ME 323 Sample Final Exam. 120pts total
May 25, 2006. Due 6/12/06 beginning final exam

True/False. Circle the correct answer. (1pt each, 7pts total)

1. A solid angle of 2π steradians defines a hemispherical shell. T F

2. The Earth irradiates the Sun. T F

3. Radiation doesn't occur in materials that are transparent such as gases. T F

4. Both natural and forced convection must be considered when designing thermal system inside the crew quarters of a Space Station. T F

5. The Rayleigh number (*Ra*) is to natural convection problems as the Reynolds number (*Re*) is to forced convection problems. T F

6. Significant natural convection occurs only when temperature gradients are perpendicular to the direction of gravity. T F

7. Snow reflects more of the suns radiation than it absorbs which explains why it appears white. T F

Short Answer. In your own words...(pts indicated)

8. Identify 4 factors that effect the radiation between surfaces. (4pts)

Temperature, wavelength, area, orientation

9. From a purely heat transfer perspective, describe the heat of a teakettle on a gas fired stove. (4pts)

Radiation: from flame to kettle base
Forced/Natural convection around kettle sides
Conduction kettle base

10. What is radiosity and the difference between spectral and total radiosity? (3pts)

Radiosity include the reflected portion of the irradiation and direct emission. Spectrum is radiosity per unit wave length interval $d\lambda$ about λ. The total is the integral over λ

11. A spinning cylindrical pot of oil is heated from above. Would you expect natural convection to play a role in the heating process? Explain. (3pts)

Yes Spinning creates an acceleration field that acts like gravity So if there is ΔT in r-direction there will be buoyancy driven flow.

$\frac{\partial T}{\partial r} > 0$?

2

12. For convective heat transfer problems, give 3 reasons why is it important to know whether the flow is laminar or turbulent? (3pts)

1 To determine the correlation that should be used.
2 Turbulent flow results in increased H.T
3. Turbulent flow " " " ΔP.

13. You are sitting in a chair on your back porch (which is attached to your house) in the summer. Provide at least 3 reasons why it seems brighter/hotter there than out in lawn, or at the same place during a different season, say, autumn. (3pts)

Reflection of house, porch floor more than that in lawn. In autumn solar angle is less, reducing green effect

14. What does diffuse gray surface imply? (3pts)

Non-black body, no direction & wavelength dependence

longer problems

15. (10 pts) The Nusselt number (Nu_x) defined at x for forced flow over a flat plate is given by

$$Nu_x = 0.332\,\mathrm{Re}_x^{1/2}\,\mathrm{Pr}^{1/3}.$$

Using this relationship compute the average Nusselt number (Nu_L) for the plate over the region of the plate identified by $0 \le x \le L$.

$$Nu = \frac{hx}{k} \Rightarrow h = \frac{Nu_x\, k}{x}$$

$$= 0.332\,\frac{\rho^{1/2} V_\infty^{1/2} x^{\frac{1}{2}}}{\mu^{1/2}\, x}\, k\, Pr^{1/3}$$

$$= 0.332\left(\frac{\rho V_\infty}{\mu}\right)^{1/2} Pr^{1/3}\, k\, x^{-\frac{1}{2}}$$

$$\bar{h}_L = \frac{1}{L}\int_0^L h\,dx$$

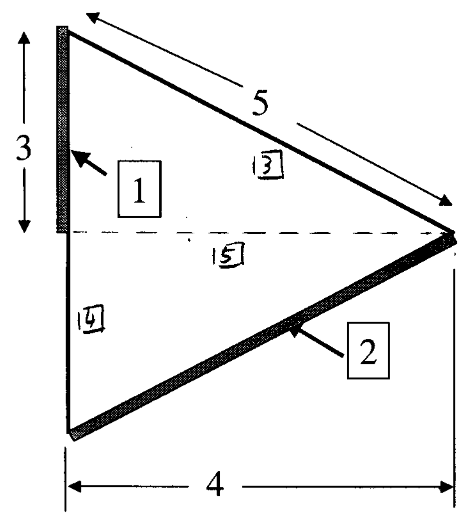
$$= \frac{1}{L}\,0.332\left(\frac{\rho V_\infty}{\mu}\right)^{1/2} Pr^{1/3}\, k \int_0^L x^{-\frac{1}{2}}\,dx$$

$$= \frac{1}{L}\,0.332\left(\frac{\rho V_\infty}{\mu}\right)^{1/2} Pr^{1/3}\, k\, 2L^{\frac{1}{2}}$$

$$= 0.664\left(\frac{\rho V_\infty}{\mu}\right)^{1/2} Pr^{1/3}\, L^{-\frac{1}{2}}$$

$$Nu_L = \frac{\bar{h} L}{k} = 0.664\, Re_L^{1/2}\, Pr^{1/3}$$

16. (8 pts) Compute the view factors F_{12} and F_{21} for the triangular cylinder.



$F_{15} + F_{13} = 1$

$F_{51} + F_{53} = 1$

$F_{31} + F_{35} = 1$

$A_1 F_{15} = A_5 F_{51} \Rightarrow F_{51} = \frac{A_1}{A_5} F_{15}$

$A_1 F_{13} = A_3 F_{31} \Rightarrow F_{31} = \frac{A_1}{A_3} F_{13}$

$A_3 F_{35} = A_5 F_{53} \Rightarrow F_{53} = \frac{A_3}{A_5} F_{35}$

$F_{15} + F_{13} = 1$

$\Rightarrow \left.\begin{array}{l} \frac{A_1}{A_5} F_{15} + \frac{A_3}{A_5} F_{35} = 1 \\ \frac{A_1}{A_3} F_{13} + F_{35} = 1 \end{array}\right\} \frac{A_1}{A_5} F_{15} + \frac{A_3}{A_5}\left(1 - \frac{A_1}{A_3} F_{13}\right) = 1$

$\Rightarrow \frac{A_1}{A_5} F_{15} - \frac{A_1}{A_5} F_{13} = 1 - \frac{A_3}{A_5}$

$\Rightarrow F_{15} - F_{13} = \frac{A_5}{A_1}\left(1 - \frac{A_3}{A_5}\right) = \frac{4}{3}\left(1 - \frac{5}{4}\right)$

$F_{35} = 1 - \frac{3}{5} \cdot \frac{2}{3} = \frac{3}{5}$

$\begin{cases} F_{15} - F_{13} = -\frac{1}{3} \\ F_{15} + F_{13} = 1 \end{cases}$

$\Rightarrow F_{15} = \frac{1}{3}$

$\Rightarrow F_{13} = \frac{2}{3}$

Reciprocity rule: $A_1 F_{12} = A_2 F_{21}$

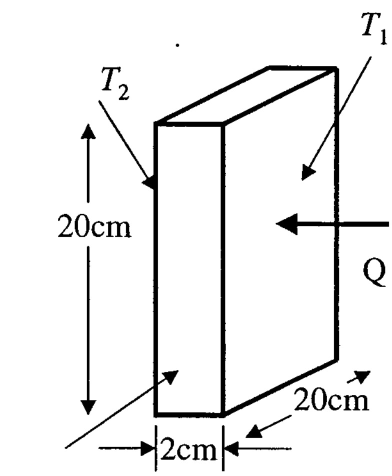
$\Rightarrow F_{21} = \frac{A_1}{A_2} F_{12} = \frac{3}{5} \cdot \frac{1}{3} = \frac{1}{5}$

Summation rule: $F_{12} + F_{13} = 1 \Rightarrow F_{12} = \frac{1}{3}$

17. Q = 50W are transferred through an enclosure. The dimensions of the enclosure are sketched below and the process takes place at approximately room temperature. The ideal gas in the enclosure has Pr = $\nu/\alpha = 1$ ($\alpha = \nu = 10^{-6}$ m^2/s).

A. (20pts) Compute the temperature difference across the enclosure. (k_{gas} = 0.026W/mK, β = 1/300K, c_p = 1000J/kgK, ρ = 0.001kg/m^3)

B. (5pts) Can your solution be verified?



Ideal gas enclosure

$q = 50$ W

$$Ra_L = \frac{g\beta(T_1 - T_2)L^3}{\alpha\nu}$$

$$= \frac{9.8 \times \Delta T\, L^3}{\alpha\nu} = \frac{9.8 \times 76.88 \times 0.02^3}{300 \times 10^{-12}} = 2 \times 10^8 < 10^9$$

$$\frac{H}{L} = \frac{20}{2} = 10$$

$$\overline{Nu}_L = 0.046\, Ra_L^{1/3} = \frac{\bar{h} L}{k} \Rightarrow \bar{h} = \frac{0.046\, Ra_L^{1/3}\, k}{L}$$

$$q = \bar{h} A \Delta T = \frac{0.046\, Ra_L^{1/3}\, k}{L} \cdot H^2 \Delta T$$

$$= \frac{0.046\, k H^2}{L}\left[\frac{g\beta\Delta T L^3}{\alpha\nu}\right]^{\frac{1}{3}} \Delta T$$

$$= 0.046\, k H^2 \left[\frac{g\beta}{\alpha\nu}\right]^{1/3} \Delta T^{\frac{4}{3}}$$

$$\Delta T^{\frac{4}{3}} = \frac{q}{0.046\, k H^2 \left[\frac{g\beta}{\alpha\nu}\right]^{1/3}}$$

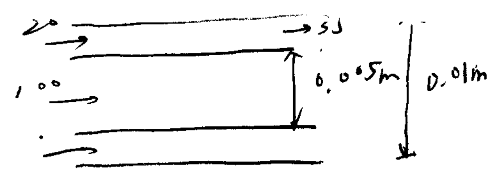
$$\Delta T = \left[\frac{q}{(0.046\, k H^2)\left[\frac{g\beta}{\alpha\nu}\right]^{1/3}}\right]^{\frac{3}{4}} = \left[\frac{50}{0.046 \cdot 0.026 \cdot 0.2^2} \cdot \left(\frac{10^{-12} \cdot 300}{9.8}\right)^{1/3}\right]^{3/4}$$

$$= 76.88\ ^\circ C$$

if $q = 5$W $\Rightarrow \Delta T = 13.67\ ^\circ C$

18. (20 pts) A water-water co-flow, parallel flow shell and tube heat exchanger has an inner tube ID of 0.005m with 0.001m wall thickness and an outer tube ID of 0.01m with 0.001m wall thickness. The flow rates in the two tubes are equal ($\dot{m}$ = 0.2kg/s, c_p = 4181J/kgK) with inlet hot (tube, core) and cold (shell, outside) temperatures of 100C and 20C, respectively. The exit temperature of the cold water flow is 35C.

A. Assume no loss to the surroundings, what is the heat transport of the heat exchanger?

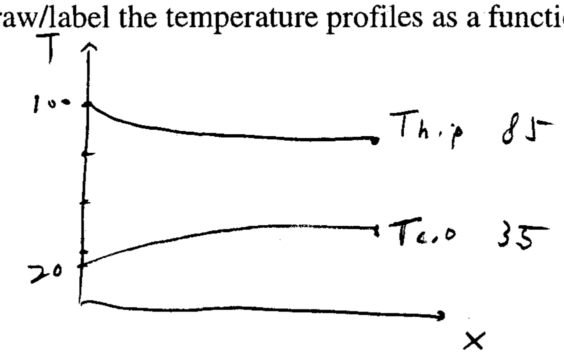


B. What is the exit temperature of the (tube side) hot water?

$$q = \dot m c_p (T_{h,i} - T_{h,o}) = \dot m c_p (T_{c,o} - T_{c,i})$$

$$\Rightarrow T_{h,o} = T_{h,i} - (T_{c,o} - T_{c,i}) = 100 - 15 = 85\ C$$

C. Draw/label the temperature profiles as a function of tube length for hot and cold flows.



D. What is the overall product UA per length of tube for this HX?

$$q = UA\,\Delta T_{lm} \qquad \Delta T_1 = 80 \qquad \Delta T_2 = 50$$

$$0.2\cdot 4181\cdot 15 = UA\,\frac{30}{\ln 5/8} \qquad \Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln \Delta T_1/\Delta T_2} = \frac{30}{\ln 8/5}$$

$$UA = \frac{0.2\cdot 4181\cdot 15\cdot \ln 8/5}{30} = 196.5$$

E. The tubes are made of copper (k = 400W/mK), and the tube side and shell side HTCs are approximately equal of $h_i = h_o$ = 100W/m^{2}K. What is the tube length?

$$\frac{1}{UA} = \frac{1}{h_i A_i} + \frac{\ln(D_o/D_i)}{2\pi k L} + \frac{1}{h_o A_o}$$

$$= \frac{1}{h_i \pi D_i L} + \frac{\ln(D_o/D_i)}{2\pi k L} + \frac{1}{h_o \pi D_o L} = \frac{1}{L}\left(\frac{1}{h_i\pi D_i} + \frac{1}{h_o \pi D_o} + \frac{\ln D_o/D_i}{2\pi k}\right)$$

$$\Rightarrow L = UA\left(\frac{1}{h_i\pi D_i} + \frac{1}{h_o\pi D_o} + \frac{\ln D_o/D_i}{2\pi k}\right)$$

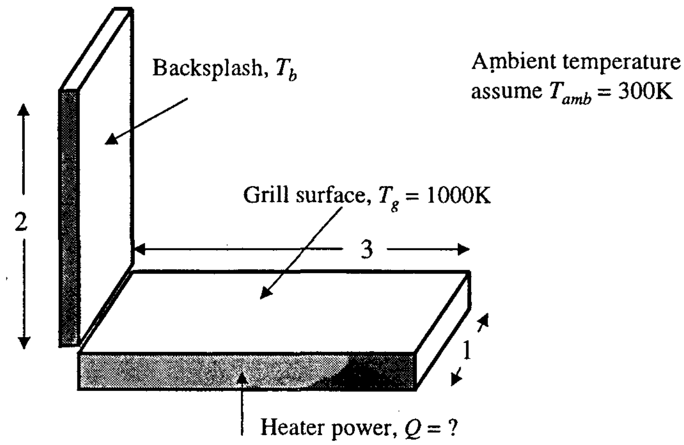
F. **(4pts extra credit)** Why or why not does your answer for tube length seem reasonable?

$$= 196.5\left(\frac{1}{100\cdot\pi\cdot 0.005} + \frac{1}{100\cdot\pi\cdot 0.007} + \frac{\ln \frac{0.007}{0.005}}{2\pi\cdot 400}\right)$$

$$= 0.018\ m = 1.8\ cm$$

$$\frac{L}{D_i} = \frac{0.018}{0.005} = 3.6$$

19. A high tech /high temperature grill T_g = 1000K is used for flash food frying. A crude schematic is provided below. A backsplash for the grill also serves as a radiation shield. Because the high surface temperature of the grill it is assumed that radiation is the dominant mode of heat loss to the surroundings, which is assumed to be T_{amb} = 300K. The surfaces is coated with an enamel that produces diffuse gray surfaces, ε = 0.8.



A. (20pts) Assuming uniform surface temperatures, what is the maximum heat that the grill will dissipate if the backsplash is to be maintained at T_b = 600K? Assume also that $\varepsilon_g = \varepsilon_b = 0.8$.

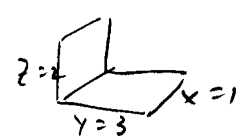
B. (7pts) Describe with some detail why and how you would access the accuracy of the simplifying assumption of purely radiation heat transfer made in problem A. above?

A. $q = \epsilon_g A_g F_{gb} \sigma (T_g^4 - T_b^4) + \sigma \epsilon A_g F_{gamb} T_g^4$

$F_{gb} + F_{gamb} = 1$

$q = 0.8 \cdot 3 \cdot 0.12 \cdot \sigma (1000^4 - 600^4)$
$+ 0.8 \cdot 3 \cdot 0.88 \cdot \sigma \, 1000^4$

F_{gb}:



$\sigma = 5.67 \times 10^{-8}$

$\frac{z}{x} = 2, \quad \frac{Y}{x} = 3$

$\Rightarrow F_{gb} = 0.12$

$F_{gamb} = 0.88$

$q = 5.67 \times 10^{-8} \times 0.8 \; 0.12 \cdot 3 \, (1000^4 - 600^4)$
$+ 5.67 \times 10^{-8} \cdot 0.8 \cdot 0.88 \cdot 3 \cdot 1000^4$

B. Evaluate the heat loss through natural convection.