<Problem 1>

(a)

0.05 kg/s

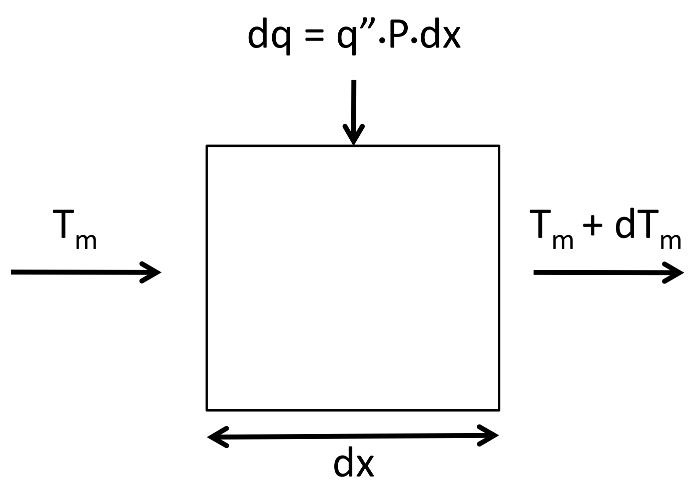
2 pts

$$\mathrm{Re}_D = \frac{4\,\dot{m}}{\pi\,D\,\mu} = \frac{4\cdot(0.5\;kg/s)}{\pi\cdot(0.005\;m)\cdot(8.6\times10^{-4}\;N-s/m^2)} = 148{,}051 > 2{,}300 = \mathrm{Re}_{D,critcal}$$

3 pts

$$\boxed{\therefore Turbulent\ Flow\ \left(\because \mathrm{Re}_D > \mathrm{Re}_{D,critcal} = 2{,}300\right)}$$

(b)



3 pts

$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = \dot{E}_{store}$$

$$\dot{E}_{gen} = \dot{E}_{store} = 0$$

$$\dot{E}_{in} = \dot{m}\,c_p\,T_m + q''\cdot P\cdot dx \quad ; \quad P = \pi\cdot D$$

$$\dot{E}_{out} = \dot{m}\,c_p\,(T_m + dT_m)$$

3 pts

$$\therefore \dot{E}_{in} - \dot{E}_{out} = \dot{m}\,c_p\,T_m + q''\cdot P\cdot dx - \dot{m}\,c_p\,(T_m + dT_m) = 0$$

3 pts

$$\dot{m}\, c_p\, dT_m = q''\cdot P\cdot dx = q''_{\max}\cdot\sin\left(\frac{\pi\, x}{2\,L}\right)\cdot\pi\cdot D\cdot dx$$

$$\int_0^x dT_m = \frac{q''_{\max}\cdot\pi\cdot D}{\dot{m}\, c_p}\cdot\int_0^x \sin\left(\frac{\pi\, x}{2\,L}\right)dx$$

3 pts

$$T_m(x) - T_{in} = \frac{q''_{\max}\cdot\pi\cdot D}{\dot{m}\, c_p}\cdot\left[-\frac{2L}{\pi}\cos\left(\frac{\pi\, x}{2L}\right)\right]\Bigg|_0^x = \frac{2\cdot q''_{\max}\cdot L\cdot D}{\dot{m}\, c_p}\cdot\left[1-\cos\left(\frac{\pi\, x}{2L}\right)\right]$$

$$\boxed{\therefore T_m(x) = T_{in} + \frac{2\cdot q''_{\max}\cdot L\cdot D}{\dot{m}\, c_p}\cdot\left[1-\cos\left(\frac{\pi\, x}{2L}\right)\right]}$$

(c)

10 pts

$$q''(x) = h\cdot\left[T_s(x) - T_m(x)\right] \Rightarrow T_s(x) = T_m(x) + \frac{q''(x)}{h}$$

5 pts

$$\boxed{\therefore T_s(x) = T_{in} + \frac{2\cdot q''_{\max}\cdot L\cdot D}{\dot{m}\, c_p}\cdot\left[1-\cos\left(\frac{\pi\, x}{2L}\right)\right] + \frac{q''_{\max}}{h}\cdot\sin\left(\frac{\pi\, x}{2\,L}\right)}$$

(d)

2 pts

The surface temperature is max at x = L because temperature rise in the fluid is induced by heat addition, which is largest at the end of the tube.

3 pts

$$\boxed{\therefore x_{\max T_s} = L}$$

<Problem 2>

(a)

5 pts

$$q = \dot{m}_{condensation} \cdot h_{fg} = (2.73\ kg/s) \times (2.342 \times 10^6\ J/kg) = 6.39366 \times 10^6\ W$$

3 pts

$$\therefore q = 6.39366 \times 10^6\ W$$

(b)

5 pts

$$q = C_c (T_{c,o} - T_{c,i}) = \dot{m}_{c,total} \cdot c_{p,c} \cdot (T_{c,o} - T_{c,i})$$

5 pts

$$\dot{m}_{c,total} = \frac{q}{c_{p,c} \cdot (T_{c,o} - T_{c,i})} = \frac{6.39366 \times 10^6\ W}{(4{,}181\ J/kg-K) \cdot (15\ °C)} = 101.9\ kg/s$$

5 pts

$$N = \frac{\dot{m}_{c,total}}{\dot{m}_{c,1}} = \frac{101.9\ kg/s}{0.141\ kg/s} = 720$$

$$\therefore N = 720$$

(c)

3 pts

$$C_h = \infty, \quad C_c = \dot{m}_c \cdot c_{p,c} = 4.26 \times 10^5\ W/K \quad \Rightarrow \quad C_{\min} = C_c$$

4 pts

$$\varepsilon = \frac{q}{q_{\max}} = \frac{C_c (T_{c,o} - T_{c,i})}{C_{\min} (T_{h,i} - T_{c,i})} = \frac{(T_{c,o} - T_{c,i})}{(T_{h,i} - T_{c,i})} = \frac{(303 - 288)K}{(340 - 288)K} = 0.288462$$

4 pts

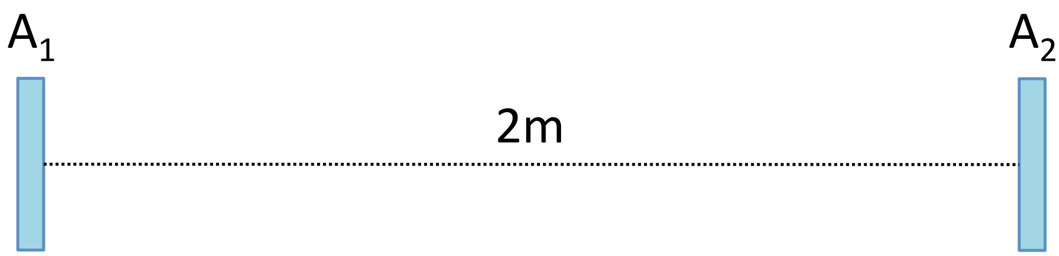
$$NTU = -\ln(1 - \varepsilon) = 0.340326 = \frac{U \cdot A_{total}}{C_{\min}} = \frac{U \cdot (N \cdot 2\pi \cdot D \cdot L)}{C_c} = \frac{U \cdot 720 \cdot 2\pi \cdot (0.019\ m) \cdot (0.8\ m)}{4.26 \times 10^5\ W/K}$$

1 pt

$$\therefore U = 2{,}108.38\ W/m^2 - K$$

<Problem 3>

(a)



4 pts

$$q_{1\to2} = I_1\ A_1 \cos\theta_1\ d\omega_{2-1}$$

$$\theta_1 = \theta_2 = 0°$$

2 pts

$$d\omega_{2-1} = \frac{A_2 \cos\theta_2}{r^2}$$

2 pts

$$G_2 = \frac{q_{1\to2}}{A_2} = \frac{I_1\ A_1 \cos\theta_1\ d\omega_{2-1}}{A_2}$$

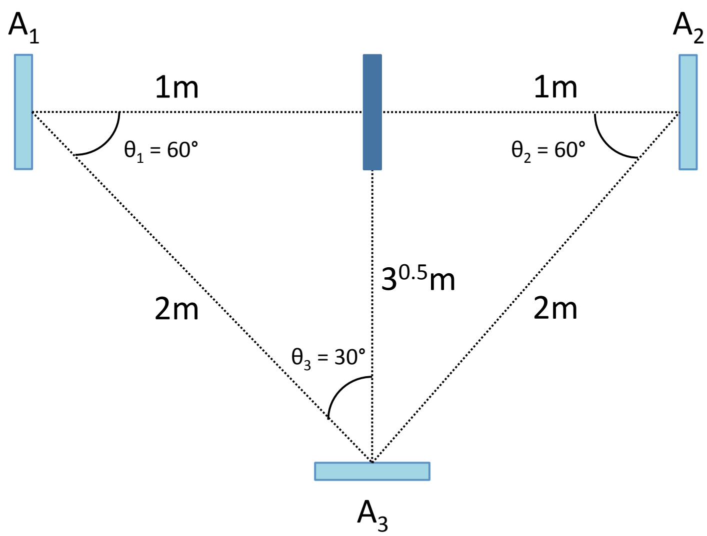
2 pts

$$= \frac{I_1\ A_1 \cos\theta_1}{A_2} \cdot \frac{A_2 \cos\theta_2}{r^2} = \frac{I_1\ A_1 \cos\theta_1 \cos\theta_2}{r^2}$$

$$= \frac{\left(80{,}000\ W/m^2 - sr\right) \cdot \left(10^{-4}\ m^2\right) \cdot (1) \cdot (1)}{\left(2\ m\right)^2} = 2\ W/m^2$$

$$\therefore G_2 = 2\ W/m^2$$

(b)



4 pts

$$q_{1\to3} = I_1\ A_1 \cos\theta_1\ d\omega_{3-1}$$

$$\theta_1 = \theta_2 = 60°$$

$$\theta_3 = 30°$$

2 pts

$$d\omega_{3-1} = \frac{A_3 \cos\theta_3}{r^2}$$

2 pts

$$G_3 = \frac{q_{1\to3}}{A_3} = \frac{I_1\ A_1 \cos\theta_1\ d\omega_{3-1}}{A_3}$$

2 pts

$$= \frac{I_1\ A_1 \cos\theta_1}{A_3} \cdot \frac{A_3 \cos\theta_3}{r^2} = \frac{I_1\ A_1 \cos\theta_1 \cos\theta_3}{r^2}$$

$$= \frac{\left(80{,}000\ W/m^2 - sr\right)\cdot\left(10^{-4}\ m^2\right)\cdot\left(\frac{1}{2}\right)\cdot\left(\frac{\sqrt{3}}{2}\right)}{\left(2\ m\right)^2} = \frac{\sqrt{3}}{2}\ W/m^2 = 0.866\ W/m^2$$

$$\therefore G_3 = \frac{\sqrt{3}}{2}\ W/m^2 = 0.866\ W/m^2$$

(c)

4 pts

$$I_3 = \frac{G_3}{\pi} = \frac{0.866\ W/m^2}{\pi} = 0.275664\ W/m^2 - sr$$

4 pts

$$q_{3\to 2} = I_3\ A_3 \cos\theta_3\ d\omega_{2-3}$$

$$d\omega_{2-3} = \frac{A_2 \cos\theta_2}{r^2}$$

$$G_2 = \frac{q_{3\to 2}}{A_2} = \frac{I_3\ A_3 \cos\theta_3\ d\omega_{2-3}}{A_2}$$

2 pts

$$= \frac{I_3\ A_3 \cos\theta_3}{A_2} \cdot \frac{A_2 \cos\theta_2}{r^2} = \frac{I_3\ A_3 \cos\theta_3 \cos\theta_2}{r^2}$$

$$= \frac{\left(0.275664\ W/m^2 - sr\right) \cdot \left(3 \times 10^{-4}\ m^2\right) \cdot \left(\frac{\sqrt{3}}{2}\right) \cdot \left(\frac{1}{2}\right)}{\left(2\ m\right)^2} = 8.95245 \times 10^{-6}\ W/m^2$$

$$\boxed{\therefore G_2 = 8.95245 \times 10^{-6}\ W/m^2}$$