GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1998

Heat Transfer
EXAM AREA

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

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

Please **p r i n t** your name here.

The Exam Committee will get a copy of this exam and will not be notified whose paper it is until it is graded.

Ph.D. Qualifying Examination in Heat Transfer
October 1998
All problems are equal credit

1.

a. Water at a mean temperature of $40°\ C$ flows over both sides of a refrigerated plate that is *10 cm* in length and held at a uniform temperature of $10°\ C$. The Reynolds number of the water at the end *(L=10cm)* of the plate is 1.6×10^5, the Prandtl number at the mean film temperature is *3.0* and fluid thermal conductivity at the mean temperature of the water is $k_f = 0.65\ W/m\text{-}C$. Select the most appropriate form of the equation for the local Nusselt number from the following correlations.

$$Nu_x = 0.332\ Re_x^{1/2}\ Pr^{1/3}$$

$$\text{or } Nu_x = 0.0296\ Re_x^{0.8}\ Pr^{1/3}$$

$$\text{where } Nu_x = (h_x x/k_f);\ Re_x = (Ux)/\nu$$

Determine the rate of heat transfer to the plate if the width of the plate is *0.5* meters.

b. An expert in the field suggests modifying the configuration stated in part (a) into 5 strips each that are *2 cm* in the flow direction by *50 cm* wide (assuring same total heat transfer surface area) and arranges them such that there will be spaces between each *2 cm* strip. Will this arrangement increase or decrease the heat transfer rate? Estimate the new value for the heat transfer rate from this modified geometry and express the result as ratio, using the results of part (a). Using your answer, explain whether the expert's suggestion will increase or decreates the heat transfer rate to the plate.

c. Sketch the thermal boundary layer thickness for these two cases depicted in parts (a) and (b), that is, δ_t *vs. x)* as well as local heat transfer coefficient, h_x *vs. x*. How can you use this sketch to further strengthen your explanation presented in part (b)?

d. If the strips indicated in part (b) are rotated 90 degrees so that the water is incident normal to the plane of the strips, will this arrangement have favorable or adverse effect on heat transfer? **No calculations please. Review changes in flow patterns and their consequence on the heat transfer coefficient and the heat transfer rate.**

e. If the source of refrigeration is turned off, all else being the same, how does this action affect the convective heat transfer coefficients you have estimated?

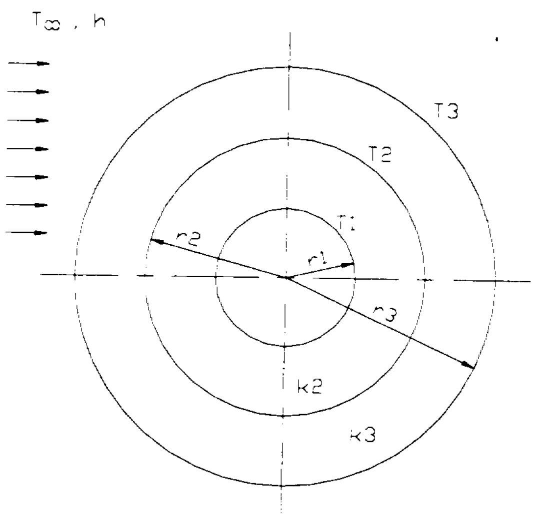
2.

The spherical container shown in the figure includes an empty sphere with radius r_1 at its center. Radioactive material that generates volumetric heat at the rate of $\dot{q}$ is stored in the shell with inner and outer radii r_1 and r_2, respectively. A metallic shell, with an outer radius r_3, covers the radioactive material. The outer surface of the container is cooled by water which is at temperature T_∞, with a convective heat transfer coefficient h.

Under steady-state, and assuming spherical symmetry and constant properties, derive expressions for T_1, T_2, and T_3.

The heat diffusion equation is:

$$\rho C \frac{\partial T}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}(kr^2 \frac{\partial T}{\partial r}) + \dot{q}$$



3.

A disk-shaped heating element of diameter D and thickness t is well-insulated on all surfaces except the top surface. A metallic, hemispherical cover (also diameter D) is placed cover the top of the heating element, and the covered heater assembly is placed in a large room. Room air (temperature T_∞) flows over the outside surface of the hemispherical over causing the convective heat transfer coefficient to be h. Convection inside the hemispherical space is negligible.

Assume that the power input to the heating element is known, that the walls of the room are in thermal equilibrium with the air, that all surfaces (heating element, cover, and room walls) are diffuse and gray, and that all surface radiative properties are known.

Show how one should estimate the temperature of the hemispherical cover. Justify all additional assumptions. Develop your solution from fundamental principles and energy balances, as appropriate.