Assignment #6

1) Module with 10,000 hollow fibers

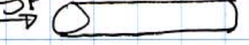
Internal Diameter, ID = 0.9 mm = 0.0009 m

Length $L = 1.2$ m

Cross flow velocity $V_x = 1.0$ m/s

a) Find feed flow Q_F in m³/day

Consider A ⊥ to length of hollow fiber



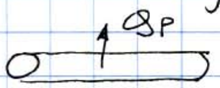
$$Q_F = V_x A_\perp = V_x \pi r^2 \qquad Q_F = VA = V$$

$$= 1.0\frac{m}{s} \times \pi(0.00045m)^2 \times 3600\frac{s}{h} \times 24\frac{h}{day} \times 10{,}000\frac{\text{hollow fibers}}{\text{module}}$$

$$= \underline{549.7\ m^3/day.}$$

②

b) Find permeat flow rate Q_P (in m³/day) across membrane if permeate flux, $J = \frac{70\ L}{m^2 \cdot h}$



Area through membrane along length

$$Q_P = JA = \frac{70\ L}{m^2 \cdot h} \times \pi d\ \text{length}$$

$$= \frac{70\ L}{m^2 \cdot h} \times \pi(0.0009\ m)(1.2m) \times \frac{1\ m^3}{1000\ L} \times \frac{24\ h}{day} \times 10{,}000\frac{\text{hollow fibers}}{\text{module}}$$

$$= \underline{57\ m^3/day}$$

②

c) $Q_F - Q_P$ = By pass water $= 549.7 - 57 = 492.7\ m^3/day.$

$$V_{\text{by-pass water}} = \frac{Q}{A_\perp} = \frac{492.7\ m^3}{day\ \pi(0.00045m)^2} \times \frac{day}{24\ h} \times \frac{h}{3600\ s}\ \frac{\text{module}}{10{,}000\ h.f.}$$

$$= \underline{0.896\ m/h}$$

②

2)

$J = 50\ L/m^2\text{-}h$ $\qquad$ 0° 1.781 $\quad 0.263/5 = 0.0526 \qquad 1.728\ \mu$ @ 1°C.

$T = 1°C$ $\qquad$ 5° 1.518

$\Delta P = 0.65$ bar

a) $$J_s = J_m\left(\frac{\mu_m}{\mu_s}\right) = \frac{50\ L}{m^2 \cdot h}\left(\frac{1.728\times10^{-3}\ N.s/m^2}{1.002\times10^{-3}\ N.s/m^2}\right) = 86.25\ \frac{L}{m^2 \cdot h}$$

$$J_{sP,20°C} = \frac{J_s}{\Delta P} = \frac{86.25\ L}{m^2 \cdot h \times 0.65\ \text{bar}} = 132.7\ \frac{L}{m^2 \cdot h \cdot \text{bar}}$$ ②

b) $$J_s = J_m (1.03)^{T_s - T_m}$$
$$= 50\ \frac{L}{m^2 \cdot h}(1.03)^{20-1} = 87.67\ \frac{L}{m^2 \cdot h}.$$ ①

c) error in using the empirical equation:

$$\frac{87.67 - 86.25}{86.25} = 1.65\%\ \text{error}.$$

value from part (a) is in the denominator ②

d) Find K_m at 20°C:

$$J = \frac{\Delta P}{\mu K_m}\ ; \quad K_m = \frac{\Delta P}{J_s \mu}$$

$$K_m = \frac{\Delta P}{J_s \mu} = \frac{0.65\ \cancel{\text{bar}}\quad \cancel{m^2}}{1.002\times10^{-3}\ \cancel{N}\cdot\cancel{s}} \frac{m^2 \cdot \cancel{h}}{\times 86.25\ \cancel{L}} \times \frac{10^5\ \cancel{N}/\cancel{m^2}}{1\ \cancel{\text{bar}}} \times \frac{3600\ \cancel{s}}{1\ \cancel{h}}$$

$$\times \frac{1000\ L}{m^3}$$ ②

$$= \underline{2.71\times10^{12}\ m^{-1}}$$

3) $Q_{summer} = 190{,}000 \ m^3/d$

$Q_{winter} = 136{,}000 \ m^3/d$

$T_{summer} = 17^\circ C$

$T_{winter} = 1^\circ C$

$J = \frac{65 L}{m^2 \cdot h}$ in summer.

a) $Q = JA$

$$A = \frac{Q}{J} = \frac{190{,}000 \ m^3/d}{65 \ L/m^2 \cdot h} \times \frac{1000 \ L}{m^3} \times \frac{d}{24 h} = 121{,}795 \ m^2$$ ①

b) $$J_s = J_m (1.03)^{T_s - T_m} = \frac{65 L}{m^2 \cdot h} (1.03)^{20-17} = 71.03 \ \frac{L}{m^2 \cdot h}.$$

$$J_m = \frac{J_s}{(1.03)^{T_s - T_m}} = \frac{71.03 \ L/m^2 \cdot h}{(1.03)^{20-1}} = 40.51 \ \frac{L}{m^2 \cdot h}$$

$$Q = JA = 40.51 \frac{L}{m^2 \cdot h} \left(121{,}795 \ m^2\right) \frac{m^3}{1000 \ L} \ \frac{24 h}{d} = 118{,}413 \ \frac{m^3}{d}$$

Transmembrane pressure will need to be increased to achieve the required winter peak-day demand. ④

④

4 $D = 5790$ mm ; $S = 0.0001$; $A/A_f = 0.70$

a) From Fig. 16-4: $V_f = 0.9$ m/s and $Q_f = 1525\ m^3/min$

$A/A_f = 0.7$ so from partial flow diagram:

$y/R = 1.3$ OR $d/D = 0.65$ ⓪.₅

$d = 0.65(5790) = \underline{\underline{3764\ mm}}$. (0.5)

b) Given that $d/D = 0.65$ from partial flow diagram:

$Q/Q_f = 0.625$; $Q = 0.625(1525\ m^3/min) = \underline{\underline{953\ m^3/min}}$

c) Given that $d/D = 0.65$ from partial flow diagram:

$V/V_f = 0.915$; $V = 0.915(0.9\ m/s) = \underline{\underline{0.824\ m/s}}$ ①

5) $A = 23$ ha, pop. density = 95 persons / hectare.

③

Avg. tributary pop. = $23 \times 95 = 2{,}185$ (0.25)
Capacity factor $C = 5 \times 23^{-0.2} = 2.67$ (0.25)
probable max. pop. = $2185 \times 2.67 = 5{,}835$ (0.25)
Avg. per capita flow rate = 275 L/person/day 0.
Avg. sewage flow = $5835 \text{ persons} \times 275 \frac{L}{\text{person day}} \times \frac{1 \text{ day}}{86400 \text{ s}}$

$= 18.57$ L/s. (0.5) 1

$$Pf = 1 + \frac{14}{4 + \sqrt{5.835}} = 3.182$$ (0.5)

Peak sewage flow = 3.182×18.57 L/s $= 59.1$ L/s. (0.25)
Infiltration allowance = $22{,}500\ L/ha/d \times 23\ ha \times \frac{1\ d}{86{,}400\ s} = 5.99 \frac{L}{s}$ (0.2
Avg. dry weather flow =
$5.99 + 18.57 = \underline{24.56}$ L/s (0.25)

PDWF = 5.99 L/s + 59.1 L/s = $\underline{\underline{65.1\ L/s}}$ (0.5)

6 light industrial, 11 ha.
↳ 39,000 L/ha/d

③ avg. flow = 39,000 L/ha/d × 11 ha = 429,000 L/d (0.5)

avg. per capita flow = 275 L/person/day.

equivalent pop. = 429,000 ÷ 275 = 1560 people (0.25)

avg. flow = $429{,}000 \frac{L}{d} \times \frac{1\,d}{86{,}400\,s}$ = 4.965 L/s (0.5)

Pf for non-residential:

$$0.8\left(1 + \frac{14}{4+\sqrt{1{,}560}}\right) = 2.93$$ (0.5)

peak flow = 2.93 × 4.965 = 14.55 L/s (0.25)

infiltration allowance ^{rate} = 22,500 L/ha/d

infiltration allowance = $22{,}500 \frac{L}{ha\,d} \times 11\ ha \times \frac{1\,d}{86{,}400\,s} = 2.86 \frac{L}{s}$ (0.2

avg. dry weather flow = 2.86 + 4.96 = 7.82 L/s (0.25)

PDWF = 14.55 + 2.86 = 17.41 L/s (0.5).

7) As an existing development: A = 23 ha, Pop. density = 95 $\frac{persons}{ha}$

③ Design pop. = 23 × 95 = 2185 = 2185 (0.25)

avg. flow rate = 275 L/c/d

avg. sewage flow = $2185 \times 275 \times \frac{1}{86{,}400} = 6.95 \frac{L}{S}$. (0.5)

$$Pf = 1 + \frac{14}{4+\sqrt{2.185}} = 3.56$$ (0.5)

Peak sewage flow 3.56 × 6.95 = 24.7 $\frac{L}{S}$ (0.25)

Infiltration allowance rate = 22,500 L/ha/d

Infiltration allowance = $22{,}500 \times 23 \times \frac{1}{86{,}400}$ = 5.99 L/S

same as #3 (0.2

PDWF = 24.7 + 5.99 = 30.69 L/s (0.25)

HL Guidelines: $Q_{PDW} = \frac{G \times P \times P_f}{86.4}$

$$Q_{PDW} = \frac{340\ L/c/d \times 2.185 \times 3.56}{86.4} = 30.6\ L/s.$$ ①

#8

2b) anthracite $D = 1.5\,m$, $\varepsilon = 0.5$, $d = 1.1\,mm$, $\phi = 0.73$

sand $D = 0.3\,m$, $\varepsilon = 0.4$, $d = 0.6\,mm$, $\phi = 0.82$

$V_a = 15\,m/h = 0.25\,m/min = 0.00417\,m/s$

$T = 15°C$ $\nu = 1.156 \times 10^{-6}\,m^2/s$

For anthracite: $Re = \dfrac{\phi d V_a}{\nu} = \dfrac{(0.73)(0.0011)(0.00417\,m/s)}{1.156 \times 10^{-6}\,m^2/s} = 2.90$

$$C_d = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 = \frac{24}{2.9} + \frac{3}{\sqrt{2.9}} + 0.34 = 8.28 + 1.76 + 0.34 = 10.38$$

$$h_L = \frac{1.067}{\phi}\frac{C_D}{g} D \frac{V_a^2}{\varepsilon^4}\frac{1}{d} = \frac{1.067}{0.73} \times \frac{10.38}{9.81\,m/s^2}\frac{(0.00417\,m/s)^2}{0.5^4}\frac{1.5\,m}{0.0011\,m} = 0.586\,m$$

For sand: $Re = \dfrac{\phi d V_a}{\nu} = \dfrac{0.82 \times 0.0006\,m \times 0.00417\,m/s}{1.156 \times 10^{-6}\,m^2/s} = 1.77$

$$C_d = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 = \frac{24}{1.77} + \frac{3}{\sqrt{1.77}} + 0.34 = 13.56 + 2.25 + 0.34 = 16.15$$

$$h_L = \frac{1.067}{\phi}\frac{C_D}{g} D \frac{V_a^2}{\varepsilon^4}\frac{1}{d} = \frac{1.067}{0.82} \times \frac{16.15}{9.81\,m/s^2}\frac{(0.00417\,m/s)^2}{0.4^4}\frac{0.3}{0.0006} = 0.728\,m$$

Total $h_L = 0.586 + 0.728 = 1.314\,m$.

3) For 0.6 mm sand an equivalent size of anthracite is:

$d_1 = 0.6\left(\dfrac{2.6-1}{1.5-1}\right)^{2/3} = 1.30$ ∴ The anthracite settles below the sand after backwashing.