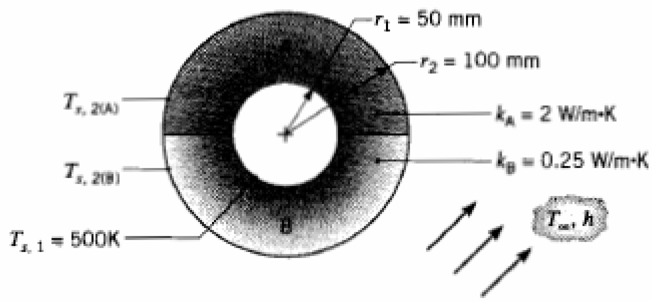
Franklin W. Olin College of Engineering
ENGR 3310: Transport Phenomena

Problem Set 7

Assigned: 10/29/04 Fall 2004
Due: 11/4/04 by 5:00 pm

(Note: All problems in this homework are from your Incropera and DeWitt Heat Transfer text. If you have difficulty making out the figures, see the book.)

3.52 Steam flowing through a long, thin-walled pipe maintains the pipe wall at a uniform temperature of 500 K. The pipe is covered with an insulation blanket comprised of two different materials, A and B.

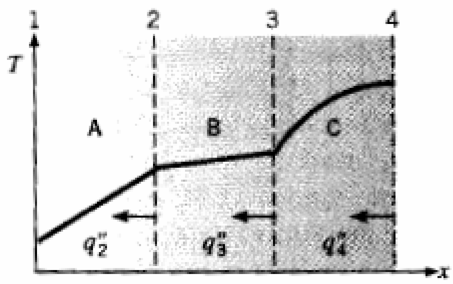


The interface between the two materials may be assumed to have an infinite contact resistance, and the entire outer surface is exposed to air for which $T_\infty = 300$ K and $h = 25$ W/m$^2 \cdot$K.

(a) Sketch the thermal circuit of the system. Label (using the above symbols) all pertinent nodes and resistances.

(b) For the prescribed conditions, what is the total heat loss from the pipe? What are the outer surface temperatures $T_{s,2(A)}$ and $T_{s,2(B)}$?

3.71 The steady-state temperature distribution in a composite plane wall of three different materials, each of constant thermal conductivity, is shown as follows.

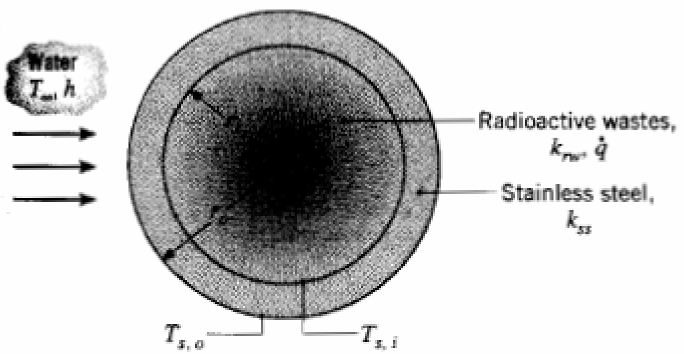


(a) Comment on the relative magnitudes of q''_2 and q''_3 and of q''_3 and q''_4.

(b) Comment on the relative magnitudes of k_A and k_B and of k_B and k_C.

(c) Sketch the heat flux as a function of x.

3.95 Radioactive wastes ($k_{rw} = 20$ W/m · K) are stored in a spherical, stainless steel ($k_{ss} = 15$ W/m · K) container of inner and outer radii equal to $r_i = 0.5$ m and $r_o = 0.6$ m. Heat is generated volumetrically within the wastes at a uniform rate of $\dot{q} = 10^5$ W/m^3, and the outer surface of the container is exposed to a water flow for which $h = 1000$ W/m^2 · K and $T_\infty = 25°$C.



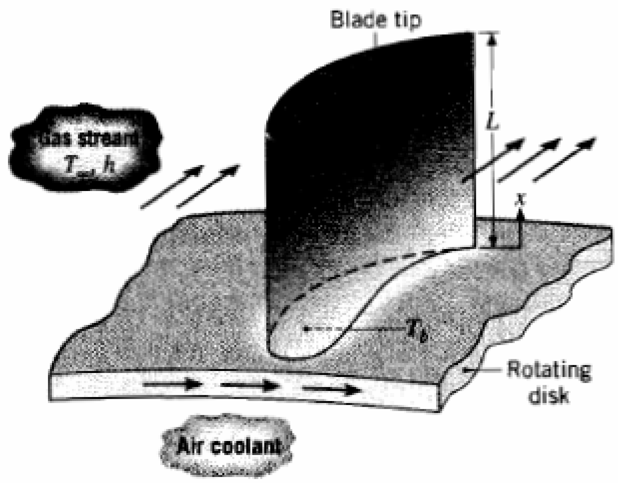
(a) Evaluate the steady-state outer surface temperature, $T_{s,o}$.

(b) Evaluate the steady-state inner surface temperature, $T_{s,i}$.

(c) Obtain an expression for the temperature distribution, $T(r)$, in the radioactive wastes. Express your result in terms of r_i, $T_{s,i}$, k_{rw}, and $\dot{q}$. Evaluate the temperature at $r = 0$.

(d) A proposed extension of the foregoing design involves storing waste materials having the same thermal conductivity but twice the heat generation ($\dot{q} = 2 \times 10^5$ W/m^3) in a stainless steel container of equivalent inner radius ($r_i = 0.5$ m). Safety considerations dictate that the maximum system temperature not exceed 475°C and that the container wall thickness be no less than $t = 0.04$ m and preferably at or close to the original design ($t = 0.1$ m). Assess the effect of varying the outside convection coefficient to a maximum achievable value of $h = 5000$ W/m^2 · K (by increasing the water velocity) and the container wall thickness. Is the proposed extension feasible? If so, recommend suitable operating and design conditions for h and t, respectively.

3.116 Turbine blades mounted to a rotating disc in a gas turbine engine are exposed to a gas stream that is at $T_\infty = 1200°C$ and maintains a convection coefficient of $h = 250\ W/m^2 \cdot K$ over the blade.



The blades, which are fabricated from Inconel, $k \approx 20\ W/m \cdot K$, have a length of $L = 50$ mm. The blade profile has a uniform cross-sectional area of $A_c = 6 \times 10^{-4}\ m^2$ and a perimeter of $P = 110$ mm. A proposed blade-cooling scheme, which involves routing air through the supporting disc, is able to maintain the base of each blade at a temperature of $T_b = 300°C$.

(a) If the maximum allowable blade temperature is 1050°C and the blade tip may be assumed to be adiabatic, is the proposed cooling scheme satisfactory?

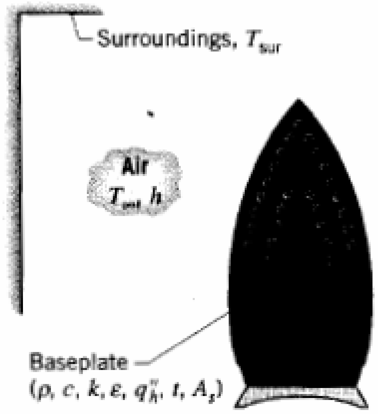
(b) For the proposed cooling scheme, what is the rate at which heat is transferred from each blade to the coolant?

3.122 The extent to which the tip condition affects the thermal performance of a fin depends on the fin geometry and thermal conductivity, as well as the convection coefficient. Consider an alloyed aluminum ($k = 180\ W/m \cdot K$) rectangular fin whose base temperature is $T_b = 100°C$. The fin is exposed to a fluid of temperature $T_\infty = 25°C$, and a uniform convection coefficient of $h = 100\ W/m^2 \cdot K$ may be assumed for the fin surface.

(a) For a fin of length $L = 10$ mm, thickness $t = 1$ mm, and width $w \gg t$, determine the fin heat transfer rate per unit width q'_f, efficiency η_f, effectiveness ε_f, thermal resistance per unit width $R'_{t,f}$, and tip temperature $T(L)$ for Cases A and B of Table 3.4. Contrast your results with those based on an *infinite fin* approximation.

(b) Explore the effect of variations in L on the heat rate for $3 < L < 50$ mm. Also consider the effect of such variations for a stainless steel fin ($k = 15\ W/m \cdot K$).

5.8 The base plate of an iron has a thickness of $L = 7$ mm and is made from an aluminum alloy ($\rho = 2800$ kg/m^3, $c = 900$ J/kg · K, $k = 180$ W/m · K, $\varepsilon = 0.80$). An electric resistance heater is attached to the inner surface of the plate, while the outer surface is exposed to ambient air and large surroundings at $T_\infty = T_{sur} = 25$°C. The areas of both the inner and outer surfaces are $A_s = 0.040$ m^2.



If an approximately uniform heat flux of $q''_h = 1.25 \times 10^4$ W/m^2 is applied to the inner surface of the base plate and the convection coefficient at the outer surface is $h = 10$ W/m^2 · K, estimate the time required for the plate to reach a temperature of 135°C.

Problem 5.17

17 A long wire of diameter $D = 1$ mm is submerged in an oil bath of temperature $T_\infty = 25$°C. The wire has an electrical resistance per unit length of $R'_e = 0.01$ Ω/m. If a current of $I = 100$A flows through the wire and the convection coefficient is $h = 500$ W/m^2 · K, what is the steady-state temperature of the wire? From the time the current is applied,

how long does it take for the wire to reach a temperature that is within 1°C of the steady-state value? The properties of the wire are $\rho = 8000$ kg/m^3, $c = 500$ J/kg · K, and $k = 20$ W/m · K.