Indian Institute of Technology, Kharagpur

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| Date of Examination: | Time: 2Hrs. Full Marks 60 |
| Mid Semester Exam. 2010 | **3th Yr (BTech+Dual Degree) ME/MF** |
| Sub No. ME30005 | Sub Name: **Heat Transfer** |
| No. of Students: 128 | of the dept. of: **Mech Engg** |

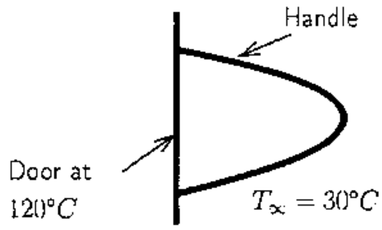
Answer all questions. The marks are given on the left margin in the box
Wherever necessary, make suitable assumptions and state them clearly

[6] 1. At a particular instant of time, in an infinite homogeneous body, the temperature distribution is given by the equation:

$$T(x,y,z) = x^3 - 3x^2y + 4z^2 - 2y^2z + 3x^2yz$$

Assuming constant properties and no internal heat generation or heat absorption, find whether at that time instant, temperature at a point A ($x = 1, y = 2, z = 1$) changes with time or not.

2. The handle of a furnace door is made of a stainless rod of 2 cm diameter (see figure). The rod has a developed length of 40 cm. The door is at 120°$C$, while the surrounding air is at 30°$C$. The heat transfer coefficient between the handle and surrounding air is 23 $W/m^2K$. If the thermal conductivity of the rod is 13.82 $W/mK$, find




[6] (a) temperature at the midpoint of the rod, and

[4] (b) heat transfer rate from the handle to the surrounding air.

3. A chemically reacting solid material in the form of sphere has a diameter of 3 cm. It has a density of 4000 $kg/m^3$, specific heat of 450 $J/kg.K$ and a thermal conductivity of 10 $W/m.K$. Initially when there is no reaction, the spherical reactor is in thermal equilibrium with the surrounding air, which is at a temperature of 30°$C$. Suddenly, the reactor is subjected to an exothermic reaction resulting in a uniform heat generation of $10^6$ $W/m^3$. The reaction ends after 7 minutes.

[8] (a) Find the temperature of the reactor at the end of reaction.

[4] (b) If the reactor is left to cool by rejecting heat to the surrounding air after the reaction is over, then find the time required for the temperature difference between the reactor and surroundings to reach 1°$C$.

[2] (c) Plot a sketch of the temperature variation with time during and after the reaction. Assume a constant convective heat transfer coefficient of 60 $W/m^2.K$ during and after the reaction.

4. A 6 cm diameter shaft rotates at 3000 rpm in a 20 cm long bearing with a uniform clearance of 0.2 mm. At steady operating conditions, both the shaft and the bearing in the vicinity of the oil gap are at 50°$C$, and the viscosity and thermal conductivity of the lubricating oil are 0.05 $Ns/m^2$ and 0.17 $W/mk$. By treating this flow in a journal bearing as flow between parallel plates. determine

[6] (a) the velocity and temperature distribution in the oil

[2] (b) the maximum temperature and where it occurs and



Continued...

[2] (c) the heat flux from the oil to the shaft and the bearing

Develop the simplified governing equations with appropriate boundary conditions and show the solution procedure. Hint: The heat dissipation term is significant.

[10] 5. A metallic airfoil of elliptical cross-section has a mass of 50 $kg$, surface area of 12 $m^2$ and specific heat of 0.05 $kJ/kg\,^\circ C$. The airfoil is subjected to air flow at 1 atm, 25°$C$ and 5 $m/s$ along its 3 m long side. The average temperature of the airfoil is observed to drop from 160°$C$ to 150°$C$ within 2 min of cooling. Assuming the temperature of the airfoil to be uniform over its entire volume and using momentum heat transfer analogy determine the average friction coefficient of the airfoil surface.

[10] 6. In a meat processing plant, 2cm thick meat slabs ($k = 0.45 W/m\,^\circ C$ and $\alpha = 0.091 \times 10^{-7} m^2/s$) that are initially at 25°$C$ are to be cooled by passing through a refrigerated room at $-11^\circ C$. The heat transfer coefficient on both sides of the meat slab is 9 $W/m^2\,^\circ C$. If both surfaces of the meat slab are to be cooled to 2°$C$, determine how long the meat slabs should be kept in the refrigerated room. The air properties are $k = 0.023 W/m\,^\circ C$ and $\alpha = 16 \times 10^{-6} m^2/s$.

For a plane wall of thickness $2L$ subjected to convection from all surfaces with Biot number Bi, the one-dimensionless conduction solution for long times (Fourier number $\tau > 0.2$) is given as:

$$\frac{T(x,t) - T_\infty}{T_i - T_\infty} = A_1 \exp(-\lambda_1^2 \tau) \cos\left(\lambda_1 \frac{x}{L}\right), \quad \text{for} \quad \tau > 0.2$$

The initial temperature of the plane wall is $T_i$ and the ambient temperature is $T_\infty$.

Here the value of $A_1$ and $\lambda_1$ for a given Biot number Bi is given in the following Table

| Bi | $\lambda_1$ | $A_1$ | Bi | $\lambda_1$ | $A_1$ | Bi | $\lambda_1$ | $A_1$ |
|---|---|---|---|---|---|---|---|---|
| 0.01 | 0.0997 | 1.0017 | 1.0 | 0.8603 | 1.1191 | 10.0 | 1.4289 | 1.2620 |
| 0.02 | 0.1410 | 1.0033 | 2.0 | 1.0769 | 1.1785 | 20.0 | 1.4961 | 1.2699 |
| 0.04 | 0.1987 | 1.0066 | 3.0 | 1.1925 | 1.2102 | 30.0 | 1.5202 | 1.2717 |
| 0.06 | 0.2425 | 1.0098 | 4.0 | 1.2646 | 1.2287 | 40.0 | 1.5325 | 1.2723 |
| 0.08 | 0.2791 | 1.0130 | 5.0 | 1.3138 | 1.2402 | 50.0 | 1.5400 | 1.2727 |
| 0.1 | 0.3111 | 1.0161 | 6.0 | 1.3496 | 1.2479 | 100.0 | 1.5552 | 1.2731 |
| 0.2 | 0.4328 | 1.0311 | 7.0 | 1.3766 | 1.2532 | $\infty$ | 1.5706 | 1.2732 |
| 0.3 | 0.5218 | 1.0450 | 8.0 | 1.3978 | 1.2570 | | | |
| 0.4 | 0.5932 | 1.0580 | 9.0 | 1.4149 | 1.2598 | | | |
| 0.5 | 0.6533 | 1.0701 | | | | | | |
| 0.6 | 0.7051 | 1.0814 | | | | | | |
| 0.7 | 0.7506 | 1.0918 | | | | | | |
| 0.8 | 0.7910 | 1.1016 | | | | | | |
| 0.9 | 0.8274 | 1.1107 | | | | | | |



End of exam