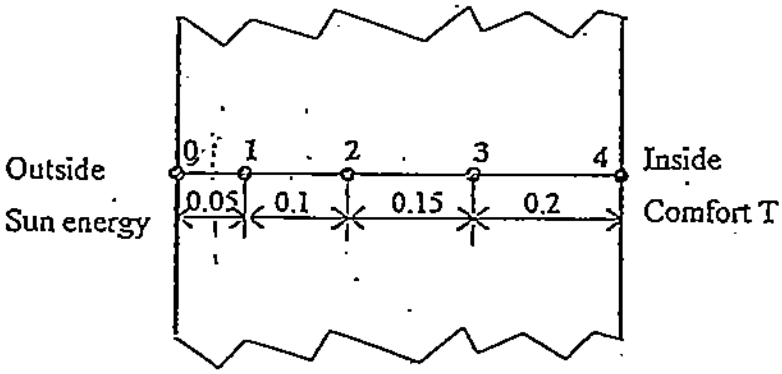
TEST– MEN310 (Heat Transfer)

May 22, 2000

1. A person is found dead at 5:00 p.m. in a room whose temperature is 20°C. The temperature of the body is measured to be 22°C when found, and the heat transfer coefficient is estimated to be 8W/m^2°C. Modeling the body as 30-cm-diameter, 1.75-m-long cylinder, and using the lumped system approach, estimate the time of death. Assume that the person was healthy before death and that the physical properties of the body material are those of water at 37°C. Comment on the accuracy of the result.

2. The local atmospheric pressure at an altitude of 1500m is measured to be 85kPa(abs). An experiment is conducted at that altitude to determine the heat loss from a heated plate at constant temperature. The experiment consists of an air stream at 20°C flowing with a velocity of 8m/s over a square flat plate (1.5mX1.5m) whose temperature is 135°C. The same experiment is conducted at sea level (p=1atm) with an air stream at the same temperature and velocity. Which elevation is better to maximizing the heat loss from the plate? Determine the relative change in heat loss (with respect to sea level) between the two elevations in order to show the effect of surroundings conditions in convective heat transfer calculations.

3. Dark painted thick masonry walls called Trombe walls are commonly used on sunny side of passive solar houses to absorb solar energy, store it during the day, and release it to the home during the night. The vertical section of such a wall (k=0.7W/m°C, α= 4.44x10^{-5} m^2/s) is sketched in the following figure with the required dimensions (in meter).



The wall is initially at constant temperature of 20°C and subjected to constant temperature (20°C) on the inner side and constant heat flux (q_s=800W/m^2) on the outer side.

Find the minimum number of time integration steps required to reach the temperature distribution in the wall after 1 hour using an explicit technique and the mesh shown in the figure. Determine the temperature distribution after 2 time steps.

Points: 1 (20%), 2 (30%) and 3 (50%).

$\rho = \frac{P}{RT}$

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1) $T_\infty = 20°C$ $\qquad h = 8\ W/m^2 °C$.

$T = 22°C$ (found)

$T_0 = 37°C$

body 30cm diameter
1.75 m long cylinder.

eq. 4.5

$\rho \approx 993\ kg/m^3$

$c_p = 4.174\ kJ/kg°C$.

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-(hA/\rho c V)\tau}$$

$$\Rightarrow \quad \tau = -\frac{\rho c V}{hA} \ln\left(\frac{T - T_\infty}{T_0 - T_\infty}\right)$$

$$\Rightarrow \quad \tau = \frac{-993 \times 4174 \times \cancel{\pi} \times \cancel{0.15^2} \times \cancel{1.75}}{8 \times \cancel{\pi \times 0.15^2} \times 2 \times \cancel{1.75}} \ln\left(\frac{22 - 20}{37 - 20}\right)$$

$\tau =$ ~~[illegible] hours~~ (not accurate at all)

$83157.259 sec = 23.099$ hours.

$$\cdot\ Bi = \frac{h(V/A)}{k} = \frac{8 \times \frac{\pi \times 0.15^2 \times 1.75}{\pi \times 0.3 \times 1.75}}{\underset{\text{from table}}{0.63}} = \cancel{[illegible]}\ 0.952$$ (not accurate at all)

Bi should be < 0.1

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2) $z = 1500\,m$
- $P = 85\,KPa\ (abs)$

$T_\infty = 20°C$
$v = 8\,m/sec$
$T_p = 135°C$

$1.5 \times 1.5\ m^2$ plate. $\longrightarrow T_f = \frac{135+20}{2} = 77.5°C = 350.$

- Same experiment, $P = 1\,atm = 1.0132 \times 10^5\ Pa.$

Experiment ①

$$\rho_{air} = \frac{85000}{287 \times 350.5} = 0.84499\ Kg/m^3.$$

$$T_f \longrightarrow \begin{cases} c = 1.009\ KJ/Kg°C \\ \mu = 2.075 \times 10^{-5}\ Kg/m.sec \\ k = 0.03003\ W/m°C \\ P_r = 0.697 \end{cases}$$

$$Re = \frac{\rho U x}{\mu} = 4.8867 \times 10^5 < 5.10^5 \longrightarrow \text{laminar.}$$

eq. 5.44 $\longrightarrow Nu_x = 0.332\ Re_x^{\frac{1}{2}}\ P_r^{\frac{1}{3}} = \frac{h_{x=L} \cdot x}{k} \longrightarrow h_{x=L} = 4.1196\ W/m^2°C$

$$\longrightarrow \boxed{\bar{h} = 8.2392\ W/m^2\,°C}$$

$$\longrightarrow q = \bar{h} A (T_w - T_\infty) = \boxed{2131.893\ \text{Watts} = q_{1500m}.}$$

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Exp. 2

$$\rho_{air} = \frac{1.0132 \times 10^5}{287 \times 350.5} = 1.007222 \ kg/m^3.$$

$Re_x = 5.82489 \times 10^5 > 5 \times 10^5 \rightarrow$ turbulent.

eq. 5-85 $\longrightarrow \quad \overline{Nu_L} = Pr^{\frac{1}{3}} \left(0.037 Re_L^{0.8} - 871\right) = \frac{\bar{h} L}{k}$

$\longrightarrow \bar{h} = 11.4324 \ W/m^2 \, ^\circ C$

$\rightarrow \boxed{q_{sea\ level} = 2958.148 \text{ Watts}}$

max. heat at sea level.

$$\frac{q_s - q_{1500}}{q_s} = 0.27931 \Rightarrow \approx 28\% \text{ difference.}$$

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3) $k = 0.7\,W/m\,^\circ C$ $\qquad \alpha = 4.44\times10^{-5}\,m^2/sec$

$T_i = 20^\circ C$ $\qquad \alpha = \frac{k}{\rho c}$

Node 0

$$\frac{T_1 - T_0}{R_{10}} \mp q_s \cdot A = C_0 \frac{T_0^{p+1} - T_0^{p}}{\Delta\tau}$$

$$R_{10} = \frac{0.05}{0.7\times A} \longrightarrow \frac{1}{R_{10}} = \frac{0.7A}{0.05} = 14A$$

$$\rightarrow 14(T_1 - T_0)A \mp 800A = \rho c V \frac{T_0^{p+1} - T_0^{p}}{\Delta\tau}$$

$$\rightarrow 14T_1 - 14T_0 \mp 800 = \frac{0.7\times10^5}{4.4}\times\frac{0.05}{2}\cdot\frac{T_0^{p+1} - T_0^{p}}{\Delta\tau}$$

$$\rightarrow \boxed{14T_1 - 14T_0 \mp 800 = 397.73\,\frac{T_0^{p+1} - T_0^{p}}{\Delta\tau}} \text{ — (1)}$$

$$\rightarrow T_0^{p+1} = \frac{\Delta\tau}{397.73}\left[14T_1 - 14T_0 \mp 800\right] + T_0^{p}$$

$$\rightarrow \boxed{T_0^{p+1} = \frac{\Delta\tau}{397.73}\left[14T_1^{p} \mp 800\right] + \left(1 - \frac{14\Delta\tau}{397.73}\right)T_0^{p}}$$

$$1 - \frac{14}{397.73}\Delta\tau \geq 0 \rightarrow 1 \geq \frac{14}{397.73}\Delta\tau$$

$$\Rightarrow \boxed{\Delta\tau \leq 28.40\ sec}$$

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Node 1

$$\frac{T_0 - T_1}{R_{01}} + \frac{T_2 - T_1}{R_{21}} = C_1 \frac{T_1^{p+1} - T_1^{p}}{\Delta\tau}$$

$1/R_{01} = 14A$, $R_{12} = \frac{0.1}{0.7A} \rightarrow 1/R_{12} = 7A$, $C = \frac{k}{\alpha} \cdot \left(\frac{0.05}{2} + \frac{0.1}{2}\right) A$

$$14T_0 + 7T_2 - 21T_1 = 1182.432 \frac{T_1^{p+1} - T_1^{p}}{\Delta\tau}$$

$$\boxed{T_1^{p+1} = \frac{\Delta\tau}{1182.432}\left[14T_0 + 7T_2\right] + \left[1 - \frac{21\Delta\tau}{1182.432}\right] T_1^{p}}$$

$\Delta\tau \leq 56.306$ sec.

Node 2:

$$\frac{T_1 - T_2}{R_{12}} + \frac{T_3 - T_2}{R_{23}} = C_2 \frac{T_2^{p+1} - T_2^{p}}{\Delta\tau}$$

$R_{23} = \frac{0.15}{0.7A} \rightarrow 1/R_{23} = 4.67A$, $C_2 = \frac{0.7 \times 10^5}{4.44} \times \left(\frac{0.1}{2} + \frac{0.15}{2}\right) A$

$$7T_1 + 4.67T_3 - 11.67T_2 = 1970.72 \frac{T_2^{p+1} - T_2^{p}}{\Delta\tau}$$

$$\boxed{T_2^{p+1} = \frac{\Delta\tau}{1970.72}\left[7T_1 + 4.67T_3\right] + \left[1 - \frac{11.67\Delta\tau}{1970.72}\right] T_2^{p}}$$

$\Delta\tau \leq 168.87$ sec.

Node 3:

$$\frac{T_2 - T_3}{R_{23}} + \frac{T_4 - T_3}{R_{34}} = C_3 \cdot \frac{T_3^{p+1} - T_3^{p}}{\Delta\tau}$$, $R_{34} = \frac{0.2}{0.7A} \rightarrow 1/R = 3.5A$

$C_3 = \frac{0.7 \times 10^5}{4.44}\left(\frac{0.15}{2} + \frac{0.2}{2}\right) A$

$$4.67T_2 + 3.5T_4 - 8.17T_3 = 2759.009 \cdot \frac{T_3^{p+1} - T_3^{p}}{\Delta\tau}$$

$$\boxed{T_3^{p+1} = \frac{\Delta\tau}{2759.009}\left[4.67T_2 + 3.5T_4\right] + \left(1 - \frac{8.17\Delta\tau}{2759.009}\right) T_3^{p}}$$, $\Delta\tau \leq 337.7$ sec

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3) Cont'd

Node 4

$T_4 = 20°C$.

choose $\Delta T \leq 28.409$ sec $\left(\rightarrow \boxed{\Delta T = 28 \text{ sec}} \right)$

1 hour = 3600 sec

$3600 / \Delta T = 28.409 = 126.7204 \cong$ iteration

$\Rightarrow \boxed{127 \text{ iteration}}$

after
2 time steps of $\Delta T = 28.409$.

Assume all @ $T = 20°C$.

iterate $\longrightarrow$ ---

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