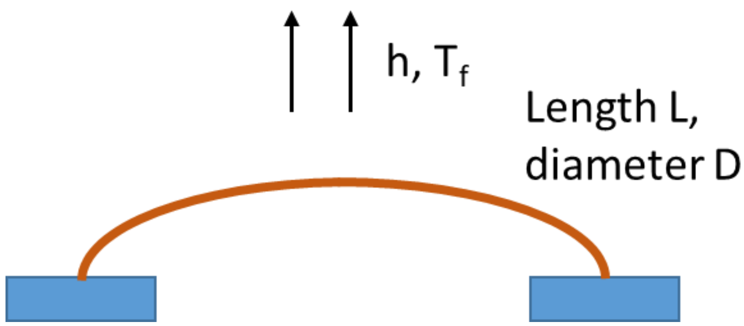
PhD Qualifying Exam
Heat Transfer, Written Exam

Problem 1

A copper interconnect of length L, diameter D, and thermal conductivity k connects two chips at a temperature of T_c, which is higher than the ambient temperature T_f. A constant current of I passes through the interconnect. If the electrical resistivity of the interconnect is ρ_e :

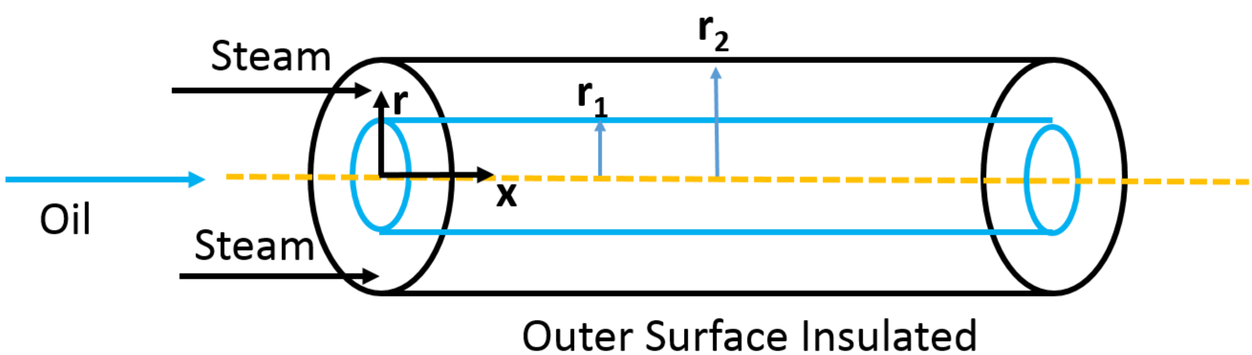
1. (50%) Develop a suitable equation and boundary conditions to determine the temperature variation in the interconnect.
2. (50%) Determine an expression for the maximum temperature and its location.



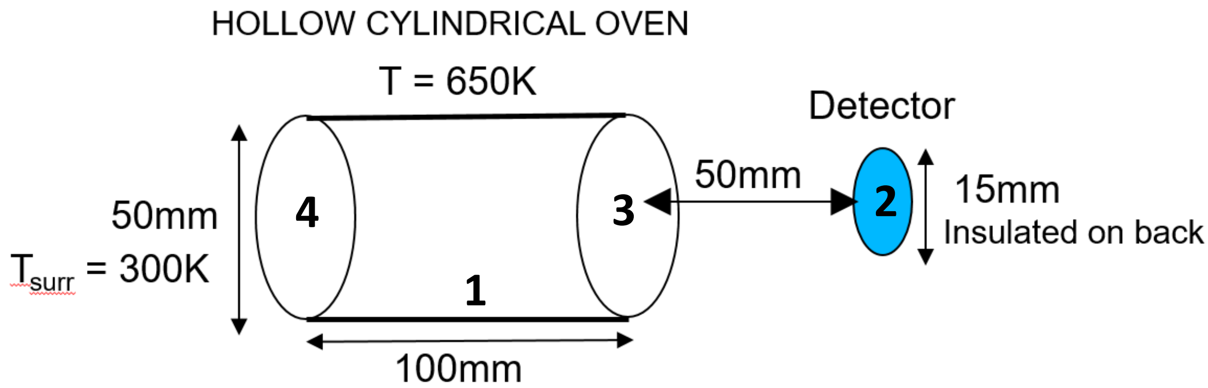
Problem 2

Oil is flowing inside a tube of radius r_1 and heated by steam flowing through the annular channel whose outer radius is r_2. The mass flow rate of oil is $\dot{M}o$ and specific heat is C_o and mass flow rate of steam is $\dot{M}s$ and specific heat is C_s. The temperature difference between steam and oil is ΔT_1 at entrance and ΔT_2 at exit. For both oil and steam, it can be assumed that flow is thermally and hydraulically fully developed. Axial conduction and viscous dissipation are negligible and fluid properties can be assumed as constant for both fluids. The outer surface of annular channel is insulated. Thickness of inner tube is t, length is L and its thermal conductivity is k.

a) Plot the mean temperature for both oil and steam along the pipe length. (**1 points**)
b) State your assumption and by performing energy balance across an appropriate control volume, derive an expression for total rate of heat transfer for the pipe in terms of ΔT_1, ΔT_2. (**6 points**)
c) If steam starts condensing at the inlet of annular tube and it can be assumed that the mean temperature of the condensing steam is constant along the length of tube, how will you compute total rate of heat transfer from steam to oil using an expression derived in part (b). Heat transfer coefficient of condensing steam can be assumed constant. (**3 points**)



Problem 3

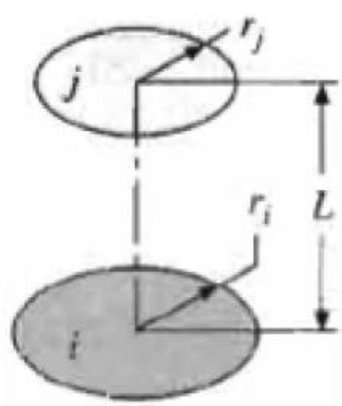


Consider the cylindrical oven (surface 1) shown above which is black and at a constant temperature of 650K, open at both ends (surfaces 3 and 4) to surroundings at 300K. A detector of circular shape (surface 2) is placed a distance of 5cm away from the oven on the center axis of the cylinder. The detector is opaque diffuse and gray with emissivity 0.5.

Assume uniform irradiation, steady-state, and neglect convection heat transfer.

1. Calculate the view factor between the detector disk and the oven cylinder (F_{12}).
   - If you cannot find F_{12} and you need it for solving the rest of the problem, assume a realistic value for your calculations.
2. Calculate the irradiation incident on the detector (assume that oven surface is much smaller than the surroundings, i.e., $A_1 << A_{surr}$, and treat the surroundings as a black body at T_{surr}).
3. If the detector is insulated on the back, find the radiosity for the detector (surface 2)
4. Determine the emissive power and temperature of the detector.

Coaxial Parallel Disks (Figure 13.5)



$$R_i = r_i/L, \; R_j = r_j/L$$

$$S = 1 + \frac{1 + R_j^2}{R_i^2}$$

$$F_{ij} = \frac{1}{2}\{S - [S^2 - 4(r_j/r_i)^2]^{1/2}\}$$