Fall 2009 Qualifying exam

Heat transfer

Closed book exam
The three problems must be worked out
Box all answers

Allotted time: 2 hours

Problem 1:

A thin-walled copper sphere of radius r_i and at temperature T_i is used to transport a chemical at a temperature less than that of the ambient air at T_∞ around the sphere. An insulation of thickness $r - r_i$ and thermal conductivity k is added around the copper sphere. Let h be the external convective heat transfer coefficient around the sphere.

Consider the following data:

Copper sphere radius:	$r_i = 4$ cm
External convective heat transfer coefficient:	$h = 3$ W/(m^2.K)
Insulation thermal conductivity:	$k = 0.18$ W/(m.K)

1. The critical radius of insulation r_c is defined as the outer radius of the insulation for which the total thermal resistance is minimum.

   Calculate its numerical value. Give all the details of your calculations.

2. Calculate the numerical value of the convective resistance of the bare sphere.

3. Calculate the numerical value of the total resistance for an infinite thickness of insulation.

4. What is the optimum thickness of insulation?

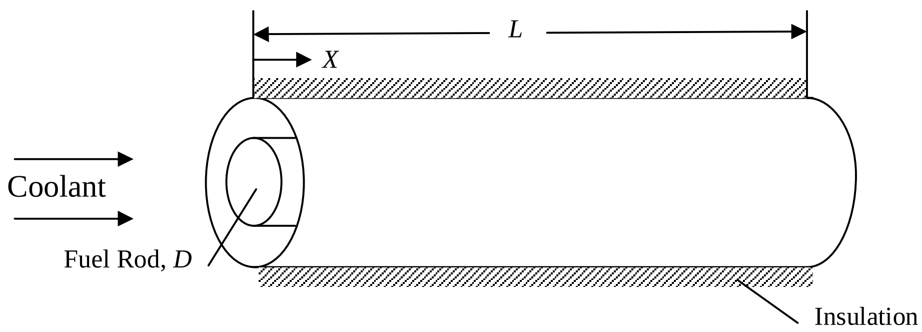
Important:

- Define clearly all your symbols.
- Give the symbolic expressions before inserting any numerical value.

Problem 2:

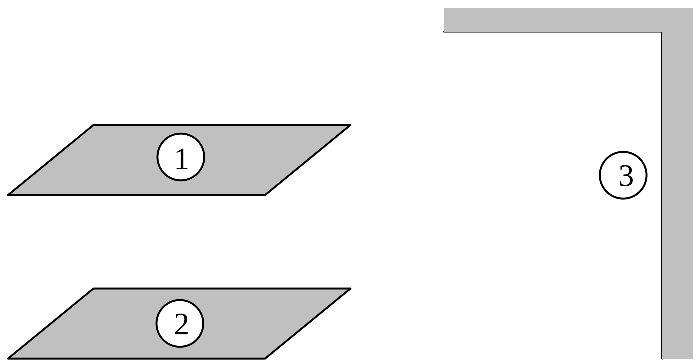
A nuclear fuel rod of length L and diameter D is encased in a concentric tube. Water flows through the annular region between the rod and the tube at a rate of $\dot{m}$. The outer surface of the tube is well insulated. Heat generation occurs in the fuel rod. The volumetric generation rate is known to vary sinusoidally with distance along the rod and is given by $\dot{q}(x) = \dot{q}_0 \sin\left(\frac{\pi x}{L}\right)$ where $\dot{q}_0$ (in W/m^3) is a constant. A uniform convection coefficient h may be assumed to exist between the surface of the rod and the water.

a) Obtain expressions for the local heat flux $q''(x)$ and the total heat transfer q from the fuel rod to the water.
b) Obtain an expression for the variation of the mean temperature $T_m(x)$ of the water with distance x along the tube.
c) Obtain an expression for the variation of the rod surface temperature $T_s(x)$ with distance along the tube.
d) Develop and expression for the x location at with the surface temperature from part c) is maximum.



Problem 3:

Two parallel plates 0.5 by 1.0 m are spaced 0.5 m apart, as shown in the figure. Plate 1 (emissivity $\varepsilon_1 = 0.2$) is maintained at $T_1 = 1000\,°C$ and plate 2 (emissivity $\varepsilon_2 = 0.5$) at $T_2 = 500\,°C$. The plates are located in a very large room, the walls of which are maintained at $T_3 = 27\ °C$. The plates exchange heat with each other and with the room, but only the plate surfaces facing each other are to be considered in the analysis.



1. Calculate the view factors F_{12}, F_{13} et F_{23}. The view factors for aligned parallel plates are given in the figure below.

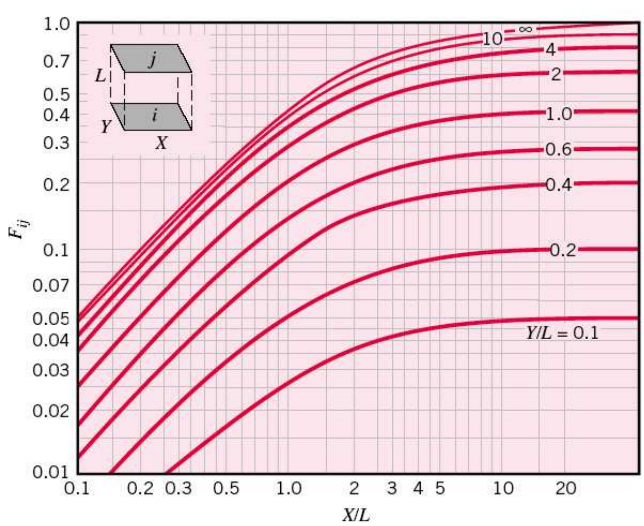


FIGURE 13.4 View factor for aligned parallel rectangles. **(from Incropera *et al*.)**

2. Draw the radiation network between the three surfaces.

3. Determine the numerical values:

   - of the surface and space resistances,
   - of the emissive powers of the three surfaces,
   - of the radiosities of surfaces 1 and 2,
   - of the heat rate lost by surface 1,
   - of the heat rate lost by surface 2,
   - of the heat rate received by surface 3.

Important:

- Define clearly all your symbols.
- Give the symbolic expressions before inserting any numerical value.
- Stefan-Boltzmann constant: $\sigma = 5.67 \times 10^{-8}$ W/(m^2.K^4).