ChE 306: HEAT TRANSFER
FALL 2010
Homework #4 Ch 6 & 7 (80 points)
DUE: WEDNESDAY, SEPTEMBER 29
(Appendix Tables A.4 to A.7 will be helpful for the HW set.)

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1. A 3-inch diameter titanium sphere at 0 ^oF is dropped into an oil bath at 200 ^oF.

DATA	Titanium sphere	Oil bath
Density (lb_m/ft^3)	281	66.6
Heat Capacity (Btu/lb_m-^oF)	0.125	0.000652
Thermal Conductivity (Btu/h-ft-^oF)	12.7	0.151

A thermocouple placed in the center of the sphere gives the following data:

Time (min)	**Temperature (^oF)**
0	0
0.5	19
1	36
2	66
5	126
10	173
20	196

What is the convective heat transfer coefficient for the oil?
(Hint: go to the material we covered in Chapter 5)

2. Work Incropera and DeWitt Problem 6.3.

3. A tunnel is designed to test different fluids flowing over a flat plate. The turbine can generate air speeds of up to 50 m/s. You wish to study boundary layer formation for Reynolds numbers (Re_x) up to 10^8.
   A. How long must the flat plate be to achieve this Re_x value for air at 25 ^oC?
   B. At what x-position along the plate does the flow change from laminar to turbulent? ($Re_{x,c} = 5 \times 10^5$)

4. The same tunnel from problem 2 is used to test different fluids. For each of the situations below, find the distance from the front edge of the plate where a fluid flowing at 1 m/s parallel to the surface will change from laminar to turbulent flow. ($Re_{x,c}$ for a flat plate is $5 * 10^5$).
   A. Air at 25 ^oC, B. Air at 70 ^oC, C. Carbon Dioxide at 25 ^oC,
   D. Water at 25 ^oC, E. Engine oil at 25 ^oC, F. Mercury at 25 ^oC
   (Note: You may approximate physical properties at 25 ^oC to be those for 300 K and 70^oC/340K)

5. Four experimental fluids are tested in parallel flow at 1.0 m/s over a flat plate where the plate temperature is 49 ^oC and the fluids are at 5 ^oC. Fluids: Air, Water, Engine Oil, Mercury

   A. For each fluid, determine the hydrodynamic (velocity) boundary layer thickness at a distance 5 cm from the front edge of the plate.
   B. For each fluid, determine the thermal boundary layer thickness at the same distance (5 cm).
   C. How would your answer change if the plate was at 10 ^oC and the fluids were at 44 ^oC?

6.Convective cooling is largely responsible for cooling car engines to prevent overheating. This is especially a problem in slow-moving traffic, and the engine is idling while the car speed is low. Assuming that the only available method to dissipate heat from the engine is convection, **determine the minimum speed (in mph) a driver must go to avoid overheating.** (Note: the inside back cover of your text has useful conversion factors)

Assume that the engine can be represented accurately as a flat plate with square dimensions of 2m by 2m (length by width), with flow over the topside only. The engine surface maintains a constant surface temperature of 90 ^{o}C, and is cooled by airflow, which is the same speed as the car moves.

The heat generated in the engine (which must be dissipated by convection) is a function of car speed:

$\mathbf{q = 1000 + 75\ v^{1/2}}$ (where v in m/s, and q is in W)

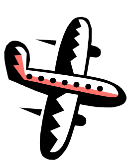
As a worst-case scenario, use the outside air temperature for a warm Alabama summer day: 100 ^{o}F (38 ^{o}C). To assist with selection of a Nu correlation, assume that the speed will be below 5 m/s (11.25 mph).

	Air properties at 337 K	Air properties at 363 K
Thermal Conductivity, k	0.029 W/m-K	0.031 W/m-K
Prandtl Number	0.702	0.697
Kinematic Viscosity, ν	$20 * 10^{-6}$ m^2/s	$23 * 10^{-6}$ m^2/s
Density, ρ	1.05 kg/m^3	0.97 kg/m^3
Heat capacity, c_p	1.008 kJ/kg-K	1.011 kJ/kg-K
Viscosity, μ	$203 * 10^{-7}$ N-s/m^2	$215 * 10^{-7}$ N-s/m^2

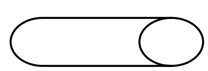
7. A 20-m long cylindrical pipe with outer diameter of 12 cm is made of aluminum (k = 237 W/m-K; wall thickness 0.2 cm) and is cooled by external forced convection using 27 ^{o}C air at 2.4 m/s. The pipe's outer surface temperature is 227 ^{o}C. *Fluid properties are included on the last page of the exam.*

Which air flow orientation (**cross-flow or parallel flow**) will result in a higher cooling rate?
Justify your answer by showing the numerical ratio of the cooling rates in cross flow to parallel flow.

8. Airplanes can be modeled as circular tubes flying in high altitudes through very cold atmospheric conditions. It is important that there is enough power on board to keep the cabin temperature normalized during flight. For the conditions below, **determine the power (in W) needed for a heater inside the plane to balance the heat lost through convection to the upper atmosphere.** Ignore the wings, tail, and nose cone of the plane, and only consider the air moving parallel to the tubular cabin.



<u>Plane dimensions</u>
Outside Diameter: 10 m
Length: 60 m
Wall thickness: 0.1 m



Internal cabin air temperature: 25 ^{o}C
External (high altitude) temperature: -40 ^{o}C
Internal convective heat transfer coefficient (h_i) = 7.0 W/m^2-K
Airspeed: 150 mph (= 67 m/s)
Thermal resistance of the shell (walls): 0.00026 K/W

You may use -23 ^{o}C as the film temperature to determine the properties of the outside air.