Int. To Heat Transfer (ME 411) Quiz 3 July 18, 2005
Name: (1 Hour)

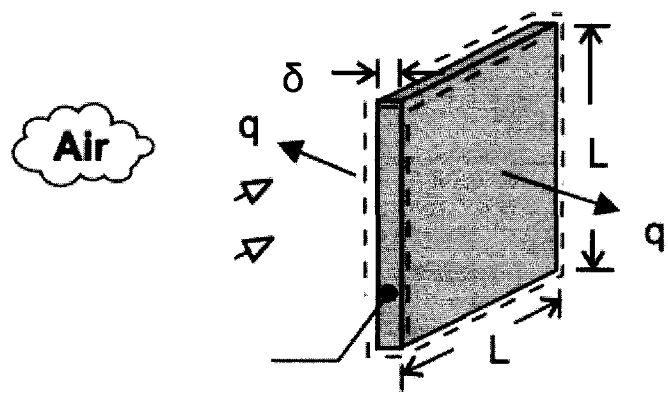
Problem 1 (10 points): Both sides of a steel plate of thickness 6 mm and length 1.5 m are cooled by atmospheric air of velocity U_∞=5 m/s and T_∞=20°C.

(a) If the initial temperature is 300°C, what is the rate of heat transfer from the plate? (3 points)

(b) What is the corresponding rate of change of the plate temperature? (4 points)

(c) If U_∞=15 m/s and the initial temperature is 350°C what is the rate of heat transfer? (3 points)

(d) **(Bonus)** If U_∞=3 m/s and the constant heat flux from the plate surfaces is 1.2 w/m^2, what is the rate of heat transfer? (3 points)



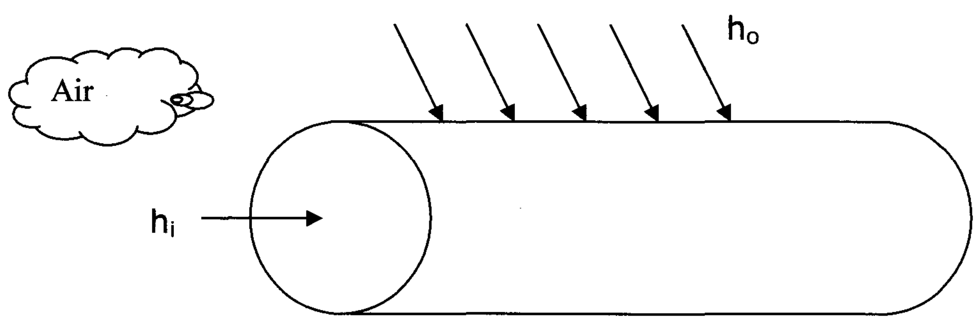
Problem 2 (10 points): Air flows through a pipe of diameter 5cm with a convection heat transfer coefficient of h_i=51 w/m^{2}K and air temperature of T_i=25C. If the thickness of the pipe is much smaller than its length and it is in cross flow with air at T_o= 25 and assuming and h_o=145w/m^{2}k,

(a) What is the wall temperature of the pipe? (2 points)

(b) Compute the Nusselt number for the cross flow. (4 points)

(c) Compute overall heat transfer coefficient (neglect conduction). (2 points)

(d) Evaluate heat loss per unit length of the pipe. (2 points)



Problem 1: Summer 2005, Heat Transfer : Quiz 3

For Stainless Steel AISI 304 and $T = 573K$ $\begin{cases} T = 400 \rightarrow K = 16.6 \\ T = 600 \rightarrow K = 19.8 \end{cases}$

Table A1. $\dfrac{573 - 600}{400 - 600} = \dfrac{K - 19.8}{16.6 - 19.8} \longrightarrow K = 19.36 \ W/mK$

$C = 560 \ J/KgK \ , \quad \rho = 7900 \ kg/m^3$

$T_f = \dfrac{T_s + T_\infty}{2} = \dfrac{300 + 20}{2} = 160^\circ C = 433 K$

for air, Table A4 $\rightarrow \nu = 30.4 \times 10^{-6} \ m^2/s$, $K = 0.0361 \ W/mK$

$Pr = 0.688$

(a)

$$Re_L = \frac{u_\infty L}{\nu} = 5 \times 1.5 / 30.4 \times 10^{-6} = 2.47 \times 10^5 < 5 \times 10^5$$

the flow is laminar

$$\overline{Nu}_L = 0.664 \ Re_L^{1/2} \ Pr^{1/3} = 0.664 (2.47 \times 10^5)^{1/2} (0.688)^{1/3} = 291.2$$

or $\bar{h} = \overline{Nu}_L \left(\dfrac{K}{L}\right) = 291.2 \left(\dfrac{0.0361}{1.5}\right) = 7.01 \ W/m^2K$

the $q = \bar{h} A (T_s - T_\infty)$

$= \bar{h} (2 \times L \times L)(T_s - T_\infty)$

$= 2 \times 7.01 \times (1.5)^2 (300 - 20) = 8.829 \ KW$

(b) $Bi = \dfrac{\bar{h} L_c}{K} = \dfrac{\bar{h}(V/A_s)}{K} = \left(\dfrac{\bar{h}}{K}\right)\left(\dfrac{L \times L \times \delta}{2(L \times L) + 4L\delta}\right) = \dfrac{\bar{h}}{K}\dfrac{\delta}{2}$

$L\delta << L^2 \rightarrow L_c = \dfrac{\delta}{2}$

$= \dfrac{7}{19.36} \times \dfrac{6 \times 10^{-3}}{2}$

$= 1.08 \times 10^{-3} < 0.1$

It means that we can ignore temperature gradient inside the plate the the Energy Balance is:

$$\cancel{\dot{E}_{in}} - \dot{E}_{out} = \dot{E}_{st} - \cancel{\dot{E}_{gen}}$$

0 0

(Zero Temp. gradient)

So $-\bar{h} A_s (T_s - T_\infty) = \rho c \forall \frac{dT}{dt}$

or $\overbrace{-\bar{h}(2L \times L)(T_s - T_\infty)}^{q_{convection}} = \rho c (L^2 \delta) \frac{dT}{dt}$

or $\frac{dT}{dt} = \frac{-8.829 \times 10^3}{7900 \times 560 \times (1.5)^2 \times 6 \times 10^{-3}} = -0.1478\ ^\circ C/s$

(c) if $U_\infty = 15\ m/s$, $T_i = 350^\circ c$

the $T_f = \frac{T_i + T_\infty}{2} = \frac{350 + 20}{2} = 185\ ^\circ c = 458\ K \simeq 450$

Table A4/Air $\nu = 32.39 \times 10^{-6}$ Pa.s, $K = 37.3 \times 10^{-3}$, $P_r = 0.686$

$Re_L = \frac{U_\infty L}{\nu} = 15 \times 1.5 / 32.39 \times 10^{-6} = 6.95 \times 10^5 > 5 \times 10^5$

So flow at the end of the plate is turbulent.

we can check if we have mixed boundary layers,

$Re_c = 5 \times 10^5 = \frac{U_\infty x_c}{\nu} = \frac{15 \times x_c}{32.39 \times 10^{-6}} \Rightarrow x_c = 1.079^m < 1.5^m$

So mixed B.L.

So

$$\overline{Nu_L} = (0.037\, Re_L^{4/5} - 871)\, Pr^{1/3}$$

$$= [0.037 \times (6.95\times10^5)^{4/5} - 871]\,(0.686)^{1/3}$$

$$= 770.8$$

$$\rightarrow \bar{h} = \frac{\overline{Nu_L} K}{L} = \frac{770.8\times 37.3\times10^{-3}}{1.5} = 19.17 \ W/m^2K$$

the $q = \bar{h}\,(2L^2)\,(T_s - T_\infty)$

$$= 19.17(2\times1.5^2)(350-20)$$

$$= 28.5 \ KW$$

(d) $V_\infty = 3\ m/s$, $q'' = 1.2\ W/m^2$ $\xrightarrow{\text{Simply}}$ $q = q'' A = 1.2 \times 2\times(1.5)^2 = 5.4\ W$

we don't know the surface temperature this time

So we need to do trial & error. lets say

$T_s = 300 \xrightarrow{\text{Then}} T_f = 433K \longrightarrow$ we have the properties

now $Re_L = \frac{u_\infty L}{\nu} = \frac{3\times1.5}{30.4\times10^{-6}} = 148026 < 5\times10^5$

the flow is entirely laminar then

(Eq. 7.53b) $\rightarrow \overline{Nu_L} = 0.680\, Re_L^{1/2}\, Pr^{1/3} = 0.680 \times (148026)^{1/2}(0.688)^{1/3}$

$$\rightarrow \overline{Nu_L} = 230.96$$

Then $\bar{h} = \overline{Nu}_L \frac{k}{L} = 230.96 \times \frac{0.0361}{1.5} = 5.558 \ W/m^2K$

now we have $\bar{h}$ and we know q'' lets check our guess for T_s is good or not,

$$q'' = \bar{h}(T_s - T_\infty) \longrightarrow 1.2 = 5.558 \times (T_s - 20)$$

$$\longrightarrow T_s = 20.22 \ °C$$

now lets use this T_s and repeat,

$$T_f = \frac{T_s + T_\infty}{2} = \frac{20.22 + 20}{2} \doteq 20.11 \ °C = 293.11 \ K$$

Table A-4 for air at $293K \simeq 300K \rightarrow \nu = 15.89 \times 10^{-6}$ Pa.s.

$k = 26.3 \times 10^{-3} \ W/mK$

$Pr = 0.707$

$$Re_L = \frac{u_\infty L}{\nu} = \frac{3 \times 1.5}{15.89 \times 10^{-6}} = 283196 < 5 \times 10^5$$

Still laminar then

$$\overline{Nu}_L = 0.680 \ Re_L^{1/2} \ Pr^{1/3} = (0.68)(283196)^{1/2}(0.707)^{1/3} = 322$$

then $\bar{h} = \overline{Nu}_L \frac{k}{L} = \frac{322.4 \times 26.3 \times 10^{-3}}{1.5} = 5.5878$ $q = 5$ W

then $q'' = \bar{h}(T_s - T_\infty) \rightarrow T_s = 20.21 \ °C$ Ans. $\rightarrow q = 2L^2 \bar{h}(T_s - T$

Problem 2.

Energy Balance:

$q''_{convec,i} = q''_{convec,o}$

$T_{\infty,i} = 25°C$, $h_i = 51\ W/m^2$

$T_{\infty,o} = 25°C$, $h_o = 145$ "

$\rightarrow h_i(T_{\infty,i} - T_w) = h_o(T_w - T_{\infty,o})$

$\rightarrow 51(25 - T_w) = 145(T_w - 25)$

(a) $\rightarrow T_w = 25.0\ °C$

for outside convection

Then $T_f = \dfrac{T_w + T_\infty}{2} = \dfrac{25+25}{2} = 25°C \cong 298\ K \approx 300\ K$

(b) Then $\nu = 15.89 \times 10^{-6}\ m^2/s$

$P_r = 0.707$

$K \approx 26.3 \times 10^{-3}\ W/mK$

Simply $\overline{Nu}_D = \dfrac{\bar{h}D}{K} = 276$

or ↓

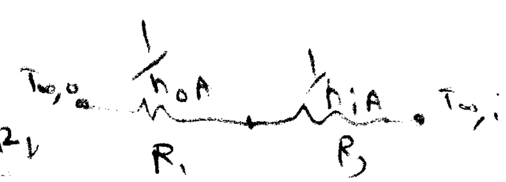
Then $Re_D = \dfrac{U_\infty D}{\nu} = \dfrac{40 \times 0.05}{15.89 \times 10^{-6}} = 125865 \leftarrow$

Then Table 7.2 $\rightarrow C = 0.027$, $m = 0.805$

Then $\overline{Nu}_D = C\, Re^{1/2}\, P_r^{1/3} = 0.027 \times Re^{0.805}\, P_r^{1/3}$

(c) So $\overline{Nu}_D = 306.6$

$\dfrac{1}{U} = \dfrac{1}{h_i} + \dfrac{1}{h_o} = \dfrac{1}{51} + \dfrac{1}{145} \rightarrow \boxed{U = 38\ W/m^2K}$ Ans.



(d) $\dot{Q} = U A_s (T_s - T_\infty) = 0$ Ans.