GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam – Fall Semester 2010

________HEAT TRANSFER_______

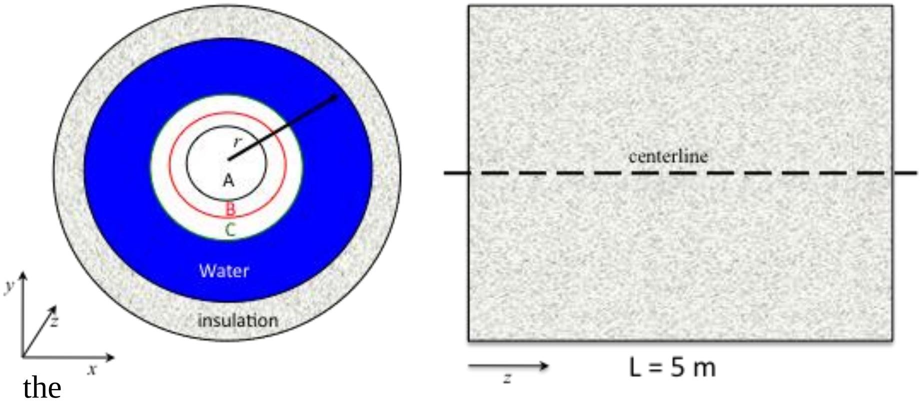
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

✷ Please sign your **name** on the back of this page —

1. Fully developed water flow at a rate of 1 g/s is used to cool a solid rod of nuclear material. The heat transfer coefficient for the water flow is h = 1000 W/m^{2}K (assume a constant cp = 4184 J/kgK for water). The water enters the cooling tube at 10°C. The rod is coated with a bilayer, ceramic composite material to prevent nuclear material from leaking into the cooling water. The thermal conductivities and dimensions of the rod (A) and the two layers of the composite (B and C) are given below (r_A is the radius of the rod and t_B and t_C are the thicknesses of materials B and C, respectively). Contact resistance between B and C is negligible; yet a contact resistance of $R''_{t,c}$= 0.01 m^{2}K/W exists between materials A and B. For Case 1, thermal energy is generated within material A at a linear rate of (10,000×*z)* W/m^3 (*z* = 0 at the entrance to the cooling tube). For Case 2, now assume that material C is the nuclear material and that thermal energy is generated within material C at the rate of (10,000×*z)* W/m^3.

k_A= 0.24 W/mK,
r_A= 10 mm;
k_B= 0.13 W/mK,
t_B= 5 mm;
k_C= 0.50 W/mK,
t_C= 8 mm.



a) Determine the location and value of the maximum temperature in the system under steady-state conditions for Case 1.
b) Sketch the steady-state temperature distribution on T-r coordinates in the cross-section where the maximum temperature occurs for Case 1, showing the value of the maximum temperature, and intermediate temperatures, on the T coordinate.
c) Sketch the steady-state temperature distribution along the axis of the point of maximum temperature in the system and for the cooling water on the same T-z coordinates.
d) Sketch qualitatively the steady-state temperature distribution on T-r coordinates in the cross-section where the maximum temperature occurs for Case 2.

1. Consider steady laminar flow of a viscous fluid in a parallel plate channel, with plate spacing 2b. The fluid enters the channel at an inlet temperature of T_i and the plates are supplied heat at a uniform flux of q_s''. Due to a chemical reaction in the fluid, heat is generated at a volumetrically uniform rate of q_o'''. Assume the flow to be fully developed, and axial conduction to be negligible.

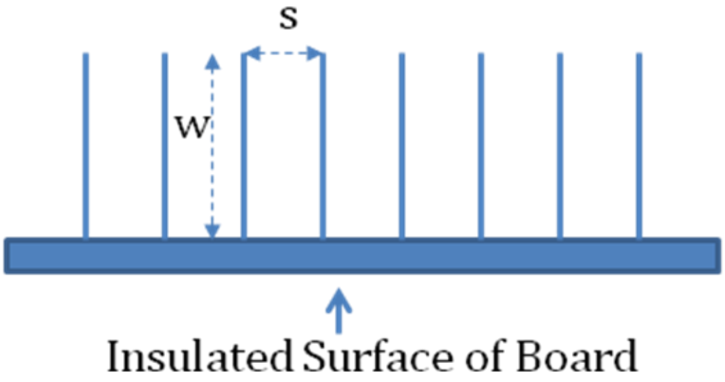
   1. (30%) Schematically show the temperature profile in the fluid at two downstream locations, x_1 and x_2. Provide the conditions to achieve a thermally fully developed condition. Illustrate the temperature profile at two locations, x_3 and x_4, once this condition is achieved. Point out any invariant features in these profiles.
   2. (50%) Develop an expression for the temperature profile in the fluid under the fully thermally developed condition.
   3. (20%) Provide the formulation necessary to calculate the Nusselt number. Do not solve.

2. Long parallel plate heaters are mounted on an insulating board to provide room heating. A heating element is inserted in each of these plates which dissipates power, q', per unit length of the plate. The width of these plates is w = 80 mm and the distance between two plates is s=20 mm (see figure below). The emissivity of the board surface is $\varepsilon = 0.5$ and the exposed surface of the heating plates has spectral emissivity of $\varepsilon_\lambda = 0.6$ for $\lambda < 5$ µm and $\varepsilon_\lambda = 0.4$ for $\lambda > 5$ µm. The ambient air and surrounding can be assumed to be at constant temperature of 300 K.

(A) As a first approximation, neglect the convective heat transfer experienced at the surfaces of this system and compute the power which need to be supplied to each plate in order to maintain it at uniform surface temperature of 400 K. List all your assumptions.

(B) How will you estimate q' of the insulated board if convective heat exchange with the air stream can't be neglected. Assume that T remains 400K. A constant convection coefficient of 10 W/m^{2}K can be assumed at all surfaces of this heating system for the convective heat exchange with the ambient air stream.

(C) How would the analysis change if there is no forced convection and natural convection has significant effect in the heat exchange?



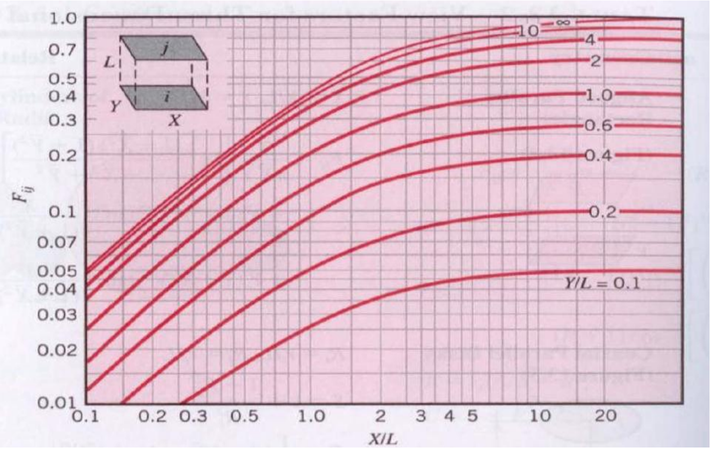
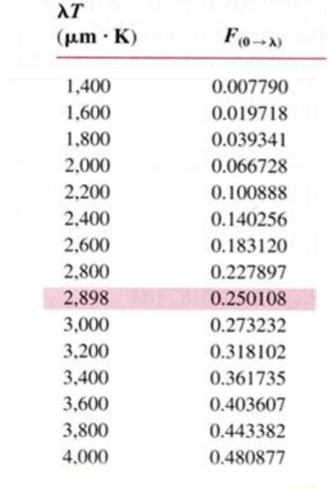


Figure : The view factor for aligned parallel rectangles.

Blackbody Radiation Functions



λT (μm · K)	$F_{(0 \to \lambda)}$
1,400	0.007790
1,600	0.019718
1,800	0.039341
2,000	0.066728
2,200	0.100888
2,400	0.140256
2,600	0.183120
2,800	0.227897
2,898	0.250108
3,000	0.273232
3,200	0.318102
3,400	0.361735
3,600	0.403607
3,800	0.443382
4,000	0.480877