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Cankaya University
Faculty of Engineering
Mechanical Engineering Department
ME 313 Heat Transfer
Midterm Exam II
Open Book Closed Notes
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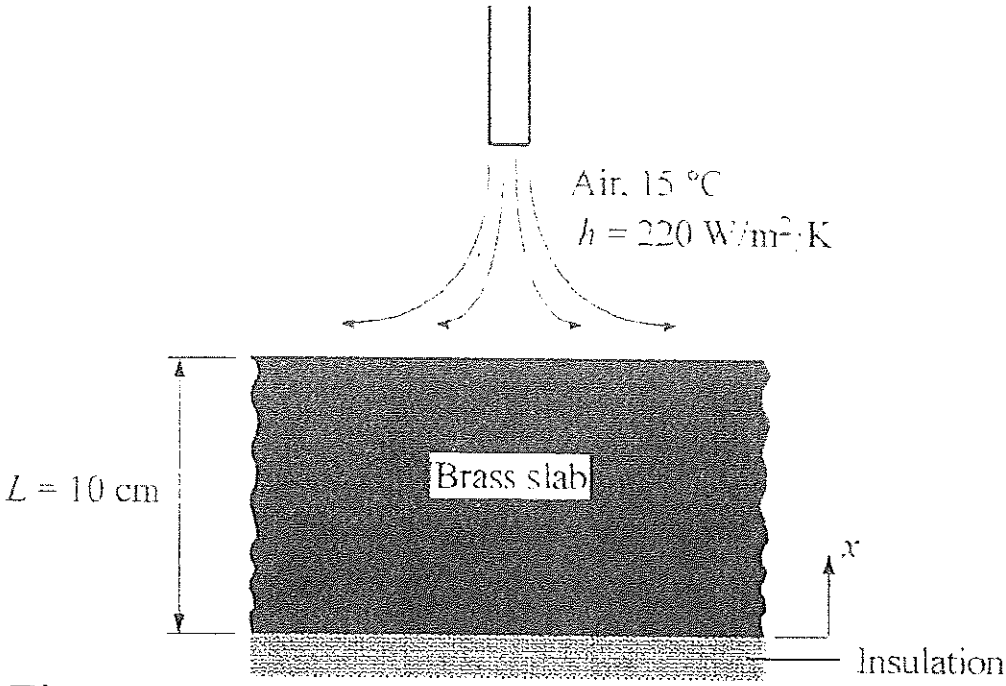
A hot brass plate is having its upper surface cooled by impinging jet of air at temperature of 15°C and convection heat transfer coefficient of 220 W/m²·K. The 10-cm thick brass plate (ρ = 8530 kg/m³, c_p =380 J/kg·K, k= 110 W/m·K, and α =33.93x10⁻⁶ m²/s) has a uniform initial temperature of 650°C, and the bottom surface of the plate is insulated. Determine the temperature at x=5 cm from insulated surface after 3 minutes of cooling.



$$Bi = \frac{hL}{k} = \frac{(220)(0.1)}{110} = 0.2 > 0.1$$ use charts

$$\frac{1}{Bi} = \frac{k}{hL} = 5$$

$$Fo = \frac{\alpha \tau}{L^2} = \frac{(33.9 \times 10^{-6})(3)(60)}{(0.1)^2} \cong 0.6 \Bigg] \frac{\theta_0}{\theta_i} \cong 1 \quad (2)$$

$$\frac{\theta_0}{\theta_i} = \frac{T_0 - T_\infty}{T_i - T_\infty} = 1 \Rightarrow T_0 = T_\infty + (T_i - T_\infty)$$

$$T_0 = 15 + (650 - 15) = 650°C$$

Next position correction chart

$$\left.\begin{array}{l} \frac{x}{L} = 0.5 \\ \frac{1}{Bi} = 0.6 \end{array}\right] \frac{T - T_\infty}{T_0 - T_\infty} \cong 0.86$$

$$T = 0.86(T_0 - T_\infty) + T_\infty$$

$$= 15 + 0.86(650 - 15) = 561°C$$

Method 2

$$Bi = 0.2 \longrightarrow \xi_1 = 0.4328 \quad C_1 = 1.0311$$

$$Fo = \frac{\alpha t}{L^2} = \frac{(33.9 \times 10^{-6})(3)(60)}{(0.1)^2} = 0.61 > 0.2$$

The temperature at (x/L)

$$\theta_w = \frac{T - T_\infty}{T_i - T_\infty} = {}_1 e^{\lambda_1 t} \cos\left[\frac{\lambda_1 x}{L}\right]$$

$$T = (T_i - T_\infty)\, {}_1 e^{\lambda_1 t} \cos\left(\frac{\lambda_1 x}{L}\right) + T_\infty$$

$$= (650 - 15)(1.0311) \exp[(0.5)(0.4328)] + 15$$

$$= 585°C$$

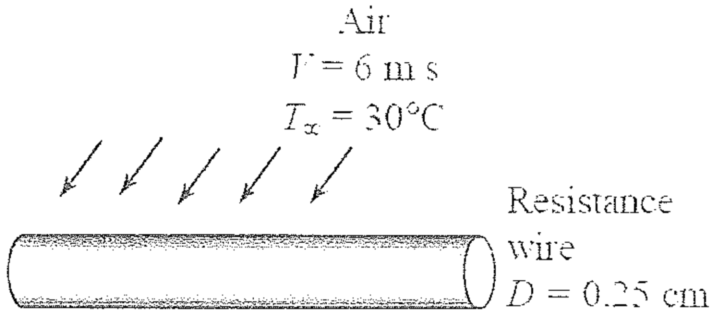
2) A 3.5 m-long, electrical resistance wire is made of 0.25-cm-diameter stainless steel ($k=15$ $W/m.K$). The resistance wire operates in an environment at 30 °C. The surface temperature of the wire is not to exceed a temperature of 370 °C. Determine the energy lost from the wire if it is cooled by a fan blowing air at a velocity of 6 m/s.

$$T_f = \frac{T_w + T_\infty}{2} = \frac{370+30}{2} = 200°C$$

$$k = 0.03779 \ W/m°C$$

$$\nu = 3.455 \times 10^{-5} \ m^2/s$$

$$Pr = 0.6974$$



$$Re_D = \frac{VD}{\nu} = \frac{(6)(0.0025m)}{3.455 \times 10^{-5}} \cong 434$$

$$\overline{Nu_D} = \frac{\bar{h}D}{k} = 0.3 + \frac{0.62\sqrt{Re_D}\,Pr^{1/3}}{\left[1+\left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re_D}{282000}\right)^{5/8}\right]^{4/5}$$

$$= 10.49$$

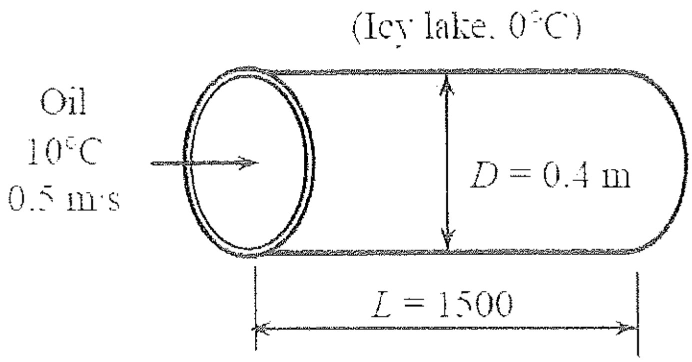
$$\bar{h} = \frac{k}{D}\overline{Nu_D} = \frac{0.03779}{0.0025}(10.49) = 158.6 \ W/m^2 °C$$

$$q = \bar{h}(\pi D L)(T_w - T_\infty)$$

$$= (158.6)(\pi)(0.0025)(3.5)(370-30)$$

$$= 1481 \ W$$

3) Consider the flow of oil at 10 °C in a 40-cm-diameter pipeline at an average velocity of 0.5 m/s. A 1500-m-long section of the pipeline passes through icy waters of a lake at 0 °C. Measurements indicate that the surface temperature of the pipe is very nearly 0 °C. Disregarding the thermal resistance of the pipe material, determine (*a*) the temperature of the oil when the pipe leaves the lake, (*b*) the rate of heat transfer from the oil, and (*c*) the pumping power required to overcome the pressure losses and to maintain the flow of oil in the pipe.



$T_{mi} = 10°C$

$\rho = 893.6\ kg/m^3$

$k = 0.146\ W/m°C$

$\mu = 2.326\ kg/m.s$

$C_p = 1839\ J/kg\ °C$

$\nu = 2.592 \times 10^{-3}\ m^2/s$

$Pr = 28750$

$$Re_D = \frac{\rho V D}{\mu} = \frac{(0.5)(0.4)(839.6)}{2.326}$$

$\cong 77.1 < 2300$ Laminar flow

$$X_{fd,t} = 0.05\, Re_D Pr D = (0.05)(77)(28750)(0.4)$$

$= 44275\ m$ so $X_{fd,t} \gg L$ thermally developing hydrodynamically developed

$$X_{fd,h} = 0.05 Re_D D = (0.05)(77)(0.4) = 1.54$$

$X_{fd,h} \ll L$

$$\text{so}\quad \overline{Nu_D} = 3.66 + \frac{0.065\left(\frac{D}{L}\right) Re_D Pr}{1 + 0.04\left[\left(\frac{D}{L}\right) Re_D Pr\right]^{2/3}} = 13.73$$

$$\bar{h} = \frac{k}{D}\overline{Nu_D} = \frac{0.146}{0.4}(13.73) = 5\ W/m^2\,°C$$

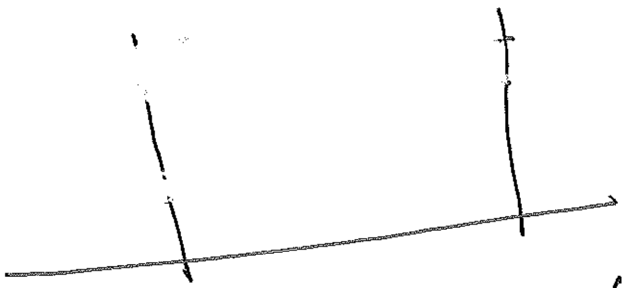
$A_s = \pi D L = \pi(0.4)(1500) = 1885\ m^2$ (5)

$\dot{m} = \rho V A_c = \rho V\left(\frac{\pi}{4}\right)(D^2) = 56.15\ kg/s$

1) $\dot{m} c_p (T_{mo} - T_{mi}) = (\pi D L)(\bar{h})\,\Delta T_{LMTD}$

2) $T_{mo} = T_w - (T_w - T_{mi})\exp\left[-\frac{\bar{h}\pi D L}{\dot{m} c_p}\right]$

$= 9.13\,°C$



$$\Delta T_{LMTD} = \frac{\Delta T_o - \Delta T_i}{\ln\left(\frac{\Delta T_o}{\Delta T_i}\right)} = \frac{(T_w - T_{mo}) - (T_w - T_{mi})}{\ln\left[\frac{T_w - T_{mo}}{T_w - T_{mi}}\right]}$$

$= 9.56\,°C$

b) $q = \bar{h}\,(\pi D L)\,\Delta T_{LMTD} \cong 90300\ W$

c) $\Delta P = f\,\frac{L}{D}\,\frac{\rho V^2}{2}$

$f = \frac{64}{Re_D} = \frac{64}{77} = 0.8294$

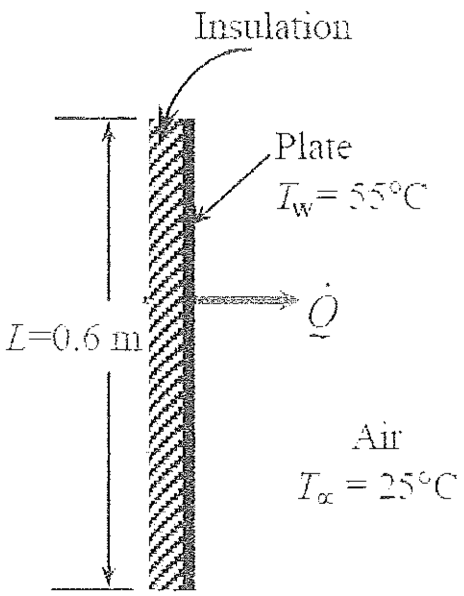
$\Delta P = (0.8294)\left(\frac{1500}{0.4}\right)\left(\frac{893.6}{2}\right)\left(0.5\,\frac{m}{s}\right)^2 \frac{kN}{1000\,\frac{kg\cdot m}{s^2}}\ \frac{1\,kPa}{\frac{kN}{m^2}}$

$= 347.4\ kPa$

$\dot{W}_p = \dot{V}\Delta P = A_c V \Delta P = \frac{\pi}{4}(0.4)^2(0.5)(347.4)\ \frac{kW}{\frac{kPa\cdot m^3}{s}}$

$= 21.8\ kW$

4) Consider a 0.6 m by 0.6 m thin square plate in a room at 25 ^{0}C. One side of the plate is maintained at a temperature of 55 ^{0}C, while the other side is insulated. Determine the rate of heat transfer from the plate by natural convection if the plate is in vertical position.



$$\overline{T_f} = \frac{T_w + T_\infty}{2} = \frac{55+25}{2} = 40°C$$

$$k = 0.02662 \ W/m^2°C$$

$$\nu = 1.702 \times 10^{-5} \ m^2/s$$

$$Pr = 0.7255$$

$$\beta \doteq \frac{1}{T_f} = \frac{1}{313} = 0.003195 \ \frac{1}{K}$$

$$L = 0.6 m$$

$$Ra = \frac{g\beta(T_w - T_\infty) L^3}{\nu^2} Pr = 5.087 \times 10^8$$

$$\overline{Nu_L} = \left[0.825 + \frac{0.387 Ra_L^{1/6}}{\left[1 + \left(\frac{0.492}{Pr}\right)^{9/16}\right]^{8/27}} \right]^2 \approx 100$$

$$\overline{h} = \frac{k}{L} \overline{Nu_L} = 4.441 \ W/m^2°C$$

$$q = \overline{h} (L)(L)(T_w - T_\infty) = 48 \ W$$