GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Spring Semester 2001

Heat Transfer
EXAM AREA

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

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

Heat Transfer

Question 1

A very long, solid copper wire (thermal conductivity k_c) of length L and outside radius r_1 has uniform generation per unit volume q''' throughout its volume. The wire is covered with a plastic electrical insulation material (thermal conductivity k_I) of outside radius r_2. The heat transfer coefficient over the outside surface of the electrical insulation is h. Assume steady state.

a. On a single figure, sketch qualitatively the temperature distribution in the wire and in the insulation.

Use energy balances and rate equations to develop expressions for the following:

b. The magnitude and direction of the heat transfer rate per unit length at the outside surface of the insulation (q'_2).

c. An expression for the temperature at the outside surface of the electrical insulation.

d. An expression for the temperature at the interface between the wire and the insulation.

Question 2

An array of nine silicon chips, thickness 0.5mm, are located on a multi-chip module. Each chip is of length 10 mm and they are spaced 0.1mm apart. The thermal conductivity of silicon is 40 W/m-K and that of the alumina substrate (1mm thick) is 36 W/m-K. The module is air cooled from both sides. The maximum allowable chip temperature is 95 °C. The heat transfer from the surface is by natural convection and T_∞ = 20 °C. Assume equal and uniform power dissipation in each chip. Calculate the maximum allowable power generation for the chips for (1) horizontal oriented module and (2) vertically oriented module.

Assume the following properties for air:

$k = 30 \times 10^{-3}$ W/m-K $\quad \alpha = 29.9 \times 10^{-6}\ m^2/s \quad \nu = 20.9 \times 10^{-6}\ m^2/s$

$\beta = 2.86 \times 10^{-3} \quad Pr = 0.7$ and $g = 9.8\ m^2/s$

Useful equations:

Vertical Plate $$\overline{Nu_L} = \left[0.825 + \frac{0.387 Ra_L^{1/6}}{\left[1 + (0.492/\mathrm{Pr})^{9/16}\right]^{8/27}}\right]^2$$

Upper surface of heated plate or lower surface of cooled plate:

$$\overline{Nu_L} = 0.54 Ra_L^{1/4} \quad \text{for } 10^4 < Ra_L < 10^7 \qquad L = A/P$$

$$\overline{Nu_L} = 0.15 Ra_L^{1/3} \quad \text{for } 10^7 < Ra_L < 10^{11}$$

Lower surface of heated plate or upper surface of cooled plate

$$\overline{Nu_L} = 0.27 Ra_L^{1/4} \quad \text{for } 10^5 < Ra_L < 10^{10} \qquad L = A/P$$

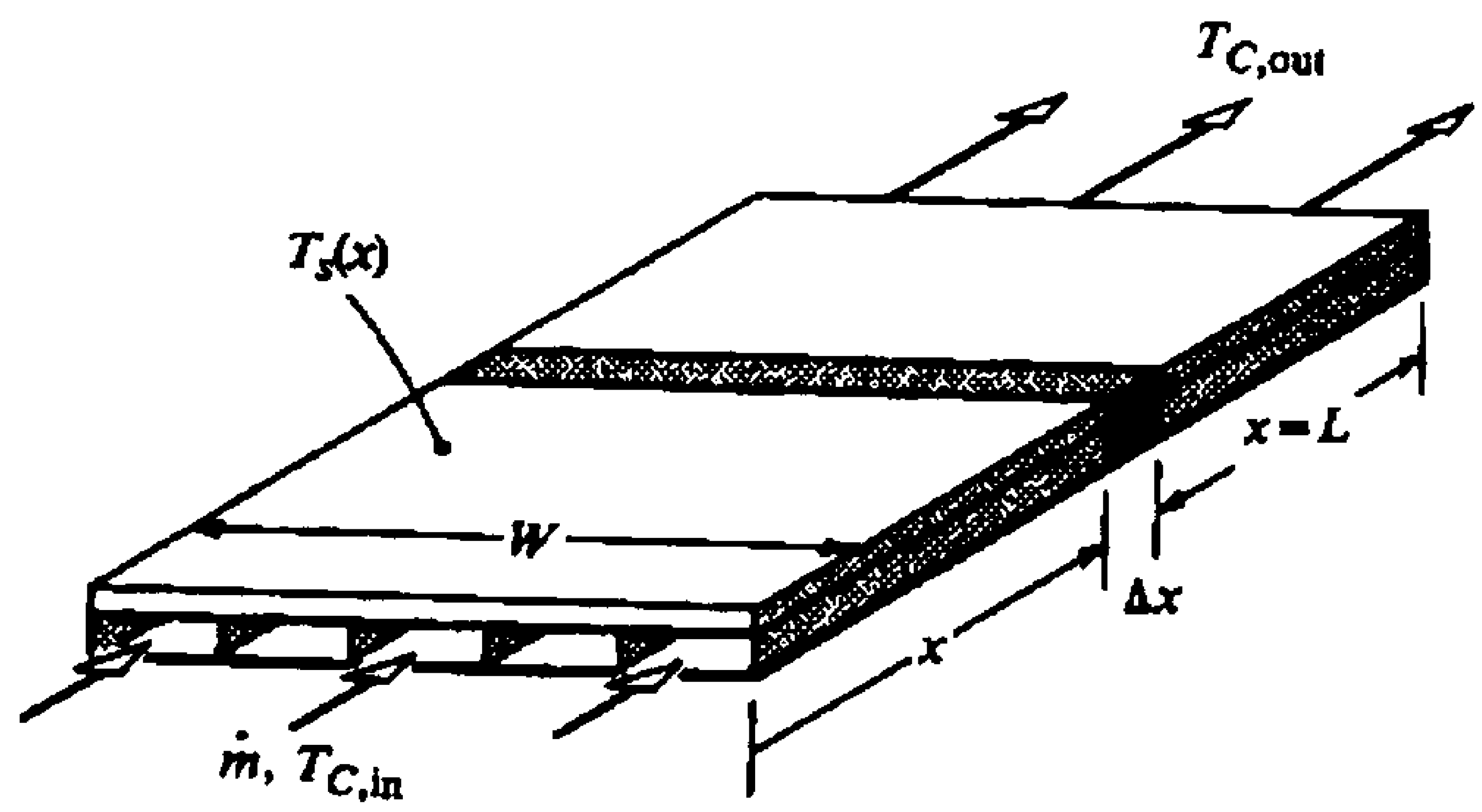
Question 3

The schematic below shows a flat-plate solar collector, which is used to heat water. It is 1 meter wide and 3 meter long and has no coverplate. The absorbing surface is selective, with an emittance of 0.14 and a solar absorptance of 0.93.

Water enters the collector at 25°C and a flow rate of 0.015 kg/s. Estimate (1) the outlet water temperature and (2) the collector efficiency (=ratio of heat transfer to the water to the radiation incident on the collector) at noon when the solar irradiation is 800 W/m^2 and the air temperature T_e is 20 °C.

Use a sky emittance of 0.6 and an overall heat transfer coefficient for heat transfer from the absorbing surface to the bulk water as U=25 W/m^{2}K. The relation $h_c=1.1(T_s-T_e)^{1/3}$ W/m^{2}K can be used to estimate the convective heat transfer from the absorbing surface to the ambient air. For the water, take c_p=4180 J/kg-K.

Formulate the problem in terms of relevant parameters, make <u>all</u> appropriate assumptions and <u>justify</u> them, state the boundary and initial conditions, and proceed as far as you can in finding an analytical solution to the problem.



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