University of New Mexico
Mechanical engineering
Spring 2017 Ph.D. qualifying examination

Heat Transfer

Notes

- Time allowed: 150 minutes.
- Closed book / Closed Notes (one 8.5 $\times$ 11.00 in. sheet of formulas is allowed).
- Calculators are allowed.
- Laptops, cell phones, and similar electronic devices are not allowed.

Part 1: General knowledge (25 points)
Circle the correct answer

1. What does the Biot number represent physically, for a solid immersed in a fluid at a different temperature?

   (a) The ratio of thermal resistance of the solid and the thermal resistance of the convective boundary layer at the interface

   (b) The ratio of thermal resistance of the convective boundary layer at the interface and the thermal resistance of the solid.

   (c) The dimensionless temperature gradient just outside the interface

2. Is it possible for the performance of insulation around a cylindrical pipe to become worse if the thickness is increased?

   (a) No, because thicker insulation always results in higher thermal resistance.

   (b) Yes, because the outer surface area increases thereby increasing the convection coefficient.

   (c) Yes, in fact increasing the insulation thickness always results in poorer performance.

3. Under what conditions is it possible to assume spatially uniform temperature within an object cooling in an external flow?

   (a) high conductivity materials.

   (b) low convection coefficient.

   (c) small Biot number.

4. When we consider a heat balance at an interface, we state that:

   (a) the net flux through the interface is zero.

   (b) the net flux into the interface must equal the rate of change of internal energy of the interface.

   (c) the flux into one side of the interface must equal the flux out of the other.

5. Birds are often seen to fluff their feathers while perching in cold weather because:

   (a) They tend to preen more in the winter because there is less to do

   (b) Feathers standing on end provide a thicker layer of still air with better insulating properties

   (c) they are trying to deter predators by looking bigger

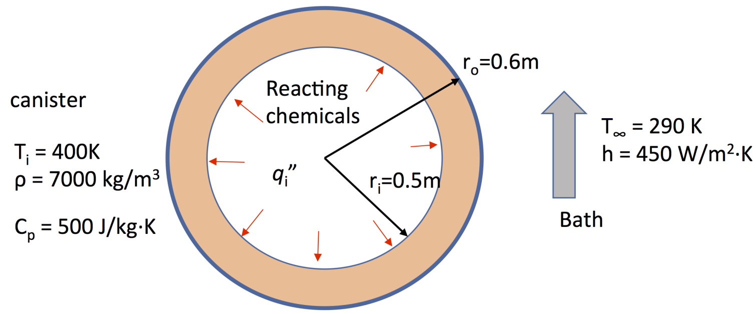
6. Newton's law of cooling states that:
   (a) The net force applied to an object is proportional to the rate of change of its momentum.
   (b) Heat flux in a material in some direction is proportional to the gradient in temperature in the same direction.
   (c) The rate of cooling of an object is proportional to the difference in temperature between the object and the ambient.
7. Turbulent boundary layers are usually associated with higher convective heat transfer. In addition, one sees in general:
   (a) lower drag
   (b) higher drag
   (c) no change in drag
8. It is probably not a wise idea to operate a boiling water nuclear reactor in the peak heat flux regime because:
   (a) cooling is not as effective as in the nucleate boiling regime.
   (b) a small change in power output of the reactor could result in a large change in operating temperature and possible core meltdown.
   (c) the operating temperature in the peak flux regime is extremely high.
9. The Nusselt number in the entrance region of a tube is:
   (a) lower than for fully developed flow.
   (b) higher than for fully developed flow.
   (c) higher, equal or lower than in fully developed flow, depending on the Prandtl number.
10. The radiosity of a surface measures:
   (a) the amount of reflected radiation.
   (b) the sum of emitted and reflected radiation.
   (c) the total emitted radiation per unit solid angle.

Part 2: Problems (25 points per question)

Attempt all problems in this section, clearly stating any assumptions and simplifications used in your solution

Problem 1

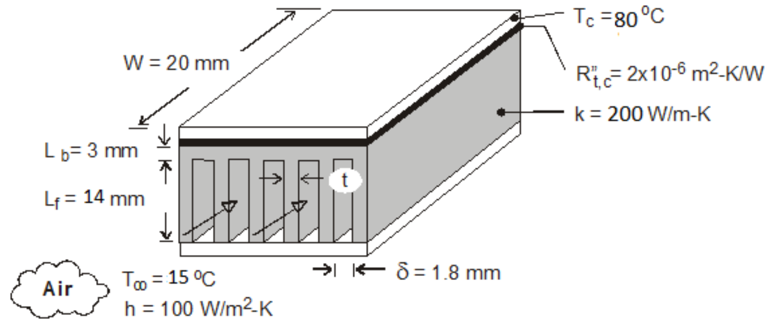
A spherical, stainless steel canister is used to store reacting chemicals that provide for a uniform heat flux q_i'' to its inner surface. The canister is suddenly submerged in a liquid bath of temperature $T_\infty < T_i$, where T_i is the initial temperature of the canister wall.



1. Assuming negligible temperature gradients in the canister wall and a constant heat flux q_i'', develop an equation that governs the variation of the wall temperature with time during the transient process. What is the initial rate of change of the wall temperature if $q_i'' = 5 \times 10^4$ W/m^2?

2. What is the steady-state temperature of the wall?

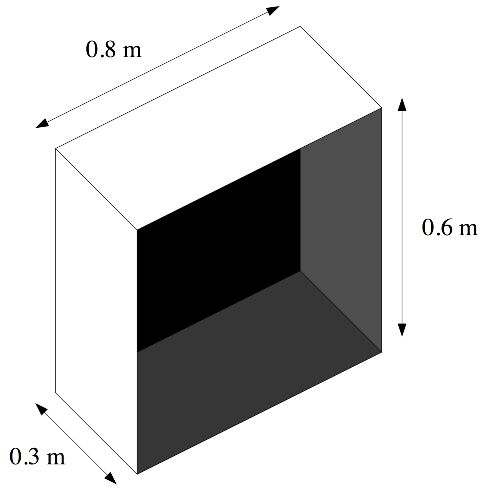
Problem 2



An isothermal silicon chip of width W=20 mm on a side is soldered to an aluminum heat sink of equal width. The heat sink has a base thickness of $L_b = 3$ mm and an array of rectangular fins, each of length $L_f = 14$ mm. Airflow at $T_\infty = 15°$C is maintained through channels formed by the fins and a cover plate, and for a convection coefficient of $h = 100$ W/m^2·K, a minimum fin spacing of 1.8 mm is dictated by limitations on the flow pressure drop. The solder joint has a thermal resistance of 2×10^{-6} m^2·K/W. Consider limitations for which the array has $N = 11$ fins, in which case the fin thickness is $t = 0.182$ mm. If the maximum allowable chip temperature is $T_c = 80°$C, what is the corresponding value of the chip power Q_c? An adiabatic fin tip condition is assumed, and airflow along the outer surfaces of the heat sink may be assumed to provide a convection coefficient equivalent to that associated with airflow through the channels. Additional assumptions are:

1. Steady-state conditions,
2. One-dimensional heat transfer,
3. Isothermal chip,
4. Negligible heat transfer from the top surface of chip,
5. Negligible temperature rise for air flow,
6. Uniform convection coefficient associated with air flow through channels and over outer surface of heat sink,
7. Negligible radiation.

Problem 3



A fireplace can be modeled as an enclosure with the dimensions shown in the figure. After burning logs for a while, the walls become very hot. If their temperature is 350°C, and their emissivity is 0.7, estimate the rate of radiant heat transfer to a large room at 22°C.

Fin efficiency follows below equation in which *L* can be approximated as the length of the fin.

$$\eta_f = \frac{\tanh mL}{mL}$$

m is calculated from $m^2 = {hP}/{kA_c}$ where A_c is the fin's cross section area and *P* is the perimeter of A_c. The thickness can be ignored in computing *P*. *k* is the fin's conductive heat transfer coefficient and *h* is the convective heat transfer coefficient of the ambient fluid.

For multiple fins, the overall efficiency is computed from the below equation:

$$\eta_0 = 1 - \frac{NA_f}{A_t}(1 - \eta_f)$$

A_f is the area of the fin which can be approximated by adding the top and bottom surface areas and A_t is the total area of '*N*' number of fins plus the exposed area at the base between the fins, A_b:

$$A_t = NA_f + A_b$$