TEST– MEN310 (Heat Transfer)

June 27, 2000

1. A vertical cylindrical furnace (1-m diameter and 1-m length) is used to heat up products using a radiating (infrared) ceiling. The ceiling and the floor are at 700K and 400K and have emissivities of 0.8 and 0.4, respectively. The lateral cylindrical wall is maintained at 300K. Determine the net radiative heat transfer at each surface during steady-state operation.

2. A double-glazed window consists of two sheets of glass (0.8-m height and 2-m width) separated by a 2-cm air gap at atmospheric pressure. If the glass temperatures are measured to be 18°C and 8°C, determine the rate of heat transfer through the window. Assume that the temperature of the glass is uniform over its entire thickness. By how much did the free convection increase the heat transfer rate with respect to pure conduction?

3. A 50-cm diameter Invar (steel with 36% Ni) ball at a uniform temperature of 300°C is removed from a hot kiln. The ball is then subjected to the flow of air at atmospheric pressure and 27°C with a velocity of 5m/s. The surface temperature of the sphere eventually drops to 200°C. Determine the average heat transfer coefficient during the cooling process and estimate the time required to achieve such a cooling. Assume that the temperature of the ball is uniform at any time.

Points: 1 (40%), 2 (30%), and 3 (30%).

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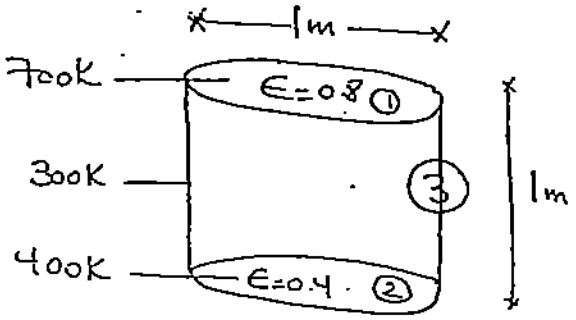
1)

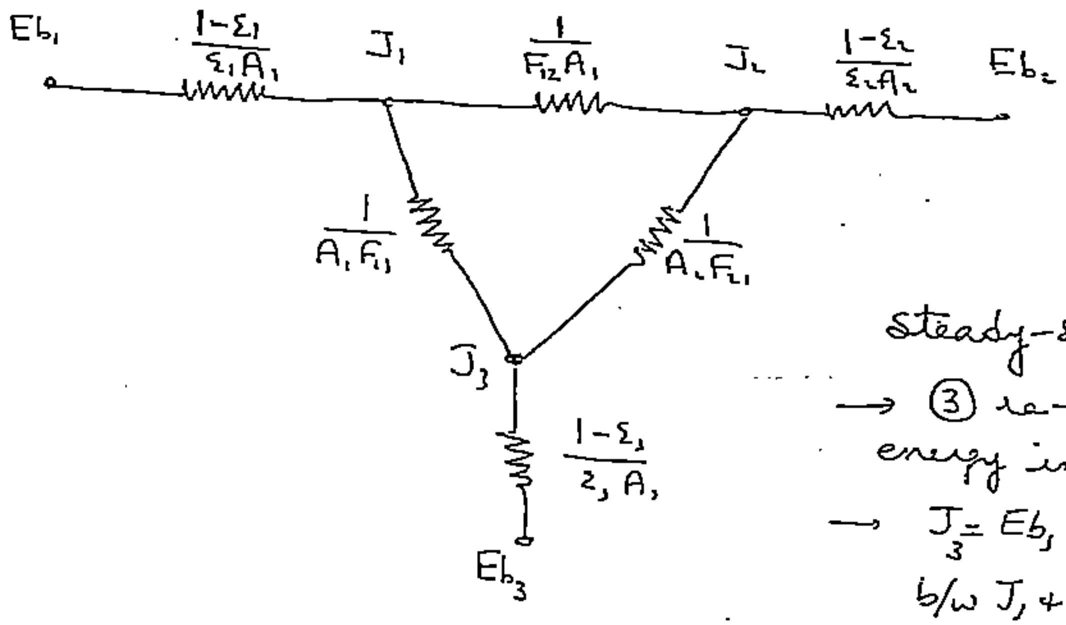


Using fig. 8-13 $\longrightarrow \frac{d}{x} = 1 \longrightarrow \boxed{F_{21} = 0.17 = F_{12}}$

$\cancel{F_{11}}^{0} + F_{12} + F_{13} = 1 \longrightarrow \boxed{F_{13} = 0.83 = F_{23}}$

$\longrightarrow \quad F_{31} = F_{32} = \frac{A_1}{A_3} F_{13} = \frac{\pi (0.5)^2}{\pi \times 1 \times 1} \times F_{13} = 0.2075$

$\longrightarrow \quad F_{33} = 0.585$



steady-state

$\longrightarrow$ ③ re-radiates all energy incident upon it

$\longrightarrow$ $J_3 = Eb_3$ $\longrightarrow$ no q flowing b/w J_3 + Eb_3.

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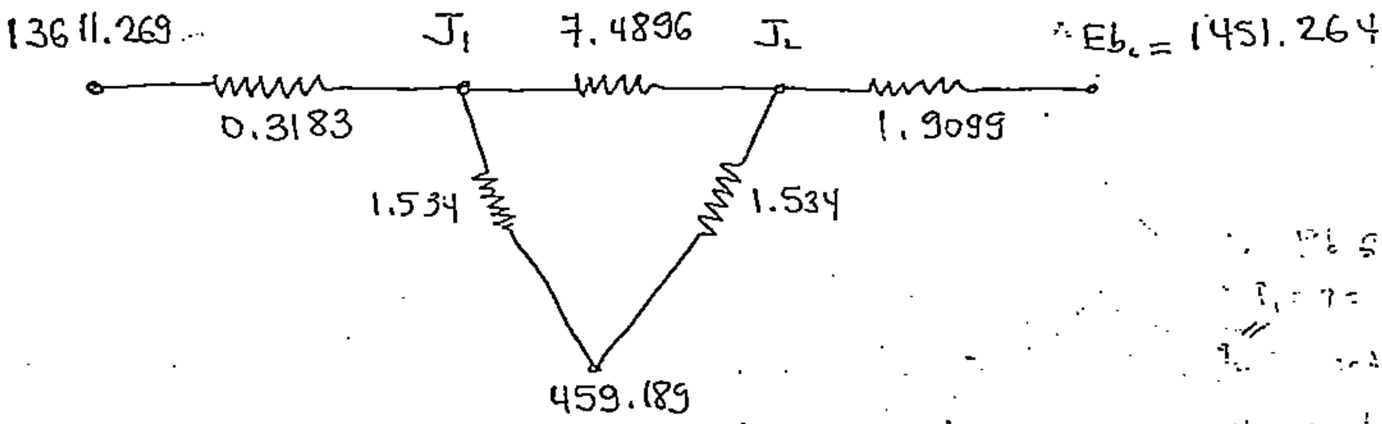

$$\begin{cases} \dfrac{13611.269 - J_1}{0.3183} + \dfrac{J_2 - J_1}{7.4896} + \dfrac{459.189 - J_1}{1.534} = 0 \\[2ex] \dfrac{J_1 - J_2}{7.4896} + \dfrac{1451.264 - J_2}{1.9099} + \dfrac{459.189 - J_2}{1.534} = 0 \end{cases}$$

$$\longrightarrow \quad J_1 = 11031.0437 \ \text{W/m}^2$$
$$J_2 = 1934.346516 \ \text{W/m}^2$$

$$q_1 = \frac{Eb_1 - J_1}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1}} = 8106.268615 \text{ Watts}$$

$$q_2 = \frac{Eb_2 - J_2}{\frac{1-\varepsilon_2}{\varepsilon_2 A_2}} = -252.936026 \text{ Watts.}$$

$$q_3 = \frac{J_1 - J_3}{R} + \frac{J_2 - J_3}{R} = 7853.332605 \text{ Watts}$$

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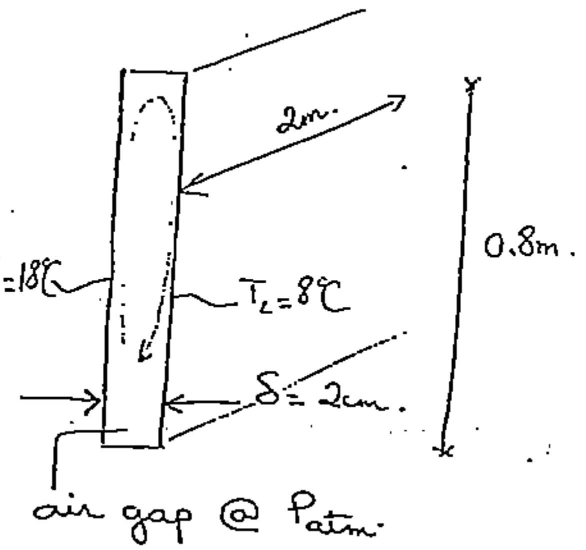
#2



$q = ?$

$$T_f = \frac{18+8}{2} = 13°C = 286K \longrightarrow \rho = \frac{1.0132\times10^5}{287\times286} = 1.234375381 \ \frac{Kg}{m^3}$$

$$\beta = \frac{1}{286} = 3.4965\times10^{-3}$$

$$\mu = 1.776984\times10^{-5} \ Kg/m.sec$$

$$k = 0.0251284 \ W/m°C$$

$$P_r = 0.71192$$

$$Gr_\delta P_r = \frac{9.8\times3.4965\times10^{-3}\,(18-8)\,(0.02)^3\times(1.2344)^2}{(1.776984\times10^{-5})^2}\times0.71192$$

$$Gr_\delta P_r = 13228.0061\times0.71192$$

$$p.\ 7.64 \longrightarrow \frac{k_e}{k} = 0.197\,(Gr_\delta P_r)^{\frac{1}{4}}\cdot\left(\frac{L}{\delta}\right)^{-\frac{1}{9}} = 1.4023\times0.71192^{1/4}$$

$$\rightarrow eq.\ 7.57 \longrightarrow q = (0.8\times2)\,(1.4023\times0.0251284)\,\left(\frac{18-8}{0.02}\right)\times0.71192^{1/4}$$

$$q = 28.19\times0.71192^{1/4} = \boxed{25.9\,W = q}$$

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pure conduction.

$$q = \frac{(T_1 - T_2)}{R} \quad \text{where } R = \frac{\Delta x}{kA} = \frac{0.02}{0.0251284 \times 0.8 \times 2}$$

$q = 20.10272$ Watts.

$$\rightarrow \quad \frac{28.19 - 20.10272}{20.10272} = 0.40229$$

$\rightarrow$ 40.23% increase.

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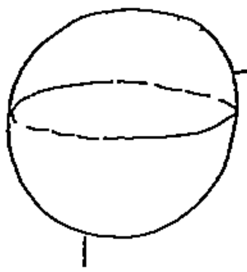
3]

$P = 1\ atm$

$T_\infty = 27°C$

$u_\infty = 5\ m/sec$

$d = 50\ cm$



$T = 300°C$

$\hookrightarrow T = 200°C$

$T_{avg} = 250°C$.

$T_{w\,avg} = \frac{T_{w1} + T_{w2}}{2} = \frac{300 + 200}{2} = 250°C$

$T_f = \frac{T_w + T_\infty}{2} = \frac{250 + 27}{2} = 138.5°C = 411.5\ K$

evaluating at T_{film}:

$T_f = \frac{27 + 250}{2} = 138.5 = 411.5K$

$\longrightarrow k = 0.0344366\ W/m°C$

$\longrightarrow \nu = 27.2363 \times 10^{-6}\ m^2/sec$

$\longrightarrow Pr = 0.68762$

$Re = \frac{u_\infty d}{\nu} = 91789.26653$ Watts (Assuming $Pr \simeq 0.71$)

$\because < Re < 3 \times 10^5$

$\longrightarrow$ equation 6.26 $\longrightarrow Nu = \frac{hd}{k} = 2 + \left(0.25 + 3 \times 10^{-4} Re^{1.6}\right)^{1/2}$

$\longrightarrow \boxed{h = 11.2768\ W/m^2°C}$

Table (A-2) p 595

$k_{steel} = 10.7\ W/m°C$

- $\tau = ?$

checking : $\frac{h(V/A)}{k} = \frac{11.2768 \times \left[4/3 \cdot \pi\, 0.25^3\right]}{4\pi(0.25)^2 \cdot (10.7)} = 0.0878 < 0.1$

$\rightarrow$ lumped capacit[y] valid

$\longrightarrow$ equation 4.5 $\longrightarrow \frac{200 - 27}{300 - 27} = e^{-\left[hA/\rho c V\right]\tau}$

Table A-... $\rho = 8137\ kg/[m^3]$

$C = 0.46 \times 10^3$

where $\frac{hA}{\rho c V} = \frac{11.2768 \times 4\pi(0.25)^2}{8137 \times 460 \times \frac{4}{3}\pi(0.25)^3} = 3.6153 \times 10^{-5}$

$\longrightarrow \tau = 12618.04555\ sec = \boxed{3.5\ hours.}$