1) Bulk mean temperature: $T_b = \frac{1}{2}(T_{m,i} + T_{m,o})$

$$= \frac{1}{2}(5+60)$$

$$= 32.5^\circ C$$

Water properties @ $32.5^\circ C$:

$c_p = 4178 \text{ J kg}^{-1} \text{K}^{-1}$

$\rho = 994.8 \text{ kg m}^{-3}$

Constant surface temperature, internal convection:

$$\dot{Q} = hA_s \Delta T_{lm}$$

$$\dot{Q} = \dot{m}_w c_p (T_{m,o} - T_{m,i}) = \dot{m}_s h_{fg}$$

Steam condensation temperature: $68^\circ C$

$$\frac{2333 - 2345.4}{70-65} = \frac{h_{fg} - 2345.4}{68-65}$$

$$h_{fg} = 2337.96 \text{ kJ kg}^{-1}$$

$$\dot{Q} = \dot{m}_s h_{fg}$$

$$= 0.6(2337.96)$$

$$= 1402.776 \text{ kW}$$

1) Log mean temperature difference:

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln \Delta T_2 - \ln \Delta T_1} = \frac{(68-60)-(68-5)}{\ln(68-60)-\ln(68-5)}$$

$$= 26.65124855\ °C$$

$$h = \frac{\dot{Q}}{A_s \Delta T_{lm}} = \frac{\dot{Q}}{n\pi D_i L \Delta T_{lm}}$$

$$= \frac{1402.776}{7\pi(25\times10^{-3})\times5\times26.65124855}$$

$$= 19.13694146\ kW m^{-2} K^{-1}$$

$$\dot{m}_w = \frac{\dot{Q}}{c_p(T_{m,o}-T_{m,i})} = \frac{1402.776 \div 7}{4.178(60-5)}$$

$$= 0.8720856931\ kg s^{-1}$$

$$\approx 0.872\ kg s^{-1}$$

$$u_m = \frac{\dot{m}_w}{\rho A_c} = \frac{0.872}{994.8\left(\pi\left(\frac{25}{2}\times10^{-3}\right)^2\right)}$$

$$= 1.785884987\ m s^{-1}$$

$$\approx 1.79\ m s^{-1}$$

2) $T_b = \frac{1}{2}(T_{m,i} + T_{m,o})$

$= \frac{1}{2}(10+80)$

$= 45°c$

Water properties @45°c:

$\rho = 990.1 \, kg \, m^{-3}$

$K = 0.637 \, W m^{-1} K^{-1}$

$\nu = 0.602 \times 10^{-6} \, m^2 s^{-1}$

$c_p = 4180 J \, kg^{-1} K^{-1}$

$P_r = 3.91$

Constant heat flux: $\dot{Q} = \dot{q} A$

$$\dot{Q} = \dot{q}A = m_w c_p (T_{m,o} - T_{m,i})$$

$$= \rho \dot{V} c_p (T_{m,o} - T_{m,i})$$

$$= 990.1 \left(\frac{5 \times 10^{-3}}{60}\right)(4.18)(80-10)$$

$$= 24.14193833 \, kW$$

$$\approx 24.1 \, kW$$

2) $Re_D = \dfrac{u_\infty D}{\nu} = \dfrac{\left(\frac{\dot{V}}{A_c}\right) D}{\nu}$

$$= \frac{\frac{5\times10^{-3}}{60} \div \left(\pi \times \left(\frac{2}{2}\times10^{-2}\right)^2\right) \times 2\times10^{-2}}{0.602\times10^{-6}}$$

$$= 8812.566063 > 2300 \text{ (Turbulent flow)}$$

$\dfrac{L}{D} = \dfrac{13}{2\times10^{-2}}$

$= 650 >> 10$

$\overline{Nu}_D = 0.023 Re_D^{\frac{4}{5}} Pr^{.4}$

$= 0.023 (8812.57)^{\frac{4}{5}} (3.91)^{0.4}$

$= 56.84345246$

$\bar{h} = \dfrac{\overline{Nu}_D k}{D}$

$= 1810.463961 \, W m^{-2} K^{-1}$

$\dot{q} = h(T_s - T_{f,m})$

$T_{s,o} = \dfrac{\dot{q}}{h} + T_{m,o}$

$= \dfrac{\dot{Q}}{h A_s} + T_{m,o}$

$= \dfrac{24.14193833}{1.810463961(0.02\pi \times 13)} + 80$

$= 96.32521958°C \approx 96.3°C$

3a) $\dot{m}c_p(T_m + dT_m) - \dot{m}c_p T_m = \delta\dot{Q}$

$$\dot{m}c_p\, dT_m = \delta\dot{Q}$$

$$\begin{aligned}\delta\dot{Q} &= \dot{q}\, dA \\ &= \dot{q}\pi D\, dx \\ &= ax\pi D\, dx\end{aligned}$$

$$\dot{m}c_p\, dT_m = ax\pi D\, dx$$

$$dT_m = \frac{a\pi D}{\dot{m}c_p} x\, dx$$

$$\int_{T_{m,i}}^{T_m} dT_m = \frac{a\pi D}{\dot{m}c_p}\int_0^x x\, dx$$

$$T_m - T_{m,i} = \frac{a\pi D}{2\dot{m}c_p} x^2$$

$$T_m = \frac{a\pi D}{2\dot{m}c_p} x^2 + T_{m,i}$$

when $T_{m,i} = 25$, $a = 400$, $\dot{m} = 0.1$, $c_p = 4178\ \mathrm{J\,kg^{-1}K^{-1}}$
$D = 25\times10^{-3}$

$$T_m = \frac{400\pi(25\times10^{-3})}{2(0.1)(4178)} x^2 + 25$$

$$T_m = \frac{25}{2089}\pi x^2 + 25$$

b) when $x = 3$

$$T_{m,o} = \frac{25}{2089}\pi(23)^2 + 25$$

$$= 44.88873281 \approx 44.9\,^\circ\mathrm{C}$$

3c) $\dot{Q} = \dot{q} A_s = \dot{m} c_p (T_{m,o} - T_{m,i})$

$$\dot{q}(25\times10^{-3})(23)\pi = 0.1(4178)(44.9-25)$$

$$\dot{q} = 4600\ \mathrm{W m^{-2}}$$

4) Properties of air @ 25°C, 100 kPa:

$\rho = 1.184\ \mathrm{kg m^{-3}}$

$k = 0.02551\ \mathrm{W m^{-1} K^{-1}}$

$\nu = 1.562\times10^{-5}\ \mathrm{m^2 s^{-1}}$

$c_p = 1007\ \mathrm{J kg^{-1} K^{-1}}$

$Pr = 0.7296$

$$D_h = \frac{4A_c}{P}$$

$$= \frac{4(0.2\times14)}{2(0.2+14)}$$

$$= \frac{28}{71}\ \mathrm{cm}$$

$$Re_D = \frac{V_{avg} D_h}{\nu} = \frac{4(\frac{28}{71}\times10^{-2})}{1.562\times10^{-5}}$$

$= 1009.900633 < 2300$ (laminar flow)

$$\frac{a}{b} = \frac{14}{0.2} = 70$$

$Nu = 8.24 = \frac{\bar{h} D}{k}$ from table

$$\bar{h} = \frac{Nu\,k}{D} = \frac{8.24\times0.02551}{\frac{28}{71}\times10^{-2}}$$

$$= 53.30132286\ \mathrm{W m^{-2} K^{-1}}$$

4) $\dot{m} = \rho u_m A_c$

$= 1.184(4)(0.2 \times 14 \times 10^{-4})$

$= 1.32608 \times 10^{-3}\ kgs^{-1}$

$\dot{Q} = \dot{m} c_p (T_{m,o} - T_{m,i}) = \bar{h} A (T_{s,o} - T_{m,o})$

$1.32608 \times 10^{-3}(1007)(T_{m,o} - 15) = 53.3(50 - T_{m,o}) \times (15 \times 20 \times 10^{-4})$

$1.33536256\, T_{m,o} - 20.0304384 = -1.599039686\, T_{m,o} + 79.95198429$

$T_{m,o} = 34.07250074°C$

$\dot{Q} = \dot{m} c_p (T_{m,o} - T_{m,i})$

$= 1.32608 \times 10^{-3}(1007)(34.07 - 15)$

$= 25.46870341$

Actual $T_b = \frac{1}{2}(34.07 + 15)$

$= 24.53625037°C$

$\therefore$ The assumption is acceptable.