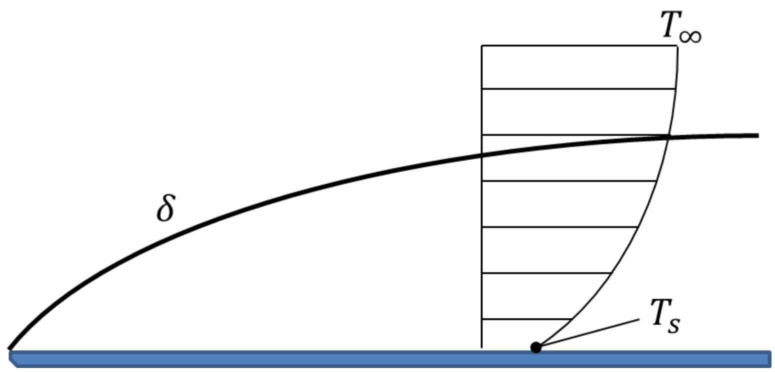
Problem 1 (a)



i) Answer: b. $\delta < \delta_t$

From the figure, it can be inferred that the thermal boundary layer, δ_t is thicker than the momentum boundary later, δ based on the temperature profile provided.

ii) Answer: a. From the fluid to the plate

From the temperature profile, it can be say that $T_\infty > T_s$. Therefore, the direction of heat transfer should be from the fluid to the plate.

iii) Answer: a. $\delta > \delta_c$

The relationship between the momentum boundary layer thickness, δ and the concentration boundary layer thickness, δ_c is the following;

$$\frac{\delta}{\delta_c} = Sc^n \; ; n = \frac{1}{3} ,$$

where Sc is the Schmidt number. The Schmidt number is given as Sc = 10, therefore the following relationship can be drawn;

$$\frac{\delta}{\delta_c} = (10)^{\frac{1}{3}} = 2.15443 \quad \rightarrow \quad \delta = (2.15443) \cdot \delta_c ,$$

$$\therefore \delta > \delta_c$$

Problem 1 (b)

$$D_2 = 2 \cdot D_1 \quad and \quad V_1 = 2 \cdot V_2$$

$$\mathrm{Re}_1 = \frac{\rho V_1 D_1}{\mu}$$

$$\mathrm{Re}_2 = \frac{\rho V_2 D_2}{\mu} = \frac{\rho \left(\frac{1}{2} V_1\right)\left(2 D_1\right)}{\mu} = \mathrm{Re}_1$$

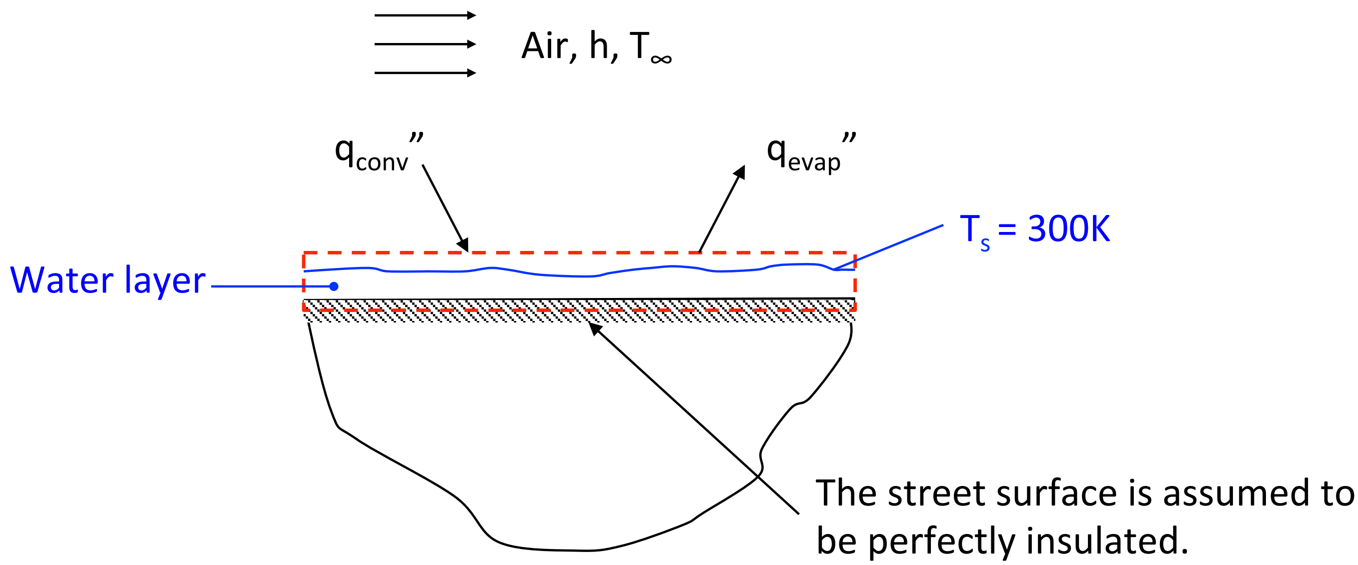
$$\mathrm{Pr}_1 = \mathrm{Pr}_2$$

$$Nu = \frac{h \cdot D}{k} = fn\left(\mathrm{Re}, \mathrm{Pr}\right) \quad \rightarrow \quad Nu_1 = Nu_2$$

$$h_1 = \frac{Nu_1 \cdot k}{D_1} \quad and \quad h_2 = \frac{Nu_2 \cdot k}{D_2} = \frac{Nu_1 \cdot k}{2 \cdot D_1} = \frac{1}{2} \cdot h_1$$

$$\boxed{\therefore h_1 = 2 \cdot h_2}$$

Problem 2



(a)

Assumptions

1) Steady state conditions
2) Constant properties
3) Radiation is negligible
4) The street surface is perfectly insulated
5) Heat-mass transfer analogy is applicable

$$\dot{E}_{in}'' - \dot{E}_{out}'' + \dot{E}_{gen}'' = \dot{E}_{store}'' \; ; \dot{E}_{gen}'' = \dot{E}_{store}'' = 0$$

$$\therefore \dot{E}_{in}'' = \dot{E}_{out}''$$

$$\dot{E}_{in}'' = q_{conv}'' = h\left(T_\infty - T_s\right)$$

$$\dot{E}_{out}'' = q_{evap}'' = n_A'' \, h_{fg} = h_m \left(\rho_{A,\, sat\ at\ T_s} - \rho_{A,\infty}\right) h_{fg} \; ; \quad \rho_{A,\infty} = 0 \; (dry\ air)$$

$$\frac{Nu}{\Pr^n} = \frac{Sh}{Sc^n} \quad \rightarrow \quad \frac{h}{h_m} = \rho\, C_p\, Le^{1-n} = \rho\, C_p \left(\frac{\alpha}{D_{AB}}\right)^{\frac{2}{3}}; \quad n = \frac{1}{3}$$

$$\dot{E}_{in}^{"} = \dot{E}_{out}^{"} \quad \rightarrow \quad h\left(T_\infty - T_s\right) = h_m\, \rho_{A,\, sat\ at\ T_s}\, h_{fg}$$

$$\rightarrow \quad T_\infty = T_s + \frac{h_m}{h}\, \rho_{A,\, sat\ at\ T_s}\, h_{fg} = T_s + \frac{\rho_{A,\, sat\ at\ T_s}\, h_{fg}}{\rho\, C_p\, Le^{2/3}}$$

$$\boxed{\therefore T_\infty = T_s + \frac{h_m}{h}\, \rho_{A,\, sat\ at\ T_s}\, h_{fg} = T_s + \frac{\rho_{A,\, sat\ at\ T_s}\, h_{fg}}{\rho\, C_p\, Le^{2/3}}}$$

(b)

Evaluate water properties at $T_s = 300$ K;

$$\rho_{A,s} = \frac{1}{v_g} = \frac{1}{39.13\, m^3/kg} = 0.025556\, kg/m^3$$

$$h_{fg} = 2438 \times 10^3\ J/kg$$

$$T_\infty = T_s + \frac{\rho_{A,\, sat\ at\ T_s}\, h_{fg}}{\rho\, C_p\, Le^{2/3}}$$

$$= 300\ k + \frac{\left(0.025556\, kg/m^3\right)\cdot\left(2438 \times 10^3\ J/kg\right)}{\left(1.161\, kg/m^3\right)\cdot\left(1007\ J/kg-K\right)\cdot\left(\dfrac{22.5 \times 10^{-6}\ m^2/s}{26 \times 10^{-6}\ m^2/s}\right)^{2/3}} = 358.68\ K$$

$$\boxed{\therefore T_\infty = 358.68\ K}$$

Problem 3

(a)

$$Bi = \frac{h\,L_c}{k_{solid}} = \frac{h\left(r_0/3\right)}{k_{solid}} = \frac{\left(100\,W/m^2 - K\right)\cdot\left(0.1\,m/3\right)}{350\,W/m - K} = 0.009524 << 0.1$$

The lump capacitance model is VALID.

$$\frac{\theta}{\theta_i} = \frac{T - T_\infty}{T_i - T_\infty} = \exp\left[-\left(Bi\right)\cdot\left(Fo\right)\right] = \exp\left[-\left(Bi\right)\cdot\left(\frac{\alpha\,t}{L_c^2}\right)\right]$$

$$\frac{500\ K - 300\ K}{800\ K - 300\ K} = \exp\left[-\left(0.009524\right)\cdot\frac{\left(2.5\times10^{-6}\ m^2/s\right)\cdot t}{(0.1\,m/3)^2}\right]$$

$$\boxed{\therefore t = 42{,}759.4\ s}$$

(b)

$$Bi = \frac{h\,L_c}{k_{solid}} = \frac{h\left(r_0/3\right)}{k_{solid}} = \frac{\left(100\,W/m^2-K\right)\cdot\left(0.1\,m/3\right)}{1.0\,W/m-K} = 3.33 >> 0.1$$

The lump capacitance model is NOT VALID, and the analytical solution for a sphere needs be used .

$$\theta_0^* = \frac{T_{center}-T_\infty}{T_i-T_\infty} = C_1\cdot\exp(-\varsigma_1^2\cdot Fo)\,; \quad Fo = \frac{\alpha\,t}{L_c^2} \quad where \quad L_c = r_0$$

$$Bi = \frac{h\,L_c}{k_{solid}} = \frac{h\,r_0}{k_{solid}} = \frac{\left(100\,W/m^2-K\right)\cdot\left(0.1\,m\right)}{1.0\,W/m-K} = 10$$

From table 5.1 using the Bi = 10, C_1 = 1.9249 and ζ_1 = 2.8363.

$$\theta_0^* = \frac{T_{center}-T_\infty}{T_i-T_\infty} = \frac{500\,K-300\,K}{800\,K-300\,K} = (1.9249)\cdot\exp\left[-\left(2.8363\right)^2\cdot\frac{\left(2.5\times10^{-6}\,m^2/s\right)\cdot t}{(0.1\,m)^2}\right]$$

$$\boxed{\therefore t = 781.23\,s}$$