CHE 260: THERMODYNAMICS AND HEAT TRANSFER

QUIZ #2

18th NOVEMBER 2013

NAME:

STUDENT ID NUMBER:

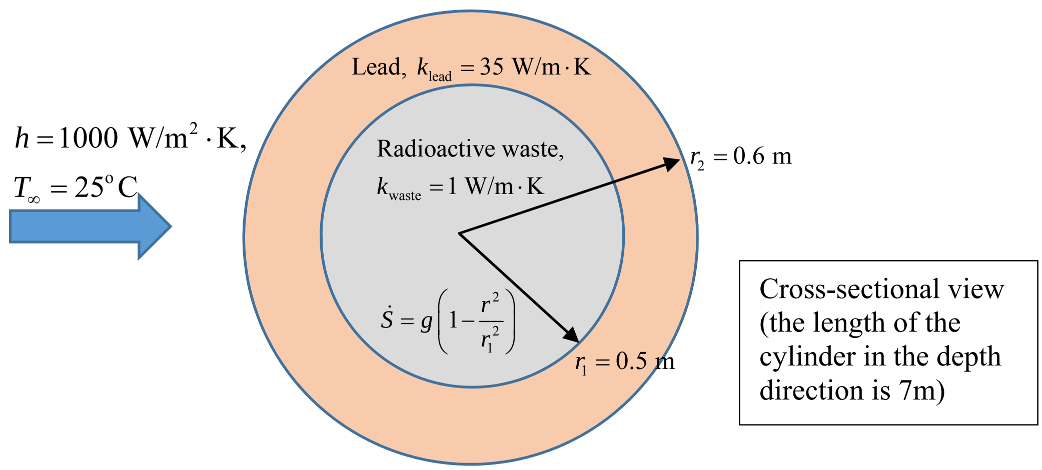
Q1	Q2	Q3	Q4A	Q4B	Q4C	Q4D	Total
25	25	25	5	5	5	10	100

INSTRUCTIONS

1. This examination is open textbook, open notes, but closed internet, closed all communication devices.
2. Please write legibly. If your handwriting is unreadable, your answers will not be assessed.
3. Answers written in pencil will NOT be re-marked. This is University policy.
4. For all problems, you must present the solution process in a step by step fashion for partial marks.
5. **Answers written on the blank, left sides of the answer book will not be assessed. Use the left sides for rough work only.**

Q.1. [25 points]

Solid radioactive waste (k_{waste} = 1 W/m·K) is packed inside a hollow, cylindrical lead container (k_{lead} = 35 W/m·K) with inner and outer diameters of 1.0 and 1.2 m, respectively. The length of the cylinder is 7 m. There is negligible thermal contact resistance at the boundary between the two phases. Thermal energy is generated within the waste material at a rate of $\dot{S} = g\left(1 - \frac{r^2}{r_1^2}\right)$ where g = 5 x 10^5 W/m^3, r is the radial co-ordinate measured from the center of the cylinder, and r_1 = 0.5 m is the inner radius of the container. The outer surface is exposed to water at 25°C, with a heat transfer coefficient of 1000 W/m^2·K.



Answer the following questions:

(a) Starting with the main heat conduction equation [see end of question booklet for this], for steady state conditions, write down the governing equations and boundary conditions for the temperature distributions in the radioactive solid phase, and the lead shell. Assume negligible contact resistance between the radioactive solid and the lead shell.

(b) Determine the rate of heat transfer at steady state from the outer surface of the container at steady state.

(c) Derive the steady-state temperature distributions in the radioactive waste, and in the lead shell. Evaluate the temperature at the center of the cylinder.

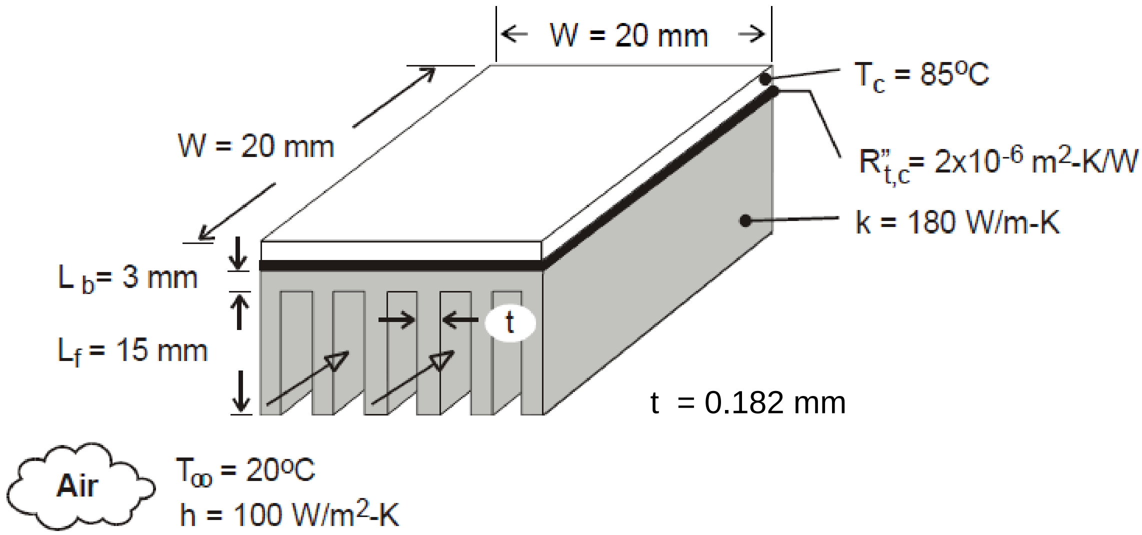
(d) Evaluate the temperature at the inside surface of the lead shell. If the melting point of lead is 323°C, is the choice of lead as the shell material a good design choice?

Q.2. [25 points]

A spherical cryosurgical probe may be embedded in a diseased tissue for the purpose of freezing and destroying the tissue. Consider a probe of 3 mm diameter whose surface is maintained at -30°C when embedded in a tissue at 37°C. At steady state, a spherical layer of frozen tissue forms around the probe at a temperature of 0°C existing at the phase front between the frozen and normal tissues. If the thermal conductivity of frozen tissue is approximately 1.5 W/m-K, and heat transfer at the phase front may be characterized by an effective convection coefficient of 50 $W/m^2 \cdot K$, what is the thickness of the layer of frozen tissue (assuming negligible perfusion)? [**Hint:** Draw a picture of the situation first. This problem is not longer than a few lines if you think about it right. Use a resistance approach to set it up. You should get a quadratic equation for the thickness of the frozen tissue; pick the physical root.]

Q.3. [25 points]

A square isothermal silicon chip of width $W = 20$ mm is soldered to a square aluminum heat sink ($k = 180$W/m·K) of equivalent width. The heat sink has a base thickness of $L_b =$ 3 mm and an array of 11 rectangular fins, each of length $L_f = 15$ mm and a fin thickness of $t = 0.182$ mm. Air flow at $T_\infty = 20$°C is maintained through channels formed between the fins, which results in a convection coefficient of $h = 100$ W/m^2·K. The solder joint has a thermal contact resistance of $R''_{t,c} = 2\times10^{-6}$ m^2·K/W.



If the maximum allowable chip temperature is 85°C, what is the corresponding value of the chip power $\dot{Q}$? Use the resistance approach.

Q.4A. [5 points]

A hot liquid produced in a microfluidic reactor is transported using a plastic tube to a storage chamber. Currently, a tube with the inner diameter (ID) of 1.5 cm and a wall thickness of 0.1 cm is being used for this transport. (The wall thickness is the difference between the outer and inner radius of the tube). However, this tube is found to be inadequate in restricting the heat loss, and the tube wall thickness needs to be increased to improve the insulation. A tube vendor provides tubes of the same wall material with the desired 1.5 cm ID, but with three other wall thicknesses: 0.2 cm, 0.3 cm and 0.4 cm. If radiation effects are negligible, as a heat transfer engineer, which tube would you pick? You must justify your choice to get credit. Take the thermal conductivity of the plastic to be 0.1 W/m·K, and the heat transfer coefficient due to natural convection in air to be 10 $W/m^2 \cdot K$.

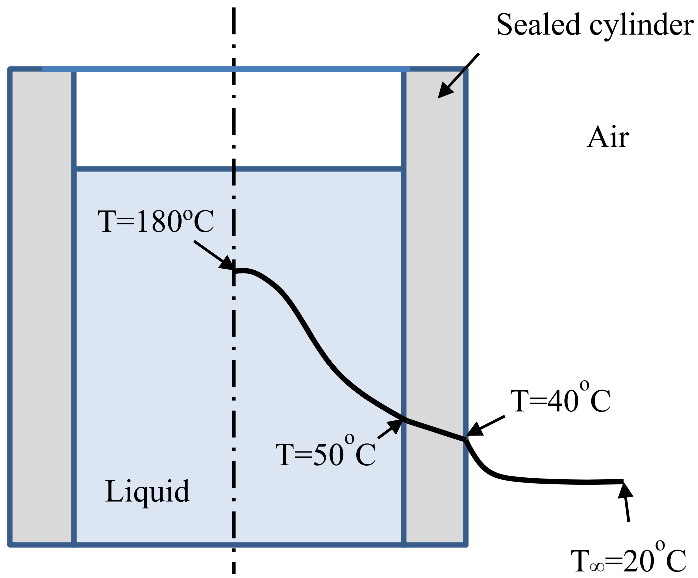
Q.4B. [5 points]

In an experiment to measure the thermal conductivity of a polymeric liquid, a concentric cylindrical cell with heaters contacting the inner and outer cylindrical surfaces is used. Due to the temperature gradients, circulation currents are setup in the cell, with a velocity of 2 mm/min. The scientists performing this experiment claim that these convection currents are so weak that their influence on the heat transfer process is negligible; hence they are truly measuring conductive heat transfer in the cylindrical gap. Would you trust the thermal conductivities reported from such an experiment? Explain why/why not. The gap between the cylinders is 2 cm. The density of the liquid is 1000 kg/m^3, its specific heat capacity is 2500 J/kg·K, and the true thermal conductivity of the liquid is 0.3 W/m·K.

Q.4C. [5 points]

The diurnal cycle (the cycle of day and night) heats and cools the earth's surface. Obtain an approximation for the depth of penetration of the thermal front into the earth's crust due to this cycle. Take the thermal diffusivity of earth's crust to be 1 mm^2/s.

Q.4D. [10 points]



(The temperature profile is shown only on the right half of the picture. The cylinder is axisymmetric)

You are working in a chemical manufacturing facility. In one manufacturing step in this facility, a hot liquid is cooled down in a sealed, cylindrical vessel from a temperature of T_0 = 200°C to room temperature. According to the existing practice in the facility, the liquid in the cylinder is left stagnant (unmixed), and cooling occurs due to natural convection in the air external to the cylinder. The liquid itself is highly viscous, and natural convection within the liquid can be neglected as a heat transfer mechanism.

Your boss is interested in speeding up the rate of cooling. A senior engineer in your group suggests during a group discussion that if you switched from natural to forced convection on the outside by adding some blowing fans, you can improve the rate of heat transfer. Before suggesting this idea to your boss, you measure the temperature profile in the system some time after the hot liquid is loaded, and it appears as shown in the figure (assume that this profile is the same across the depth of the cylinder). Neglect radiation in this problem, and answer the following questions:

(a) Going by your knowledge of the relationship between temperature profiles and thermal resistances, would you accept the senior engineer's suggestion? Why/Why not?

(b) What would be your suggestion to improve the rate of heat transfer? Why?