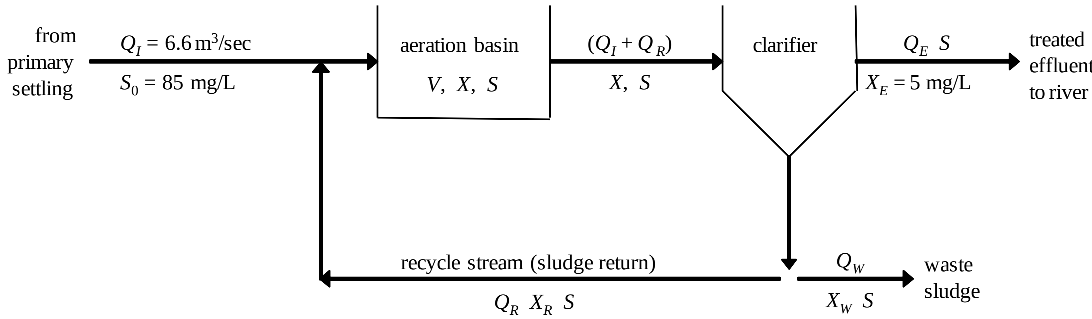
Background information for the rest of this assignment:

Recall from Problem Set #5 that a wastewater treatment plant in the city of Nastyville operates with only primary treatment, and they can't meet the requirements of the Clean Water Act, so now they have to add secondary treatment to their facility. You work for an engineering firm that has been hired to design and build an activated sludge system for secondary treatment at the wastewater treatment plant. To design the activated sludge system, you must specify three things: the **volume of the aeration basin**, the **oxygen input into the aeration basin**, and the **sludge return (recycle) rate**. You also have to find the **solids retention time** and indicate **how much waste sludge** they will have to handle as a result of your design. (Another engineer in your firm will design a sludge-handling system based on what you tell him/her.) *NOTE: In 2021 we will skip the oxygen input.*

The design flow rate is 150 million gallons per day (6.6 m^3/s) of primary-settled wastewater (as in problem set #5). Under current operation, the BOD_5 of the primary-settled wastewater is usually no greater than 165 mg/L (also from problem set #5). Of that, 85 mg/L of BOD_5 comes from soluble BOD_5, and 80 mg/L of BOD_5 comes from solids.

Based on your findings in PS #5, the local regulatory agency has decided that, following construction of the new secondary treatment system, the plant's treated secondary effluent (which they will continue to discharge into the river) must contain no more than 10 mg/L of BOD_5 (total, including both soluble and suspended forms), and no more than 5 mg/L suspended solids.

Based on the information above, we have the following schematic diagram.



2. In problem 2, you will find the **solids retention time** required for the Nastyville plant.
   a. Assume that the BOD_5 of the treated effluent comes from both the *suspended solids* and the *soluble substrate* (dissolved organic carbon). That is,

   $$(BOD_5)^{total} = (BOD_5)^{soluble} + (BOD_5)^{suspended}$$

   Recall that the regulatory agency has said that the secondary effluent must contain no more than 10 mg/L of BOD_5 in *total*.
   A rule of thumb is that the BOD_5 of the suspended solids is equal to about 60% of the suspended solids concentration. [NOTE: in my experience, that statement gives students a lot of trouble each year. It is actually quite simple: $(BOD_5)^{suspended} \approx 0.60*X$.] Assume that the suspended solids concentration in the treated effluent (X_E) is at its maximum allowable concentration of 5 mg/L, as shown in the figure on the previous page. Then, what is the maximum allowable BOD_5 that you can have from the *dissolved* organic carbon in the treated effluent? This quantity is S, the soluble substrate concentration in the mixed liquor of the aeration basin. Hint: this problem is really easy – if you are trying something complicated, you are on the wrong track.
   b. What percentage of S_0, the dissolved substrate concentration coming from the primary settling, must be removed in the aeration basin in order to achieve the effluent standard?

   The following parameters would be typical values in an aeration basin at 20 °C:
   maximum specific growth rate constant for bacteria, $\mu_m = 3\ day^{-1}$
   yield coefficient, $Y = 0.60$ mg biomass formed per mg BOD_5 utilized
   half-saturation constant, $K_S = 60$ mg/L BOD_5
   bacterial death rate constant, $k_d = 0.10\ day^{-1}$

   c. Write a *material balance* for the mass of bacterial cells (i.e., X). Your control volume should be the entire secondary treatment process; the sludge recycle stream should be completely contained within your control volume. From this material balance, derive an expression for the solids retention time.

problem 2 continues →

2. continued
   d. Use the Monod parameters given above to calculate the solids retention time (SRT) required to meet the effluent standard for soluble BOD_5. Report the SRT in units of days. Is it within the expected range of 2–30 d?

3. In problem 3, you will find the **volume of the aeration basin** that is required to meet the plant's effluent standard for soluble BOD_5. A typical range for the concentration of mixed-liquor volatile suspended solids (MLVSS, also called biomass, X) in an aeration basin is 1500–3000 mg/L. Let's assume X = 2400 mg/L for the Nastyville treatment plant.
   a. *Write a material balance* for the soluble substrate (i.e., S), with the aeration basin as your control volume. From this material balance, derive an expression for the required volume, V. (Note: in practice, you might have multiple aeration basins running in parallel, each with a portion of the overall volume. At the Howard Curren plant, they run 6 aeration basins in parallel, each with a design flow rate of 16 million gallons per day.)
   b. Find the average hydraulic residence time, θ. Report your answer in units of minutes. Is the value reasonable? Hint: consider that θ at the Howard Curren Advanced Wastewater Treatment Plant in Tampa is about 45 minutes.

4. Now you will calculate the **flow rate of the return activated sludge**, Q_R, required to maintain the desired performance in the aeration basin.
   a. *Write a material balance* for biomass (i.e., X). This time, for your control volume, use the aeration basin. From this material balance, derive an expression for the sludge return rate, Q_R.
   b. A reasonable value for the biomass concentration in the sludge return stream would be $X_R \approx$ 9500 mg/L. (Something to think about: why is X_R so much higher than X?) Based on this value of X_R, calculate Q_R. Report your answer as the ratio Q_R/Q_I. Typically, the sludge returned to the aeration basin is about 20–30% of the incoming wastewater flow. However, at the Howard Curren plant in Tampa, the sludge return rate is about 35% of the influent flow rate, so we'll say that 20–35% is an acceptable range for sludge return. Does your design for the Nastyville plant fall within this acceptable range?

5. Now let's calculate the **sludge "wasting" rate**, $Q_W X_W$.
   a. Write a material balance for biomass (i.e., X). This time, for your control volume, use the clarifier. Ignore the source and sink terms in the material balance; assume that bacterial growth and death are both negligible in the clarifier (unlike the aeration basin, where you add a lot of oxygen). From the material balance, derive an expression for the sludge production rate, $Q_W X_W$.

problem 5 continues →

5. continued
   b. Use the equation you just derived to calculate the value of the sludge production rate, $Q_W X_W$. For purposes of this calculation, you can assume that the effluent flow rate Q_E is approximately equal to the influent flow rate Q_I. Report your sludge production rate in units of kg/d. Does it sound like a lot of sludge? Consider that a Toyota Yaris automobile weighs approximately 1000 kg; how many Toyota Yarises (Yares? Yarii?) worth of sludge does your plant produce in one day?

6. Let's think a little bit more about the solids retention time.
   a. Re-calculate SRT using equations 9.10, 9.11, and 9.14 in your text. Do all the estimates come out about the same? If not, why not?
   b. Equation 9.10 in your text has the term $Q_W X_W$ in the denominator. I actually think the denominator should be ($Q_W X_W + Q_E X_E$). Calculate the SRT using my denominator; how much difference does it make if we include the $Q_E X_E$ term, as I think we should? Is it OK to ignore that term, as your book does in equation 9.10? Hint: you can estimate Q_E because you know Q_I and you can easily calculate Q_W after having completed problem 5.
   c. Is the solids residence time equal to the hydraulic residence time? Since the cells and the water are moving through the same aeration basin, should they have the same residence time? If you answer "no," then explain why not.

7. What is the *F/M* ratio for your designed Nastyville plant? Is it in the range you'd expect based on Table 9.7 in your text?

8. *Possibly skip this one in 2021 – check with instructor*
   Your supervisor recently went to a seminar about recovering valuable energy and nutrients from wastewater sludge. She now wants you to do some preliminary calculations and design to see what might be recovered from the waste sludge (see question 5). This will be accomplished through the process of anaerobic digestion of the waste sludge.
   a. Assume that you want to add your sludge at a rate of 3 kg VSS per m^3 of digester volume per day. What size of digester is required? If the digester is cylindrical in shape, and the height is one-third the diameter, then what will be the dimensions of the digester?
   b. But wait! We forgot to account for all the sludgte coming from primary settling, too. Assume that 30,400 kg/d of sludge come from primary treatment. Re-size your digester so that it can handle the sludge from both primary treatment and secondary treatment.
   c. Assume that, during the anaerobic digestion process, 40% of the sludge is broken down anaerobically. The sludge contains 1.5 g of BOD per gram of VSS. You can produce 0.35 m^3 of CH_4 per kg of BOD stabilized (assuming standard temperature and pressure for the methane). What is the rate of methane production in m^3/d?
   d. The heat value of methane is about 35,800 kJ/m^3 at standard conditions. What is the energy value of the produced methane, in units of kW? (Recally that 1 W = 1J/s.)

9. At the Howard Current Advanced Wastewater Treatment Facility in Tampa, the average rate of treatment is 57.2 million gallons per day. Sometimes the flow rate to the plant deviates significantly from this average. Usually, that is not a problem, because the design flow rate is 96 million gallons per day, i.e., the plant is over-designed relative to the average flow rate. However, life at the Howard Curren facility would probably be easier if they had an *equalization basin* to handle temporary increases in the flow rate. Imagine that the flow rate into the Howard Curren plant could be described by the following mathematical equation:

$$Q(t) = Q_{avg}\left[1 - 0.5\sin\left(\frac{2\,\pi\,t}{12\,\text{hr}}\right)\right]$$

where t is the time of day, measured in hours. That is, t = 1 corresponds to 1:00 AM, t = 15.5 corresponds to 3:30 PM, etc.

a. Graph $Q(t)$ vs time of day. Make the range of your graph be from midnight of one day to midnight of the following day. At what time(s) is flow into the plant highest? At what time(s) is flow into the plant lowest? Does the equation appear reasonable?

b. Given this equation for flow rate, what *volume* of equalization basin would be required if the plant wanted to always operate at a flow rate Q_{avg}? Hint: your graph from part (a) can help you figure out the required volume.

10. *Skip this one in 2021*
Answer problem 9.17 in your text. Some of the 7 statements might be tough, but do your best.

A note for engineering students (i.e., all of you): In many of the problems above, I had you compare your calculated answers to "typical" values. It is always a good idea to stop and take a periodic "reality check" when performing design calculations. As you work on your design, periodically stop and ask yourself: do my calculations make sense? Are they realistic? Are they consistent with other numbers that I know to be typical, reasonable, or appropriate? If you are working in a new area, you might not have the experience to know what is typical or reasonable, but hopefully you can find an authoritative source (perhaps a text book) to give you some guidance on what your answer "should" be. Evaluating whether your design is reasonable is just as important as coming up with the design in the first place!