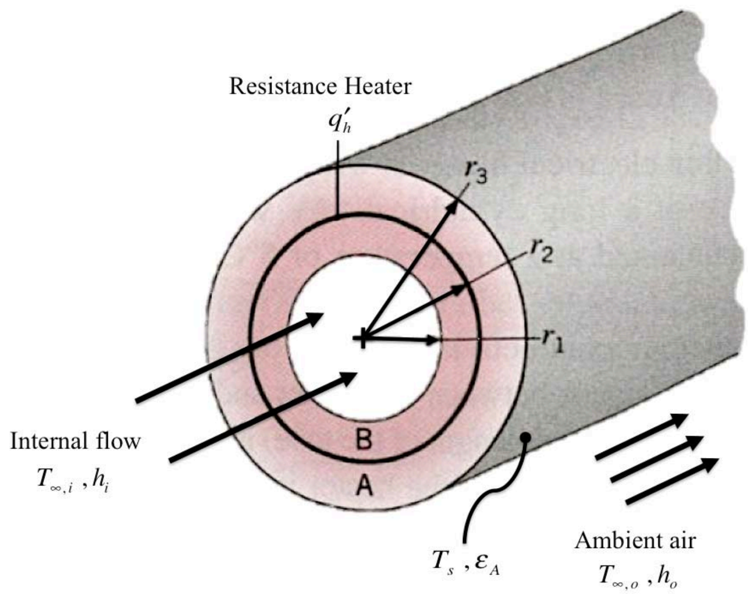
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF MECHANICAL ENGINEERING

2.051 Introduction to Heat Transfer

Quiz 1 – Review Problems

Problem 1 :



A composite cylindrical wall is composed of two materials of thermal conductivity k_A and k_B, and are separated by a very thin, electric resistance heater at radius r_2. The resistance of the heater and the interfacial contact resistances between the heater and materials A and B are negligible. Liquid at temperature $T_{\infty,i}$ is pumped through the tube and provides a convection coefficient h_i at the inner surface (radius r_1) of the composite. The outer surface (radius r_3) has an emissivity of ε_A and is maintained at temperature T_s. The temperature of the air is $T_{\infty,\square}$, which is of the same order of magnitude as T_s , and the convective heat transfer coefficient between the outer surface and ambient air is h_o. Under steady-state conditions, a uniform heat flux per unit length of the cylinder of q_h' (W/m) is dissipated by the heater.

Given parameters: k_A, k_B , h_i , h_o , ε_A , T_s , $T_{\infty,o}$, q_h' , r_1, r_2 , r_3

a) Draw the thermal resistance network for the heat transfer from the liquid to ambient air. Identify all the resistance elements and write down their expressions in terms of the parameters of the problem

b) (8 points) In terms of the given variables, determine the liquid temperature, $T_{\infty,i}$

Problem 2: Solar Power at Sea

Bonzo is designing new at-sea power systems involving a combination of solar, wind and wave power. In this problem, we study the solar component only and analyze two independent designs. For each design, we consider only the base system and steady operating conditions. The net solar radiation heat flux is assumed uniform in all incident directions, on average at $q_{rad} = 400$ W/m^2. The outside air is at temperature $T_\infty = 295$ K and its total heat transfer coefficient with solid aluminum is $h_\infty = 5$ W/m^2-K. The sea water is at temperature $T_w = 280$ K and its total heat transfer coefficient with solid PVC plastic is $h_w = 50$ W/m^2-K. The thermal conductivity of aluminum is $k_{al} = 235$ W/m-K and of PVC plastic $k_{pvc} = 0.35$ W/m-K.

Its base system (Fig. 1) consists of a half spherical shell made of aluminum (inner and outer radii: $r_i = 19$ m and $r_o = 21$ m), fixed on top of a hollow cylinder made of special PVC plastic (horizontal thickness $t_{pvc} = 0.1$ m). Both the half spherical shell and hollow cylinder are filled with air (total heat transfer coefficient $h_i = 3$ W/m^2-K). The system is dimensioned such that the spherical shell is above the waterline. You can neglect the heat transfer between the shell and cylinder where they are in direct contact, at the edges of the shell (see Fig. 1: this is because of contact resistances and of the small relative area of this contact).

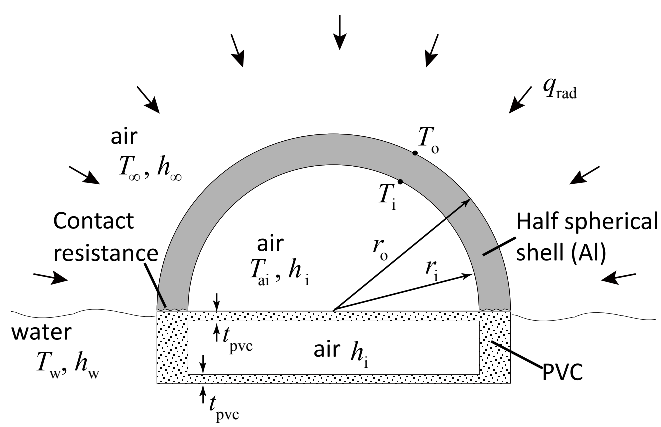


Fig 1: Cross-section in base system of design I (half spherical shell on top of hollow cylinder), not to scale.

a) To model this design I, draw the relevant heat transfer resistance diagram and determine the values of the resistances needed to determine the external temperature T_o of the half spherical shell (*Hint: a half spherical shell has a radial resistance equal to half that of a full spherical shell*).
b) What is this external temperature T_o?
c) What is the heat transfer rate $\dot{Q}_w$ from the air inside of the half spherical shell to the sea water?
d) What is the temperature Ta_i of the air inside the half spherical shell? (Note: the difference between this Ta_i and the water temperature T_w could be used by a power-generating cycle).

Problem 3

The fuel for a certain nuclear power station consists of cylindrical pellets of 0.48-cm radius, made of slightly enriched uranium dioxide (UO_2). Heat is "generated" by nuclear fission within these pellets at a uniform rate, $\dot{q}_{gen}$ = 24 W/g and is conducted out to the reactor coolant.

a) Calculate the radial distribution of the temperature within the pellet. The outer surface of the pellet is at 400°C. The axial and azimuthal dependence of the temperature can be neglected. Assume steady-state operation.
b) What is the maximum temperature within the pellet?

The thermal conductivity of UO_2 is 3 W/m-K. The density of UO_2 is 10.4 g/cm^3. The radial part of the Laplace operator in cylindrical coordinates is $\nabla^2 T = \frac{1}{r}\frac{d}{dr}\left[r\frac{dT}{dr}\right]$

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