Birla Institute of Technology and Science Pilani
K. K. Birla Goa Campus
Mid-Semester Examination 2022-23

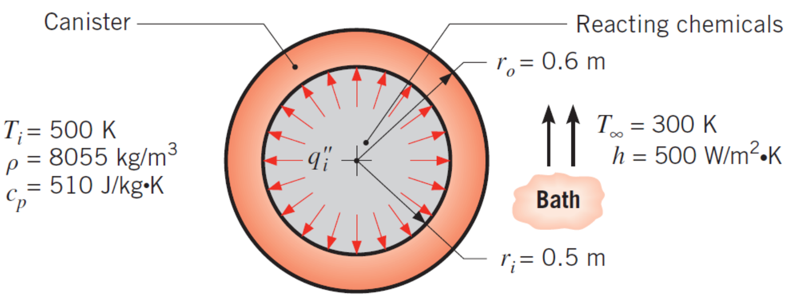
Heat Transfer (ME F220)

Date: 14-03-2023 Time: 11.00 AM - 12.30 PM Total Marks: 60

Instruction:

- All questions are compulsory.
- Answer all parts of the question in the same place and start each question in a new page.
- Symbols have their usual meaning.
- Make suitable assumptions whenever necessary. Please state your assumptions clearly.

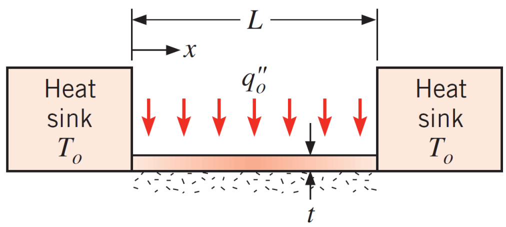
Q 1. A spherical, stainless steel (AISI 302) canister is used to store reacting chemicals that provide for a uniform heat flux q_i'' to its inner surface. The canister is suddenly submerged in a liquid bath of temperature $T_\infty < T_i$, where T_i is the initial temperature of the canister wall.



(a) Assuming negligible temperature gradients in the canister wall and a constant heat flux, develop an equation that governs the variation of the wall temperature with time during the transient process. What is the initial rate of change of the wall temperature if $q_i'' = 10^5$ W/m^2? [10]

(b) What is the steady-state temperature of the wall? [2]

Q 2. A thin flat plate of length L, thickness t, and width $W \gg L$ is thermally joined to two large heat sinks that are maintained at a temperature T_0. The bottom of the plate is well insulated, while the net heat flux to the top surface of the plate is known to have a uniform value of q_0''.



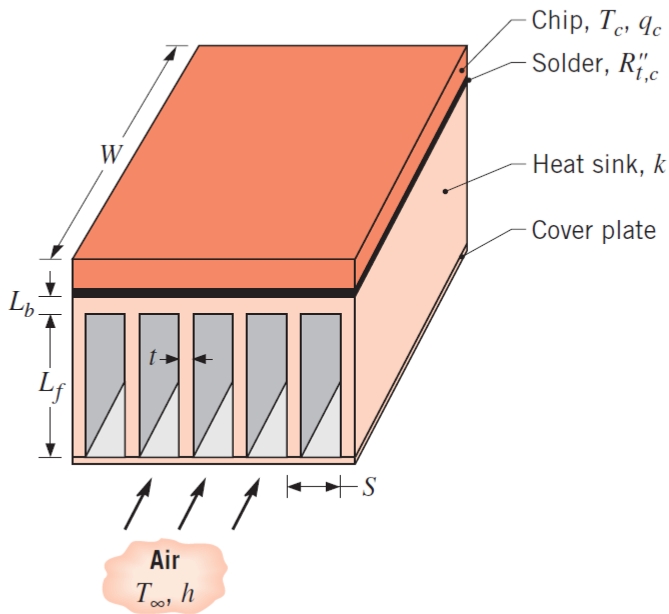
(a) Derive the differential equation that determines the steady-state temperature distribution $T(x)$ in the plate. [6]

(b) Solve the foregoing equation for the temperature distribution, and obtain an expression for the rate of heat transfer from the plate to the heat sinks. [6]

Q 3. (a) During a heat treatment process, copper spheres of diameter d are heated to T_i in a furnace and then suddenly cooled to an airstream at a temperature $T_\infty < T_i$. The spheres cool due to the convection heat transfer at the solid-liquid interface with a convection coefficient h. Assuming negligible temperature gradients in a sphere, derive the expression for the time t required to cool the sphere from its initial temperature T_i at $t = 0$ to some temperature T. [6]

(b) Consider a sphere of 10 mm diameter is heated to 75 °C and then cooled in an airstream at 23 °C with a velocity of 10 m/s. The convection heat transfer coefficient between the sphere and the air is 116 $W/m^2 \cdot K$. Estimate the time required to cool the sphere to a temperature of 30 °C using the expression derived in part (a). The properties of the copper are $\rho = 8933\,kg/m^3$, $C_p = 387\,J/kg \cdot K$ [6]

Q 4. An isothermal square silicon chip of width $W = 20\,mm$ on a side is soldered to an aluminum heat sink ($k = 180\,W/m \cdot K$) of equivalent width. The heat sink has a base thickness of $L_b = 3\,mm$ and an array of rectangular fins ($N = 11$ fins, and thickness $t = 0.182\,mm$), each of length $L_f = 15\,mm$. Airflow at $T_\infty = 20\,°C$ is maintained through channels formed by the fins and a cover plate, and for a convection coefficient of $h = 100\,W/m^2 \cdot K$, a minimum fin spacing of 1.8 mm is dictated by limitations on the flow pressure drop. The solder joint has a thermal resistance of $R''_{t,c} = 2 \times 10^{-6}\ m^2 \cdot K/W$. If the maximum allowable chip temperature is $T_c = 85\,°C$, what is the corresponding value of the chip power q_c? Assume adiabatic fin tip condition. The efficiency of a fin with adiabatic tip is $\eta_f = \tanh(mL)/mL$. [12]



Q 5. Answer the following in ONLY One -Two sentences:

(a) Explain the difference between steady state and thermal equilibrium. [2]

(b) What is the critical radius of insulation? How is it defined for a cylindrical layer? [2]

(c) Hot water is to be cooled as it flows through the tubes exposed to atmospheric air. Fins are to be attached to enhance heat transfer. Would you recommend attaching the fins inside or outside the tubes? Why? [2]

(d) What is a semi-infinite medium? Give examples of solid bodies that can be treated as semi-infinite mediums for heat transfer purposes. [2]

(e) Derive an expression for skin layer thickness δ for a semi-infinite body subjected to a sudden change in the surface temperature. [2]

(f) Explain when to use the lumped capacitance model, exact solution, and semi-infinite solid approximation based on the dimensionless numbers that describe transient conduction, namely the Biot number (Bi) and the Fourier number (Fo). [2]