CHE 260: THERMODYNAMICS AND HEAT TRANSFER

QUIZ FOR HEAT TRANSFER

24th NOVEMBER 2014

NAME:

STUDENT ID NUMBER:

Q1	Q2	Q3A	Q3B	Q3C	Total
15	20	5	5	5	50

Q.1. [15 points] NUSSELT NUMBER IN THE PURE CONDUCTION LIMIT

Consider a sphere of radius a whose surface is at a uniform temperature T_S . The sphere is placed in a fluid medium that is at a constant temperature T_∞ far away from the sphere. The thermal conductivity of the fluid is k_f . The fluid is stagnant far away from the sphere (there is no forced convection). If convection effects and radiation can be ignored, conduction is the only mechanism for heat transfer from the sphere surface into the fluid. There are no heat sources in the fluid. Answer the following questions:

(a) **[10 points]** Beginning from the energy conservation equation in the spherical co-ordinate system [see last page], determine the *steady-state* temperature distribution *in the fluid*. Specify the governing equations and boundary conditions clearly. Note that the domain for the governing equation will be $a \le r < \infty$, so boundary conditions have to be applied at $r = a$ and for $r \to \infty$.

(b) **[3 points]** Determine the radial heat flux, $\dot{q}_r$, at the surface of the sphere, $r = a$.

(c) **[2 points]** Calculate the heat transfer coefficient, h, if it is defined as

$$h = -\frac{\dot{q}_r\big|_{r=a}}{T_S - T_\infty}.$$

Hence, determine the Nusselt number for this heat transfer process, defined as

$$\mathrm{Nu} = \frac{ha}{k_f}.$$

2. [20 points] EXTENDED SURFACES

Use the resistance network approach to solve this problem.

An electronic device is in the form of a disk 20 cm in diameter and 2 mm in thickness. The electronic components on one face of this device dissipate 120W. The other face of the device is exposed to an airstream at 27^oC for which the convection coefficient is 60 W/m^2-^oC. The thermal conductivity of the device material is 10 W/m^oC.

(a) [4 points] What are the temperatures on the two faces of the device? The steady-state device temperature on the face with the electronic components is to be kept below 85^oC. Does the current configuration satisfy this condition? What is the dominant thermal resistance?

(b) [14 points] To improve the heat transfer rate, an aluminium fin block is glued to the device. The fin block (k = 237 W/m-^{o}C) comprises 512 cylindrical pins, each of diameter 2 mm and a length of 3 cm, attached to a circular aluminium base of 20 cm diameter and 3 mm thickness. With the addition of the fin block, the convective heat transfer coefficient is reduced to 40 W/m^2-^{o}C. Calculate the temperatures of the two faces of the device with the fin block. Also, calculate the effectiveness of the fin.

(c) [2 points] What is the maximum operating power with the attachment of the fin block, given the 85^{o}C temperature restriction on the face of the device with the electronic components?

3. **(a) [5 points]** Hot, spherical metal beads of size d = 100 μm and density ρ_S = 2,500 kg/m^3 are quenched in a cold fluid of density ρ_L =1,000 kg/m^3 and viscosity μ = 10^{-3} kg/m-s. The settling velocity, u_S, of the beads is given by Stokes law,

$$u_s = \frac{d^2}{18\mu}\left(\rho_S - \rho_L\right) g,$$

where g = 9.8 m/s^2 is the acceleration due to gravity. Will convection provide an important contribution to the cooling rate of the beads, if the thermal diffusivity of the fluid is 10^{-7} m^2/s?

(b) [5 points] Mr. X loves a specific type of soft cookie that is in the form of a cylindrical disc of 10 cm diameter and 2 cm thickness. He purchases the cookies from a departmental store, brings them home, and puts them in an oven at 250°C for 1 min. This produces a crust of thickness 5 mm on the top and bottom surfaces of each cookie, while maintaining the soft interior of the cookie. One day, he goes to the departmental store, only to find that the cookie company now supplies the same cookies, but at *half* the size: 5 cm diameter and 1 cm thickness. Reluctantly, he buys a batch and brings them home, and subjects these smaller cookies to a baking routine at the same temperature but for half the time- 0.5 min instead of 1 min. Will he get the same ratio of crunchy to soft layers in the cookie, if thermal diffusion controls the rate of crust formation? What should be the duration of the bake to get the same ratio?

(c) **[5 points]** In the textbook, it is emphasized that the fins are employed to increase the rate of heat transfer when the heat transfer coefficients are small, which is typically true for forced convection of air past a surface. Describe a situation where fins could increase the rate of heat transfer for convective heat transfer with liquids, where the heat transfer coefficients are typically much higher than for air.