

Homework 2 - Review of Basic Heat Transfer
Due: Wednesday, September 19, 2007
10 points total, 1 per problem

Feel free to work with other students on this assignment. However, each student must submit their own assignment. Make sure the work you submit is your own and that you understand the material.

It will be important for the rest of the semester that everyone is on the same page and is up to speed on basic heat transfer. Please bring your questions to class so we can discuss them as a group. A significant amount of class time during the first few weeks will be available for heat transfer review.

2.1

A solid cylindrical rod of length 0.1 m and diameter 25 mm is well insulated on its side, while its end faces are maintained at temperatures of 100 and 0°C. Calculate the heat flow through the rod if it is constructed from each of the following materials.

- a) pure copper
- b) aluminum alloy 6061-T6
- c) AISI 302 stainless steel
- d) pure silicon
- e) Loctite® 3505™ epoxy
- f) eutectic tin-lead solder

2.2

A thermopane window consists of two pieces of glass 7 mm thick that enclose an air space 7 mm thick. The window separates room air at 20°C from outside ambient air at -10°C. The convection coefficient associated with the inner (room-side) surface is 10 W/m²K, while that associated with the outer (ambient air) side is 80 W/m²K. Assume the air enclosed between the panes is stagnant.

- a) What is the heat loss through a window which is 0.8 m long by 0.5 m wide?
- b) Evaluate the Rayleigh number for the air gap and test the stagnant air assumption.

2.3

A house has a composite wall consisting of 100 mm of R-19 fiberglass insulation sandwiched between an interior 10 mm thick sheet of plaster board and an exterior 20 mm thick sheet of plywood. On a cold winter day the outside ambient air temperature is -10°C , and the wind provides a convection heat transfer coefficient of $60 \text{ W/m}^2\text{K}$. Inside the house the air is 20°C , with an associated heat transfer coefficient of $10 \text{ W/m}^2\text{K}$ on the inner wall surface.

The wall is 3 m high and 7 m wide.

- Determine a symbolic expression for the total thermal resistance of the wall, including inside and outside convection effects for the prescribed conditions.
- Determine the total heat loss through the wall.
- What is the controlling resistance that determines the amount of heat flow through the wall?

hint: <http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatloss.html#c1>

2.4

Consider the wall of problem 2.3 that includes five of the windows described in problem 2.2.

- Sketch a thermal resistance network representing this situation.
- Determine a symbolic expression for the total thermal resistance.
- Determine the total heat loss through the wall+window system.
- Identify the controlling resistance(s).

2.5

An aluminum plate 4 mm thick is mounted in a horizontal position, and its bottom surface is well insulated. A special, thin coating is applied to the top surface with a solar absorptivity of 0.8 and a thermal emissivity of 0.25.

- Consider conditions for which the plate is at a temperature of 25°C and its top surface is suddenly exposed to ambient air at $T_{\text{amb}} = 20^{\circ}\text{C}$ and to solar radiation that provides an incident flux of 900 W/m^2 . The convection heat transfer coefficient between the surface and the air is $h = 20 \text{ W/m}^2\text{K}$. What is the initial rate of change of the plate temperature?
- What will be the equilibrium temperature of the plate when steady state conditions are reached?

2.6

A 20 mm square silicon microprocessor chip, 0.3 mm thick, is to be cooled via immersion cooling in a dielectric liquid. Single-phase natural convection is expected to provide a heat transfer coefficient of $250 \text{ W/m}^2\text{K}$. Evaluate the Biot number for this chip and determine whether or not it is appropriate to assume the chip is isothermal. Be sure to justify your choice of characteristic length. Would your conclusion change if boiling was to be employed, providing a heat transfer coefficient of $4000 \text{ W/m}^2\text{K}$?

2.7

A solid object is to be cooled by submerging it in a quiescent fluid, and the associated free convection coefficient is given by $h = C \Delta T^{1/4}$, where C is a constant and $\Delta T = T_{\text{object}} - T_{\text{ambient}}$. Invoking the lumped capacitance approximation, obtain an expression for the time required for the object to cool from an initial temperature T_i to a final temperature T_f .

2.8

Airflow through a long, 0.2 m square air conditioning duct maintains the outer duct surface temperature at 10°C . If the horizontal duct is not insulated and exposed to air at 35°C , what is the heat gain per unit length of the duct?

2.9

Air at a pressure and temperature of 1 atm and 15°C is in parallel flow at a velocity of 10 m/s over a 3 m long flat plate that is heated to a uniform temperature of 140°C .

- a) What is the average heat transfer coefficient for the plate?
- b) What is the local heat transfer coefficient at the midpoint of the plate?
- c) Plot the variation of heat flux along the length of the plate.

2.10

Consider the wing of an aircraft as a flat plate of 2.5 m length in the flow direction. The plane is moving at a speed of 100 m/s in air that is at a pressure of 0.7 bar and a temperature of -10°C . If the top surface of the wing absorbs solar radiation at a rate of 800 W/m^2 , estimate its steady state temperature. Assume the wing to be of solid construction and to have a single, uniform temperature.