TEST– MEN310 (Heat Transfer)
December 17, 1999

1. A thermocouple junction may be approximated as a sphere of diameter $d=2$ mm, with $k=30$ W/m°C, $\rho=8600$ kg/m^3 and $c_p=0.4$ kJ/kg°C. The heat transfer coefficient between the gas stream and the junction is $h=280$ W/m^{2o}C. How long will it take for the thermocouple to record 98% of the applied temperature difference?

2. Air at $T_\infty=40$ °C flows with a velocity $u_\infty=8$ m/s along a flat plate $L=3$ m long which is maintained at a uniform temperature of 100 °C. Determine the local heat transfer coefficient at the end of the plate and the average heat transfer coefficient over the entire length of the plate. Assume $Re_{crit}=2X10^5$.

3. A carbon-steel bar of 4 cm by 4 cm cross section ($\alpha=1x10^{-5}$ m^2/s, $k=35$ W/m°C) is initially at uniform temperature $T_i=425$ °C. Suddenly all its surfaces are exposed to cooling by an air stream at $T_\infty=25$ °C with a heat transfer coefficient $h=100$ W/m^{2o}C. By using an explicit finite difference scheme and mesh size $\Delta x=\Delta y=1$ cm. Calculate the center temperature 10 s after the start of cooling.

Points: 1 (25%), 2 (25%) and 3 (50%).

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1) sphere $d = 2mm$

$k = 30\ W/m\,°C$

$\rho = 8600\ Kg/m^3$

$C_p = 0.4\ KJ/Kg\,°C$

$h = 280\ W/m^2\,°C$

check $Bi = \frac{h(V/A)}{k}$

$$Bi = \frac{280 \times \frac{4}{3}\pi (0.001)^3}{4\pi (0.001)^2 \times 30} = 3.11 \times 10^{-3} < 0.1 \rightarrow$$ lumped-heat capacity applie

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-[hA/\rho cV]\tau}$$

$$\longrightarrow \tau = -\frac{\rho c V}{hA} \ln \underbrace{\left(\frac{T - T_\infty}{T_0 - T_\infty}\right)}_{0.98}$$

$\tau = 0.082734$ sec.

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2) $T_\infty = 40°C$ $\quad T_p = 100°C \longrightarrow T_f = 70°C = 343\,K$

$U_\infty = 8$ m/sec

$L = 3$ m.

$Re_{crit} = 2.10^5$

$$T_f = 343\,K \longrightarrow \begin{cases} \nu = 20.0502 \times 10^{-6} \text{ m}^2/\text{sec} \\ k = 0.0294994 \text{ W/m°C} \\ Pr = 0.69854. \end{cases} \quad , \rho = 1.021116 \frac{Kg}{m^3} \quad c_p = 1.008538$$

$$Re_L = \frac{8 \times 3}{20.0502} \times 10^6 = 1.197 \times 10^6 > Re_{crit} \rightarrow \text{turbulent.}$$

eq. 5.81 $\rightarrow St_x\, Pr^{2/3} = 0.0296\, Re_x^{-0.2}$

$$\rightarrow St_x = \frac{h_x}{\rho c_p u_\infty} = \frac{0.0296\, Re_x^{-0.2}}{Pr^{2/3}}$$

(eq. 5.51 only for laminar, $\bar{h} = 2h_L$)

$\rightarrow h_L = 18.89$ W/m²°C (turbulent)

$(\bar{h} \neq 2h_L)$ $\rightarrow$ ~~$\bar{h} = 37.78$ W/m²°C~~ (to get $\bar{h}$ → we should solve the integral)

or using eq. 5.85 with A = 704 (extrapolate)

$\bar{h} = 20.44$ W/m²°C.

③ See Jan. 05, 2000, #3:

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Another Method

$$Re_{crit} = 2 \cdot 10^5 = \frac{U_\infty x_{crit}}{\nu}$$

$$\rightarrow x_{crit} = 2 \cdot 10^5 \cdot 20.0502 \cdot 10^{-6} \cdot \frac{1}{8} = 0.501255 \text{ m.}$$

(from before $h_x = 18.89$ for turbulent)

for laminar @ $x = 0.501255$ m.

$$\rightarrow \text{eq. } 5.44 \rightarrow Nu_x = \frac{hx}{k} = 0.332\, Re_x^{1/2} \cdot Pr^{1/3}$$

$$\rightarrow h = 7.753 \text{ for laminar)}$$

using equation (below 5.85)

$$h = \frac{1}{L}\left(\int_0^{x_{crit}} h_{lam} \, dx + \int_{x_{crit}}^{L} h_{turb} \, dx \right)$$

$$h = \frac{1}{3}\left(7.753 \times 0.501255 + 18.89\,(3 - 0.501255) \right)$$

$$h = 17.02917436 \text{ W/m}^2\,{}^\circ\text{C}$$

(more close to the 2nd method)