

**Problem 1**

Class Text Problem 12.10. State the two main reasons why an activated sludge system is operated at a relatively low food to microorganism ratio.

Activated sludge systems are operated at low food-to-microorganism ratios for two primary reasons. The first is that at low  $F/M$  the majority of organisms are starved for nutrients and they utilize a greater proportion of the substrate they consume just to maintain their existence. This results in higher rates of substrate consumption but low sludge production rates. The second reason is that due to the more stressed conditions of growth, the organisms exude a protective slime which makes them "sticky" and improves settling rates in secondary sedimentation.

**Problem 2**

Class Text Problem 12.25. A single stage trickling filter plant (Figure 12.21) is proposed for treating a dilute wastewater with a BOD concentration of 170 mg/L. The plant is located in a warm climate and minimum wastewater temperature anticipated is 16°C. Using a recirculation ratio of 0.5, what is the maximum allowable BOD loading for a stone media filter to achieve an average effluent BOD of 30 mg/L?

$$S_{\text{feed}} = 170 \text{ mg/L}$$

$$S_i = \frac{2}{3} \left( 170 \frac{\text{mg}}{\text{L}} \right)$$

$$= 113 \frac{\text{mg}}{\text{L}}$$

assuming  
33% removal  
in primary  
settling

For 30 mg/L effluent

$$E = 100\% \left( \frac{113 - 30}{113} \right) = 73.5\% \quad (@ 16^\circ\text{C})$$

$$E = E_{20} (1.035)^{16-20}$$

$$73.5\% = E_{20} (1.035)^{-4} \Rightarrow E_{20} = 84.3\%$$

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

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

$$= \frac{1+0.5}{(1+0.1[0.5])^2} = 1.360$$

$$84.3\% = \frac{100\%}{1 + 0.0561 \left(\frac{W}{VF}\right)^{0.5}}$$

$$\frac{W}{VF} = 11.0 \frac{\text{lb BOD}}{1000 \text{ ft}^3 \text{-day}}$$

$$\frac{W}{V} = (11.0) F = 15.0 \frac{\text{lb BOD}}{1000 \text{ ft}^3 \text{-day}}$$

15.7 if 35% removal assumed in primary settling

### Problem 3

Class Text Problem 12.41. A biological tower with high density, cross-flow packing has a surface area of 480 ft<sup>2</sup>, and a depth of 12.0 ft. The packing has a specific surface area of 42 ft<sup>2</sup>/ft<sup>3</sup>, n = 0.5, and k<sub>20</sub> = 0.0035 (gpm/ft<sup>2</sup>)<sup>0.5</sup>. The effluent from the primary clarifier is 600,000 gpd with a total BOD of 126 mg/L and soluble BOD of 62 mg/L. The wastewater temperature is 18 C and the recirculation ratio is 1.0. Calculate the effluent soluble BOD, assuming the ratio of soluble BOD to total BOD is the same ratio as in the primary effluent.

$$V = (480 \text{ ft}^2)(12 \text{ ft}) = 5760 \text{ ft}^3$$

Applying  $\frac{S_e}{S_p}$  based on soluble BOD only

$$S_p = 62 \text{ mg/L}, \quad \frac{Q}{A} = \frac{(600,000 \text{ gal/day}) \left(\frac{1 \text{ day}}{1440 \text{ min}}\right)}{480 \text{ ft}^2} = 0.868 \frac{\text{gpm}}{\text{ft}^2}$$

$$S_e = (62 \text{ mg/L}) e^{-\frac{0.0035 \left(\frac{\text{gpm}}{\text{ft}^2}\right)^{0.5} (1.035)^{18-20} (42 \frac{\text{ft}^2}{\text{ft}^3})(12 \text{ ft})}{L(1+1.0)(0.868)^{0.5}}}$$

$$1 + 1.0 \Rightarrow 1.0 e^{-\frac{0.0035(1.035)^{-2}(42)(12)}{[2](0.868)^{0.5}}}$$

$$S_e = 10.37 \text{ mg/L}$$

Keeping same ratio on effluent as on influent

$$S_{e, \text{tot}} = \left(\frac{126}{62}\right) (10.37) = 21.1 \frac{\text{mg}}{\text{L}}$$

#### Problem 4

Class Text Problem 12.49. A conventional activated sludge system treats 11,000 m<sup>3</sup>/day of wastewater with a BOD of 180 mg/l in an aeration tank with a volume of 3400 m<sup>3</sup>. The operating conditions are an effluent suspended solids of 20 mg/L, an MLSS concentration maintained in the aeration tank of 2500 mg/L, and an activated sludge wasting rate of 160 m<sup>3</sup>/day containing 8000 mg/L. From these data, calculate the aeration period, volumetric BOD loading, F/M loading, and sludge age.

$$\begin{aligned} \text{BOD loading} &= \frac{Q S_0}{V} & Q &= 11,000 \frac{\text{m}^3}{\text{day}} & S_0 &= 180 \frac{\text{mg BOD}}{\text{L}} & V &= 3400 \text{m}^3 \\ &= \frac{(11,000 \frac{\text{m}^3}{\text{day}})(180 \frac{\text{mg}}{\text{L}})}{(3400 \text{m}^3)} = 582 \frac{\text{mg}}{\text{L} \cdot \text{day}} \\ &= \left(582 \frac{\text{mg}}{\text{L} \cdot \text{day}}\right) \left(\frac{1 \text{g}}{1000 \text{mg}}\right) \left(\frac{1000 \text{L}}{\text{m}^3}\right) = 582 \frac{\text{g}}{\text{m}^3 \cdot \text{day}} \\ &\text{similarly} = 582 \frac{\text{kg}}{1000 \text{m}^3 \cdot \text{day}} // \end{aligned}$$

$$\begin{aligned} F/M &= \frac{Q S_0}{V X} & X &= 2500 \frac{\text{mg}}{\text{L}} \text{ MLSS} \\ &= \frac{(11,000 \frac{\text{m}^3}{\text{day}})(180 \frac{\text{mg}}{\text{L}})}{(3400 \text{m}^3)(2500 \frac{\text{mg}}{\text{L}})} = 0.233 \frac{1}{\text{day}} \text{ or } 0.233 \frac{\text{mg BOD}}{\text{mg MLSS} \cdot \text{day}} // \end{aligned}$$

$$\begin{aligned} \theta_c &= \frac{V X}{Q_w X_w + (Q - Q_w) X_e} & X_w &= 8000 \frac{\text{mg}}{\text{L}} \text{ MLSS} & Q_w &= 160 \frac{\text{m}^3}{\text{day}} & X_e &= 20 \frac{\text{mg}}{\text{L}} \text{ MLSS} \\ \theta_c &= \frac{(2500 \text{mg/L})(3400 \text{m}^3)}{(160 \text{m}^3/\text{day})(8000 \frac{\text{mg}}{\text{L}}) + (11,000 \frac{\text{m}^3}{\text{day}} - 160 \frac{\text{m}^3}{\text{day}})(20 \frac{\text{mg}}{\text{L}})} = 5.7 \text{ day} \end{aligned}$$

#### Problem 5

Class Text Problem 12.51. Determine the volume of three identical activated sludge tanks following primary clarification to aerate 36,000 m<sup>3</sup>/day with a BOD concentration of 180 mg/L at a BOD loading of 560 g/m<sup>3</sup>/day. What is the aeration time? For a F/M of 0.35 mg BOD/ mg SS/ day, what MLSS concentration should be maintained in the aeration tank? Estimate the operating sludge age, assuming an effluent suspended solids of 30 mg/L and the daily amount of waste activated sludge solids from Figure 13.1. If the waste sludge has a concentration of 10,000 mg/L, what is the calculated volume of sludge to be wasted each day? Determine the dimension of three identical rectangular clarifiers (length, width, and side-water depth) with a 2:1 length to width ratio.

$$\begin{aligned} \text{BOD loading} &= \frac{Q S_0}{V} = 560 \frac{\text{g}}{\text{m}^3 \cdot \text{day}} \text{ per tank} \\ Q \text{ per tank} &= \frac{36,000 \text{m}^3}{3} \text{ day} = 12,000 \frac{\text{m}^3}{\text{day}} & S_0 &= 180 \frac{\text{mg}}{\text{L}} \\ 560 \frac{\text{g}}{\text{m}^3 \cdot \text{day}} &= \frac{(12,000 \text{m}^3/\text{day})(180 \text{mg/L})}{V} \Rightarrow V = \frac{(12,000 \frac{\text{m}^3}{\text{day}})(180 \frac{\text{mg}}{\text{L}})}{560 \frac{\text{g}}{\text{m}^3 \cdot \text{day}}} \left(\frac{1 \text{g}}{1000 \text{mg}}\right) \left(\frac{1000 \text{L}}{\text{m}^3}\right) \\ \theta &= \frac{3857 \text{m}^3}{12,000 \frac{\text{m}^3}{\text{day}}} = 0.321 \text{ day} & V &= 3857 \text{m}^3 \\ &= 7.7 \text{ hr} \\ F/M &= \frac{Q S_0}{V X} = 0.35 \frac{\text{mg}}{\text{mg} \cdot \text{day}} & X &= \frac{(12,000 \frac{\text{m}^3}{\text{day}})(180 \frac{\text{mg}}{\text{L}})}{(3857 \text{m}^3)(0.35 \frac{\text{mg}}{\text{mg} \cdot \text{day}})} = 1600 \text{mg/L} \end{aligned}$$

To get sludge age  $\theta_c$ , use Fig. 13.1 & eq. 13.7  
 $W_{as} = 1.0 \times BOD \times Q \times 8.34 \times k$   $\frac{lb/day}{1b/day \text{ for } BOD(mg/L)}$   
 $\uparrow$  2.0 if no primary settling  $k = 0.47 \frac{lb SS}{lb BOD}$

$$Q = \left(36,000 \frac{m^3}{day}\right) \left(0.000264 \frac{Mg/D}{\frac{m^3}{day}}\right) = 9.54 \text{ MGD}$$

$$W_{as} = \left(180 \frac{mg}{L}\right) \left(9.54 \text{ MGD}\right) \left(8.34 \frac{lb/Mg}{mg/L}\right) \left(0.47 \frac{lb SS}{lb BOD}\right)$$

$$W_{as} = 6,730 \text{ lb/day}$$

Noting that  $W_{as} = Q_w \Sigma_w$

then  $\theta_c = \frac{V \Sigma}{W_{as} + (Q - Q_w) \Sigma_e}$  neglect  $Q_w$  w.r.t.  $Q$

Since basing  $W_{as}$  on  $Q_{tot}$ , use  $V = 3(3857 m^3) = 11,570 m^3$

$$\theta_c = \frac{(11,570 m^3) \left(264.2 \frac{gal}{m^3}\right) \left(\frac{1 Mg}{10^6 gal}\right) (1600 mg/L) \left(8.34 \frac{lb/Mg}{mg/L}\right)}{(6,730 \text{ lb/day}) + (9.54 \text{ MGD}) \left(30 \frac{mg}{L}\right) \left(8.34 \frac{lb/Mg}{mg/L}\right)}$$

$$\theta_c = 4.47 \text{ day}$$

$$Q_w = \frac{W_{as}}{\Sigma_w} = \frac{6730 \text{ lb/day}}{(10,000 mg/L) \left(8.34 \frac{lb/Mg}{mg/L}\right)} \approx 0.081 \text{ MGD}$$

$$\text{or } Q_w = (0.081 \text{ MGD}) \left(3785 \frac{m^3/day}{MGD}\right) = 305 \frac{m^3}{day}$$

Sizing clarifiers using flow per 3 clarifiers

of  $12,000 m^3/day$  &  $OFR = 33 \frac{m^3}{m^2 \cdot day}$

$$A = \frac{12,000 m^3/day}{33 \frac{m^3}{m^2 \cdot day}} = 364 m^2 \quad \text{but } L = 2W$$

$$\text{so } 364 m^2 = (2W)W \Rightarrow W = 13.5 m$$

$$\& L = 2(13.5 m) = 27 m$$

$$\text{Using } \theta = Bhr \Rightarrow V = Q\theta = \left(12,000 \frac{m^3}{day}\right) \left(\frac{3}{24} \text{ day}\right)$$

$$V = 1500 m^3 \Rightarrow \text{depth} = \frac{1500 m^3}{364 m^2} = 4.1 m$$

### Problem 6

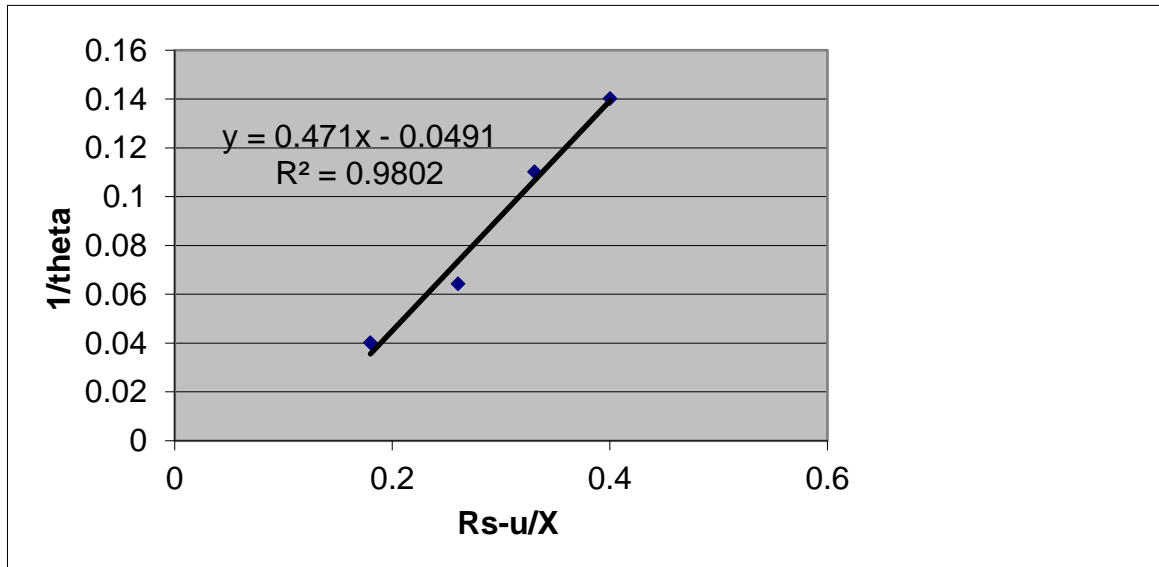
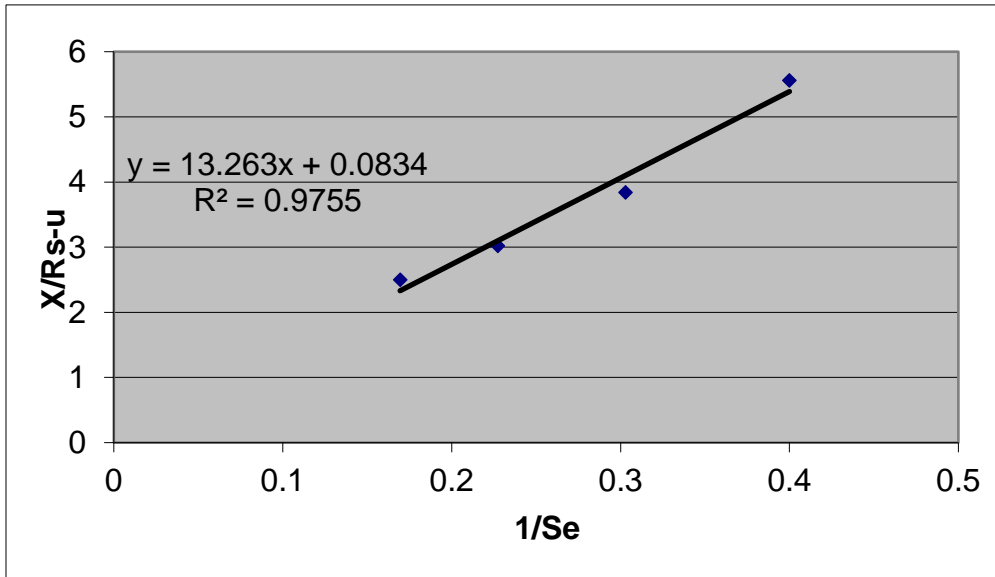
Class Text Problem 12.57. A municipal wastewater containing both domestic and food processing wastewater was tested to determine kinetic constants using a laboratory apparatus similar to the bench scale unit shown in Fig. 12.42. The volume of the aeration chamber was 10 L, and the wastewater feed was established at a constant rate of 30 L/day to provide an 8 hour aeration period for all of the tests in the runs. A measured volume of sludge was wasted once a day ( $Q_w$ ) from the tank. Determine  $Y$ ,  $k_d$ ,  $k$ , and  $K_s$  for the measured data shown below ( $Q$ ,  $S_0$ ,  $Q_w$ ,  $S_e$ ,  $X$ , and  $X_e$ ).

Q (L <sup>3</sup> /day)	S <sub>0</sub> (mg/L)	Q <sub>w</sub> (mg/L)	S <sub>e</sub> (mg/L)	X (mg/L)	X <sub>e</sub> (mg/L)
30.0	150	0.31	2460	2.5	7.7
30.0	150	0.53	1690	3.3	6.5
30.0	150	0.98	1320	4.4	5.6
30.0	150	1.27	1080	5.9	5.0

The spreadsheet below uses the data above to generate the Trendline plot fit graphs

S <sub>0</sub> (mg/L)	Q <sub>w</sub> (L/day)	1/θ <sub>c</sub> (1/day)	S <sub>e</sub> (mg/L)	X (mg/L)	X <sub>e</sub> (mg/L)	r <sub>s-u</sub> (mg/L/day)	r <sub>s-u</sub> /X (1/day)	X/r <sub>s-u</sub> (day)	1/S <sub>e</sub> (L/mg)
150	0.31	0.040293	2.5	2460	7.7	442.5	0.179878	5.559322	0.4
150	0.53	0.064335	3.3	1690	6.5	440.1	0.2604142	3.840036	0.30303
150	0.98	0.110312	4.4	1320	5.6	436.8	0.3309091	3.021978	0.227273
150	1.27	0.140301	5.9	1080	5	432.3	0.4002778	2.498265	0.169492

Q = 30 L/day      V = 10 L



Sample calc's for 1st row:  $\frac{1}{\theta_c} = \frac{Q_w \bar{X}_w + (Q - Q_w) \bar{X}_e}{V \bar{X}} = \frac{(0.31 \frac{L}{day}) (2460 \frac{mg}{L}) + (30 - 0.31) \frac{L}{day} (1.7 \frac{mg}{L})}{(10 L) (2460 \frac{mg}{L})}$

$\frac{1}{\theta_c} = 0.4103 \frac{1}{day}$   $r_{su} = \frac{S_0 - S_e}{V/Q} = \frac{(150 - 25) \frac{mg}{L} (30 \frac{L}{day})}{(10 L)} = 442.5 \frac{mg}{L \cdot day}$

$r_{su}/\bar{X} = \frac{442.5 \frac{mg}{L \cdot day}}{2460 \frac{mg}{L}} = 0.1799 \frac{1}{day}$

In the following plots based on above table values

$V/\theta_c$  vs  $\frac{r_{su}}{\bar{X}}$ ; slope =  $0.471 \frac{mg}{mg} = Y$   $k_d = -\text{intercept} = 0.0491 \frac{1}{day}$

$\frac{\bar{X}}{r_{su}}$  vs  $\frac{1}{S_e}$ ; intercept =  $\frac{1}{k} \Rightarrow k = \frac{1}{0.0834 \text{ day}} = 11.99 \text{ day}^{-1}$

$\frac{K_s}{k} = \text{slope} = 13.263 \Rightarrow K_s = 13.263 \frac{mg}{L \cdot day} (11.99 \text{ day}^{-1}) = 159.0 \frac{mg}{L}$

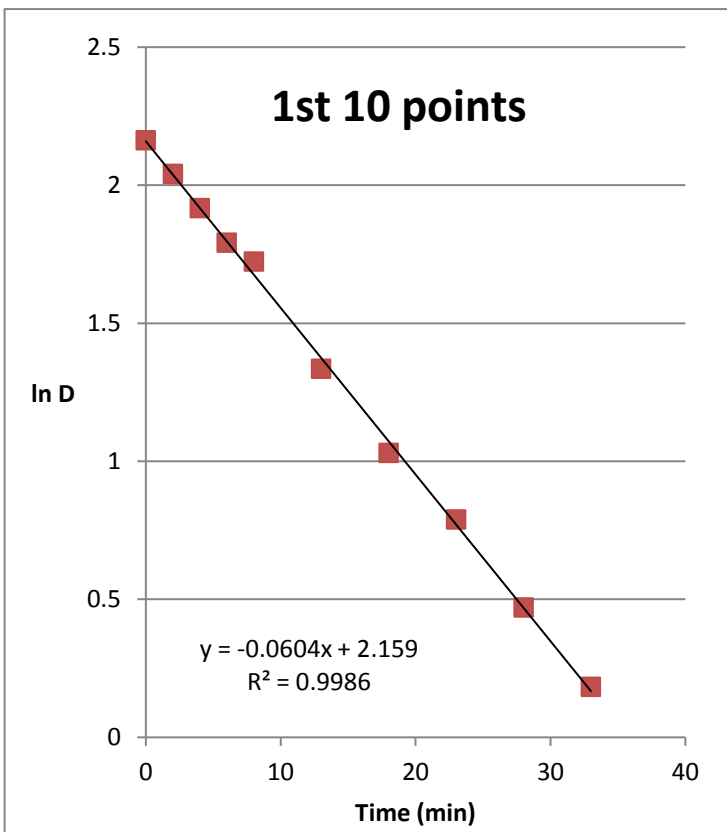
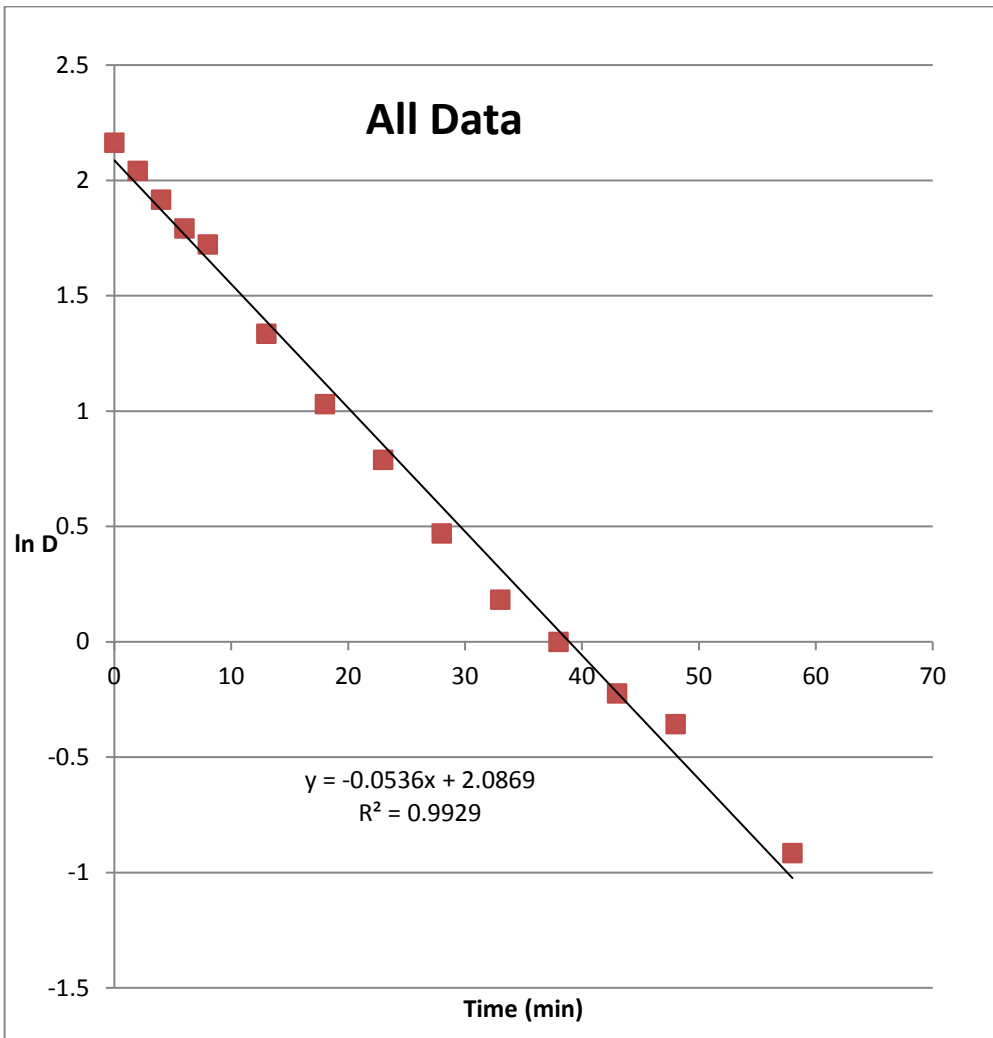
### Problem 7

Class Text Problem 12.64. A 40 hp surface aerator was tested in a 120 ft diameter tank with a water depth of 8 ft. Cobalt chloride catalyst and sodium sulfite were added to the tap water in the tank to remove dissolved oxygen. The water temperature was 21.9°C, and the saturation dissolved oxygen was 8.7 mg/L. During the test, the average electric power usage was 33.1 kW, which at 90% efficiency is equivalent to 40 hp. From the following time and dissolved oxygen data shown below, determine the value of  $K_{LA}$  corrected to 20°C, and calculate the oxygen transfer rate in lb/hp/hr; additionally estimate the actual transfer rate  $N$  in activated sludge at 10°C and 2 mg/L dissolved oxygen.

t (min)	0	2	4	6	8	13	18	23	28	33	38	43	48	58
$C_t$ (mg/L)	0	1	1.9	2.7	3.1	4.9	5.9	6.5	7.1	7.5	7.7	7.9	8	8.3
$\ln(C_s - C_t)$	2.163	2.041	1.917	1.792	1.723	1.335	1.03	0.7885	0.47	0.1823	-8.90E-16	-0.2231	-0.3567	-0.9163

$C_s$  (mg/L) 8.7  $D = C_s - C_t$

Red are calculated. Plots below. On plots,  $D = C_s - C_t$ .



Either of the two plots could be used to determine  $K_L a$ , but beyond 30 min there is a change in slope. So 1st 10 points would be better results (note that intercept =  $\ln(C_s - 0) = 2.159$  yields  $C_s = 8.7 \text{ mg/L}$  given)

Slope =  $-K_L a = 0.0604 \frac{1}{\text{min}}$   $K_L a_{20} = (1.024)^{20-21.9} (0.0604 \frac{1}{\text{min}}) (\frac{60 \text{ min}}{\text{hr}})$

$K_L a_{20} = 3.5 \frac{1}{\text{hr}}$   $R_0 = (3.5 \frac{1}{\text{hr}}) (9.2 \frac{\text{mg}}{\text{L}}) (8.34 \frac{\text{lb}_O_2}{\text{mg}_O_2}) (\pi (12 \text{ ft})^2) (8 \text{ ft}) (\frac{7.48 \text{ gal}}{\text{ft}^3}) (\frac{\text{hr}}{10^3 \text{ gal}})$

$R_0 = 4.15 \frac{\text{lb}_O_2}{\text{hr} \cdot \text{hr}}$   $R = (4.15 \frac{\text{lb}_O_2}{\text{hr} \cdot \text{hr}}) (1.024)^{6-20} \frac{40 \text{ hp}}{\beta [11.3 \text{ mg/L}] - 2 \text{ mg/L}}$

Note  $\alpha = 0.8$  to  $0.9$  &  $\beta = 0.7$  to  $0.9$ , so

$R = 3.55 \frac{\text{lb}_O_2}{\text{hp} \cdot \text{hr}} (0.514 \text{ to } 0.799) = 1.825 \text{ to } 2.836 \frac{\text{lb}_O_2}{\text{hp} \cdot \text{hr}}$

Class Text Problem 12.74. A completely mixed aerated lagoon with a volume of 1.0 million gallons treats a wastewater flow of 250,000 gallons per day with a BOD of 400 mg/L. The liquid temperature ranges from 4°C in the winter to 30°C in the summer. There are 4 5.0-hp surface aerators rated at 2.0 lb O<sub>2</sub> / hp-hr. The wastewater characteristics are  $\theta$  bio-rate correction parameter of 1.035, oxygen transfer parameters  $\alpha = 0.9$ ,  $\beta = 0.9$ , removal parameters  $k = 0.9 \text{ day}^{-1}$  at 20°C, and  $a = 1.0 \text{ lb O}_2$  utilized per lb BOD removed. The designer states that this system will remove at least 400 lb BOD per day and maintain dissolved oxygen concentration greater than 2.0 mg/L. Verify or disprove these claims by appropriate calculations.

**Note that the typed description above had a typo for the first order removal rate constant k. The solution will use the number in the text, 0.8.**

Low temp: 4°C      High temp: 30°C

$$k_4 = k_{20} \theta^{(4-20)} = (0.8)(1.035)^{-16} = 0.461 \text{ day}^{-1}$$

$$k_{30} = (0.8)(1.035)^{(30-20)} = 1.128 \text{ day}^{-1}$$

$$Q = 0.25 \frac{\text{MG}}{\text{day}} \quad S_0 = 400 \text{ mg/L} \quad V = 1 \text{ MG}$$

$$t_R = \frac{V}{Q} = (1 \text{ MG}) / (0.25 \frac{\text{MG}}{\text{day}}) = 4 \text{ day} \quad S_e = \frac{S_0}{1 + k t_R}$$

$$\text{@ } 4^\circ\text{C} \quad S_e = \frac{400}{1 + (0.461)(4)} = 140.6 \text{ mg/L}$$

$$\text{@ } 30^\circ\text{C} \quad S_e = \frac{400}{1 + (1.128)(4)} = 72.6 \text{ mg/L} \quad \text{BOD Rem} = Q(S_0 - S_e)$$

$$\text{@ } 4^\circ\text{C} \quad \text{BOD removal} = (0.25 \frac{\text{MG}}{\text{day}})(400 - 140.6) \frac{\text{mg}}{\text{L}} (8.34 \frac{\text{lb/MG}}{\text{mg/L}}) = 541 \frac{\text{lb BOD}}{\text{day}}$$

$$\text{@ } 30^\circ\text{C} \quad \text{BOD rem} = (0.25)(400 - 72.6)(8.34) = 683 \frac{\text{lb BOD}}{\text{day}} \quad \text{Both} > 400 \frac{\text{lb BOD}}{\text{day}} \text{ OK}$$

Aerators rated @ 2  $\frac{\text{lb O}_2}{\text{hp-hr}}$  @ 20°C, clean water ( $R_0$ )

$$\text{in aerated lagoon } R = R_0 \frac{(C_s - 2 \text{ mg/L})}{9.2 \text{ mg/L}} \propto \theta^{(T-20)} \quad \theta = 1.024$$

$$R_4 = (2 \frac{\text{lb}}{\text{hp-hr}}) \frac{(0.9[13.1 \text{ mg/L} - 2 \text{ mg/L}])}{9.2 \text{ mg/L}} (0.9)(1.024)^{(4-20)} = 1.29 \frac{\text{lb O}_2}{\text{hp-hr}} \quad C_s = 13.1 \text{ mg/L}$$

$$R_{30} = (2) \frac{(0.9[7.6 - 2])}{9.2} (0.9)(1.024)^{(30-20)} = 1.20 \frac{\text{lb O}_2}{\text{hp-hr}} \quad C_s = 7.6 \text{ mg/L}$$

With four 5-hp aerators, total power = (4)(5hp) = 20 hp

& with  $a = \frac{1 \text{ lb BOD rem.}}{16 \text{ O}_2 \text{ consumed}}$  (Assuming  $S_0$  is ultimate BOD)

$$\text{@ } 4^\circ\text{C} \text{ need } (541 \frac{\text{lb O}_2}{\text{day}}) (\frac{1}{20 \text{ hp}}) (\frac{1 \text{ day}}{24 \text{ hr}}) = 1.13 \frac{\text{lb O}_2}{\text{hp-hr}} < 1.29 \frac{\text{lb O}_2}{\text{hp-hr}} \text{ OK}$$

$$\text{@ } 30^\circ\text{C} \text{ need } (683) (\frac{1}{20}) (\frac{1}{24}) = 1.14 \frac{\text{lb O}_2}{\text{hp-hr}} > 1.20 \frac{\text{lb O}_2}{\text{hp-hr}} \text{ not OK}$$

Thus the designer needs to add another aerator

Also, if the given waste BOD were BOD<sub>5</sub> rather than ultimate, the BOD removal would increase by a factor of 1.4-1.5 making the need for greater aeration more significant