5 points total for entire homework

CEE 371 Fall 2009

Homework #9 Wastewater Treatment

Consider the design of a wastewater treatment plant (WWTP) for a community with average daily and peak hourly wastewater design flows of 2.0 MGD and 5.0 MGD. The raw sewage has an average of 230 mg/L BOD_5 and 260 mg/L of suspended solids.

1. After screening and grit removal, the WW is to be treated by primary sedimentation in two parallel treatment trains of circular clarifiers (so 2 sedimentation tanks, each gets ½ the flow).

1 point for #1

a. Determine the diameter of each tank and the nominal side water depth for design criteria of an overflow rate of 700 gpd/ft^2 and detention time of 3 hours at average flow.

With a total flow of 2 MGD, each tank must process 1 MGD. You can determine surface area from the flow and overflow rate.

$$A = \frac{Q}{V_o} = \frac{1x10^6 \frac{gal}{d}}{700 \frac{gal}{d-ft^2}} = 1420 ft^2$$

So then calculate the diameter from this area

$$A = \pi r^2 = \pi \frac{D^2}{4}$$

$$D = \sqrt{\frac{4}{\pi} A} = \sqrt{\frac{4}{3.1415} 1420 ft^2} = \mathbf{43 ft}$$

Now determine depth from the retention time

$$t_R = \frac{V}{Q} = \frac{AxD}{Q}$$

So:

$$D = \frac{t_R Q}{A} = \frac{3hr\left(\frac{1d}{24hr}\right)1x10^6 \frac{gal}{d}\left(\frac{7.48 gal}{ft^3}\right)}{1420 ft^2} = \mathbf{11.7 ft}$$

Post script (not necessary for a "correct answer", but helpful): Use 12 ft nominal depth; possibly expanding it to 16 ft to account for sludge volume

b. Also, determine the overflow weir loading rate at peak hourly flow if the weir is placed all around the circumference of the tank. Compare to design standards.

The weir will have a length equal to the circumference.

$$weir\ length = \pi D = 3.1415(43 ft) = 135\ ft$$

Peak flow per tank is just one-half the overall peak flow, or 2.5 MGD. Therefore,

$$weir\ loading = \frac{2.5x10^6 \frac{gal}{d}}{135ft} = \mathbf{18,518} \frac{\mathbf{gpd}}{\mathbf{ft}}$$

Design standard is up to 30,000 gpd/ft at peak flow based on Ten States Standards (pg 70-4), and may even be up to 40,000 at average flow based on EPA standards (Table 11-2 in text), so this is OK

2. Assume that the primary sedimentation process removes 60% of the suspended solids and 40% of the BOD_5 of the raw sewage.

1 point for #2

a. Determine the SS and BOD_5 concentrations in the primary sedimentation effluent flow.

$$SS_{primary\ effluent} = (1 - 0.60)260 \frac{mg}{L} = \mathbf{104} \frac{\mathbf{mg}}{\mathbf{L}}$$

$$BOD5_{primary\ effluent} = (1 - 0.40)230 \frac{mg}{L} = \mathbf{138} \frac{\mathbf{mg}}{\mathbf{L}}$$

b. Also determine the mass of primary sludge produced per day at average flow conditions, as both dry solids and as wet sludge assuming a sludge concentration of 6% solids and a specific gravity of 1.03.

so the per tank production rate of dry solids at average flow would be:

$$SS_{dry\ mass} = Q\ {}^{\Delta}SS = 1.0x10^6 \frac{gal}{d}(260 - 104)\frac{mg}{L}\left(\frac{3.785L}{gal}\right)\left(\frac{1lb}{453{,}592mg}\right) = \mathbf{1302} \frac{\mathbf{lb}}{\mathbf{d}}$$

And accounting for 6% solids by weight:

$$SS_{wet\ mass} = \frac{1302 \frac{lb}{d}}{0.06} = \mathbf{21,698} \frac{\mathbf{lb}}{\mathbf{d}}$$

Which corresponds to a flow of:

$$Q_{sludge} = \frac{21{,}698 \frac{lb}{d}}{1.03 \frac{Kg}{L}}\left(\frac{1gal}{3.785L}\right)\left(\frac{0.4536Kg}{lb}\right) = \mathbf{2524} \frac{\mathbf{gal}}{\mathbf{d}}$$

3. The primary effluent is to be treated by two parallel trains of the complete mix activated sludge process. Assume average flow conditions, and the primary sedimentation performance as described in part 2 above. Assume the following for the activated sludge process:

- Plant effluent BOD_5 of 8 mg/L
- Biomass yield of 0.55 kg biomass / kg BOD
- Endogenous decay rate (k_d) = 0.04 day^{-1}
- Solids Retention Time (θ_C) = 8 days
- MLVSS concentration in the aeration tank of 3000 mg/L
- Waste and recycle solids concentration of 12,000 mg/L

2 points for #3

a) Determine the aeration tank volume in cubic meters.

Use the combined model equation developed in class and on the slides:

$$\frac{1}{\theta_c} = \frac{YQ(S_o - S)}{VX} - k_d$$

$$\frac{1}{8d} = \frac{0.55\left(1x10^6\frac{gal}{d}\right)\frac{3.785L}{gal}(138-8)\frac{mg}{L}}{V3{,}000\frac{mg}{L}} - 0.04d^{-1}$$

$$V = \frac{(8d)0.55\left(1x10^6\frac{gal}{d}\right)\frac{3.785L}{gal}(138-8)\frac{mg}{L}}{3{,}000\frac{mg}{L}\left(1+8d(0.04d^{-1})\right)} = 546{,}800L = \mathbf{547m^3}$$

b) Determine the mass and volumetric flow rates (kg/day and cubic meters per day) of wasted sludge.

Recall that:

$$\theta_c = \frac{XV}{(Q-Q_w)X_e + Q_wX_r} \approx \frac{XV}{Q_wX_r}$$

So, rearranging, we can isolate the mass loading rate (Q_Wx_r):

$$Q_Wx_r = \frac{XV}{\theta_c}$$

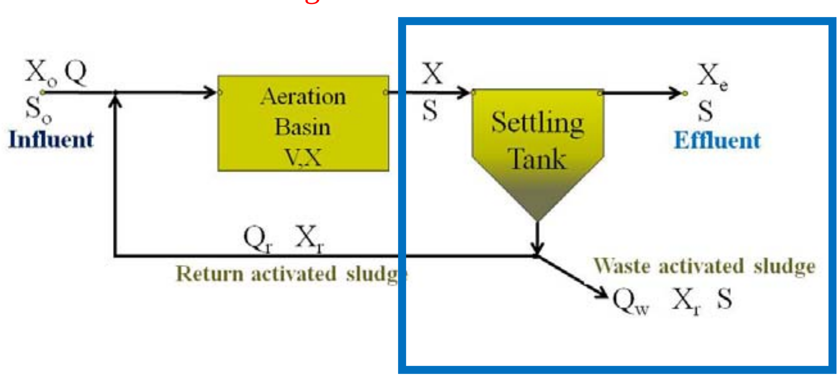
$$Q_Wx_r = \frac{3\frac{Kg}{m^3}(547m^3)}{8d} = \mathbf{205\frac{Kg}{d}}$$

And now the volumetric flow (Q_W) is obtained by:

$$Q_W = \frac{Q_Wx_r}{x_r} = \frac{205\frac{kg}{d}}{12\frac{Kg}{m^3}} = \mathbf{17\frac{m^3}{d}}$$

c) Determine the return (recycle) flow rate in cubic meters per day (and in MGD).

Develop a mass balance around the settling tank:



$$(Q+Q_r)X = Q_rX_r + Q_WX_r + (Q-Q_W)X_e$$
$$(Q+Q_r)X \approx Q_rX_r + Q_WX_r$$

$$Q_r(X - X_r) \approx Q_w X_r - Q_x$$

$$Q_r \approx \frac{Q_w X_r - Q_x}{(X - X_r)} = \frac{17\frac{m^3}{d}(12\frac{g}{L}) - 3785\frac{m^3}{d}(3\frac{g}{L})}{3\frac{g}{L} - 12\frac{g}{L}} = \mathbf{1239\frac{m^3}{d} = 0.33\ MGD}$$

d) Determine the volumetric BOD loading to the aeration tank in lb BOD per 1000ft^3.

The volumetric BOD loading will be:

$$Volumetric\ BOD\ Loading = \frac{QS_o}{V} = \frac{1x10^6 gal(\frac{3.7854L}{gal})\left(\frac{lb}{453{,}592mg}\right)138\frac{mg}{L}}{546{,}800L(\frac{0.035315ft^3}{L})} = 0.05964\frac{lb}{ft^3}$$

$$Volumetric\ BOD\ Loading = \mathbf{59.6\frac{lb}{1000ft^3}}$$

(NB: upper end of typical range)

e) Determine the food to microorganism ratio (F/M) for the aeration tank in kg BOD per day per kg MLVSS.

$$F/_M\ ratio = \frac{QS_o}{XV} = \frac{1x10^6\frac{gal}{d}\left(\frac{3.7854L}{gal}\right)138\frac{mg-BOD}{L}}{3000\frac{mg-MLVSS}{L}546{,}800L} = 0.318\frac{mg-BOD}{mg-MLVSS} = \mathbf{0.318\frac{lb-BOD}{lb-MLVSS}}$$

f) Determine the design hydraulic detention time (θ) in hours.

$$\theta = \frac{V}{Q} = \frac{546{,}800L}{1x10^6\frac{gal}{d}3.785\frac{L}{gal}} = 0.144d = \mathbf{3.47\ hr}$$

4. Suppose that the primary effluent is to be treated by two parallel high-rate single stage tricking filters with the following characteristics:
   - 6 feet deep rock trickling filter media
   - Design BOD loading of 50 lb/day/1000 ft^3
   - Design hydraulic loading of 0.30 gpm/ft^2
   - Recirculation ratio of 1.5

   a) Determine the volume (ft^3) and diameter (ft) of each trickling filter.

1 point for #4

Calculated volume based on actual BOD loading and design loading

BOD load equals QS_o, for each train

$$Actual\ BOD\ laod = 1x10^6 \frac{gal}{d}\left(\frac{3.7854L}{gal}\right) 138 \frac{mg-BOD}{L} = 1151 \frac{lb}{d}$$

$$Volume = \frac{1151 \frac{lb}{d}}{50 \frac{lb/_d}{1000ft^3}} = 23.0\ x\ 10^3\ ft^3$$

$$Volume = area\ x\ depth = \frac{\pi}{4} D^2\ x\ 6ft = 23{,}000ft^3$$

D = 70 ft

b) Determine the effluent BOD concentration at 20 ºC and at 10 ºC and comment on the results.

Use NRC formula

$$E_{20} = \frac{100}{1 + 0.0561\left(\frac{W}{VF}\right)^{0.5}}$$

$$F = \frac{1 + R}{(1 + 0.1R)^2}$$

$$F = \frac{1 + 1.5}{\left(1 + 0.1(1.5)\right)^2} = 1.89$$

$$E_{20} = \frac{100}{1 + 0.0501\left(\frac{50}{1.89}\right)^{0.5}} = 77.6\%$$

So

$$BOD_{effluent} = \left(1 - \frac{77.6}{100}\right) 138 = \mathbf{31\ mg/L}$$

$$E_T = E_{20} 1.035^{(T-20)}$$

$$E_{10} = E_{20} (1.035)^{(10-20)} = 55\%$$

So:

BOD_{efflu} = (1-0.55)138 mg/L = **62 mg/L**