# INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
## Mid-Autumn Semester 2019-20

Date of Examination: **18-09-2019** Session: **AN** Duration: **2 hrs** Full Marks: **60**
Subject No. : **ME30005** Subject : **Heat Transfer**
Department/Center/School: **Mechanical Engineering**
Specific charts, graph paper, log book etc., required: **Nil**
Special Instructions (if any): **Answer all questions**

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**1.** A double pane glass window as shown in the figure is used in a passenger train compartment. The space between the glass panes is perfectly evacuated. The design outside and inside air temperatures are **45°C** and **25°C**, respectively. The convective heat transfer coefficient between outside air and outer glass is **30 W/m².K**, while it is **8 W/m².K** between the inner glass and indoor air. The glass panes are **6 mm thick** and their thermal conductivity is **1.16 W/m.K**. To reduce the heat transfer rate across the window, inner surfaces of the glass are treated so that they have an emissivity ε. **a)** What should be the value of this emissivity so that the heat transfer rate per unit area across the window under the design conditions is not more than **60 W/m²**? **b)** Discuss with the help of a resistance network, what changes have to be made in the analysis, and what happens to the heat transfer rate, if over a period of time, the vacuum between the glass panes breaks and is filled with air. State clearly all the assumptions made. Take the value of Stefan-Boltzmann Constant, $\sigma = 5.67 \times 10^{-8}$ **W/m².K⁴**. **(10)**

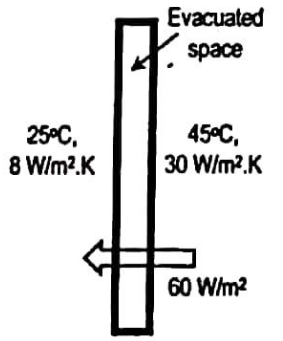

Figure for Problem 1

**2.** The handle of a tea kettle is made out of a stainless steel rod (**k = 15 W/m.K**) of **1 cm.** diameter and its length (**L**) is **30 cm** (see the figure). Find: a) whether the length of the handle provided is sufficient to ensure that **it does not cause pain** to the **human hand** that holds the tea kettle. Studies show that human beings experience **pain** if the **skin temperature exceeds 40°C**, b) Also find the **heat transfer rate** from the handle to the surroundings. The temperature of water that boils in the tea kettle is **90°C**, the surrounding air temperature ($T_\infty$) is **30°C** and the heat transfer coefficient (**h**) between air and the tea kettle is **10 W/m².K**. Assume the **tip** of the handle to be perfectly insulated. **State clearly all the assumptions made.** For the extended rod with adiabatic tip, the temperature distribution is given by the following equation: **(10)**

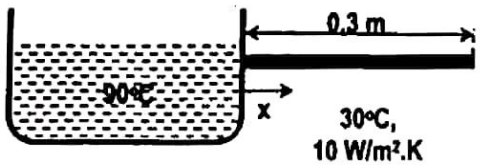

Figure for Problem 2

$$\frac{T_x - T_\infty}{T_{x=0} - T_\infty} = \frac{cosh[m(L-x)]}{cosh[mL]}; \quad where\ m = \sqrt{\frac{hP}{kA}}$$

P is the perimeter and A is the cross sectional area of the rod.

3. The porosity or void fraction (ε) of a porous medium is defined as the ratio of the volume of the void phase to the total volume. Show that for a porous medium having porosity ε, and the void spaces filled with a fluid of thermal conductivity $k_f$, the effective thermal conductivity ($k_e$) of the porous medium in the direction of heat flow will lie between $\varepsilon k_f + (1-\varepsilon)k_s$ and $\left(\varepsilon/k_f + (1-\varepsilon)/k_s\right)^{-1}$ where $k_s$ is the thermal conductivity of the solid phase. **(10)**

4. A body of volume $V$, surface area $A$, density ρ and specific heat $C_p$ is initially at a temperature $T_o$. The body is immersed at $t=0$ in a fluid reservoir at $T_o + \Delta T$. At time $t = t_1$ it is taken out from the hot fluid reservoir and plunged into a cold reservoir which is at $T_o - \Delta T$. Derive an expression for time $t_2$, when the body returns to its original temperature $T_o$. Show that the time spent by the body in the cold fluid ($t_2$) can never be greater than the time spent by the body in the hot fluid ($t_1$). Assume the heat transfer coefficient to be the same for both reservoirs and Biot number, Bi < 0.1. **(10)**

5. Starting from fundamental equations, derive the governing, steady heat conduction equation for a square plate shown in the figure. Using the method of Separation of Variables, obtain the expression for temperature distribution, T(x,y). Explain how the heat transfer from the plate can be calculated from T(x,y). Assume constant properties and no internal heat generation. **(10)**

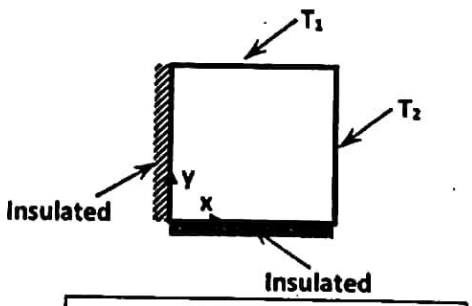

Figure for Problem 5

6. Using a linear velocity profile, $\frac{u}{u_\infty} = \frac{y}{\delta}$ for flow over a flat plate, obtain an expression for the velocity boundary layer thickness (δ) as a function of x.

If the heat transfer correlation is given in the form of $Nu_x = CRe_x^n f(Pr)$, obtain an expression for the ratio of heat transfer coefficients, $\frac{\bar{h}}{h_{x=L}}$ in terms of C and n. Note that all the symbols used here have the usual meaning. **(10)**

**End of the question paper**