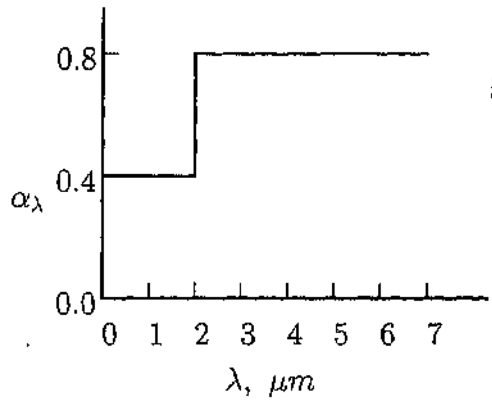
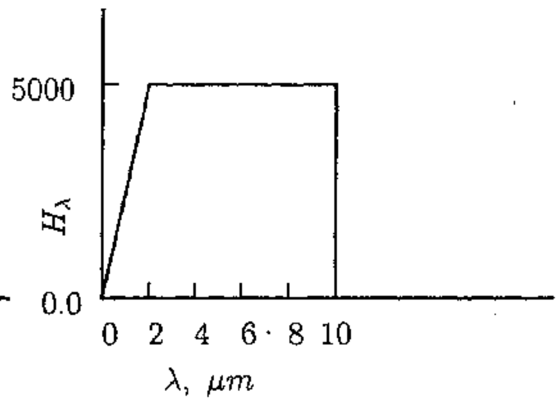
Indian Institute of Technology, Kharagpur

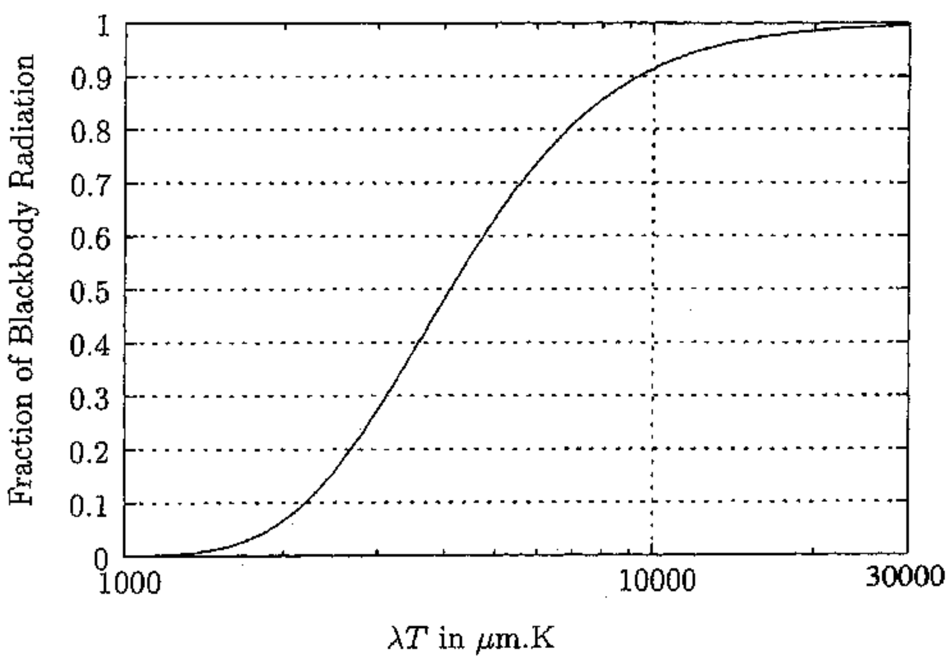
Date of Examination:	Time: 3Hrs. Full Marks 80
End Semester Exam. 2010	**3th Yr (BTech+Dual Degree) ME/MF**
Sub No. ME30005	Sub Name: **Heat Transfer**
No. of Students: 128	of the dept. of: **Mech Engg**

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

[10] 1. Consider an opaque, diffuse surface for which the spectral hemispherical absorptivity and irradiation H_λ are given in figure. What is the total hemispherical absorptivity of the surface for the prescribed irradiation? If the surface is at a temperature of 1250K, what is the emissive power. Consider $\epsilon_\lambda = \alpha_\lambda$. The fraction of blackbody radiation in wavelength interval $[0 - \lambda T]$ is given is figure.







[10] 2. Two very large parallel plates of emissivity $\epsilon = 0.2$ and $\epsilon = 0.7$ exchange heat by radiation. Find the percentage reduction in radiation heat transfer when a polished aluminum sheet of emissivity $\epsilon = 0.05$ is placed between them. Show the radiation network diagram. Assume diffuse gray surfaces.

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10 3. Calculate the radiation equilibrium temperature for a plate exposed to a solar flux of 800 w/m^2 and a surrounding temperature of 300K if the surface is coated with black paint of emissivity 0.95. Assume gray diffuse surface and $\alpha_\lambda = \epsilon_\lambda$. In addition to radiation heat transfer if there is convection heat transfer to surrounding with convective heat transfer coefficient $h = 10\,W/m^{2\circ}C$ calculate the approximate radiation-convection equilibrium temperature. Show only 3 to 4 steps of iteration for solution where iterative solution is ncessary.

10 4. An experimental arrangement for measuring the thermal conductivity of solid materials involves the use of two long rods that are equivalent in every respect, except that one is fabricated from a standard material of known conductivity and another from a material whose thermal conductivity k_B is to be determined, and are instrumented with thermocouples to measure the temperature at a fixed distance x_1 of the heat source at temperature $T_{\text{base}} = 100°C$. The standard material is aluminium, with thermal conductivity $k_A = 200\,W/m\,K$, and measurements reveal values of $T_A = 75°C$ and $T_B = 60°C$ at x_1 for surrounding temperature $T_\infty = 25°C$. What is the thermal conductivity k_B of the test material?

5. An incompressible fluid with constant properties flows through a circular tube of inner radius (r_0) 12 mm. At a particular axial location, the velocity and temperature distributions are given by the equations:

$$u(r) = 2.7\left[1 - \frac{r^2}{r_0^2}\right] \quad \text{and} \quad T(r) = 320\left[1 - \frac{0.05\,r}{r_0}\right]$$

here u is in m/s and T is in Kelvin. The thermal conductivity of the fluid $k_f = 0.6\,W/m.°C$. From the above equations find

1 (a) the mean velocity, and

3 (b) mean temperature of the fluid,

1 (c) also find whether the fluid is being cooled or heated as it flows through the tube.

3 (d) find the local Nuselt number Nu_d based on tube diameter at this axial location.

12 6. A copper sphere of 10 mm diameter and initially at a uniform temperature of $80°C$ is quenched by dropping it in a large water tank. The temperature of the water in the tank is $30°C$. What should be the minimum height of the tank so that the centre temperature of the copper sphere reduces from $80°C$ to $40°C$ as it drops through the water in the tank. Assume that the copper sphere attains terminal velocity as soon as it touches the water and then drops freely through the water with the constant terminal velocity. The coefficient of drag (C_D) of the copper sphere may be assumed to be equal to 0.45. (Hint: Terminal velocity is obtained by equating the drag force on the copper sphere with the gravitational force acting on the sphere). Use the following property data, and Whitaker's correlation for estimating heat transfer coefficient between the falling copper sphere and surrounding water:

Copper: $c_p = 389$ J/kg-K; $\rho = 8918$ kg/m^3; $k = 398.3$ W/m-K;

Water at $30°C$: $\rho_f = 995.7$ kg/m^3, $k_f = 0.603$ W/m-K; $\mu_f = 797.7 \times 10^{-6}$ kg/m-s; Pr = 5.534;

Water at $60°C$: $\mu_{fs} = 466.6 \times 10^{-6}$ kg/m-s

Whitaker's correlation:

$$Nu_{d,\text{avg}} = \frac{h_{\text{avg}} d}{k_f} = 2 + (0.4\,\mathrm{Re}_d^{1/2} + 0.06\,\mathrm{Re}_d^{2/3})\mathrm{Pr}^{0.4}\left(\frac{\mu_f}{\mu_{fs}}\right)^{1/4} \quad \text{where} \quad \mathrm{Re}_d = \frac{\rho_f V d}{\mu_f}$$

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In the above equation, V is the relative velocity between the fluid and the sphere of diameter d and μ_{fs} is the viscosity of the fluid at the solid surface temperature

[10] 7. The annular space between two long, horizontal, concentric cylinders is filled with quiescent air. The outer diameter of the inner cylinder (d_i) is 50 mm, while the inner diameter of the outer cylinder (d_o) is 100 mm. The inner cylinder is maintained at $T_h = 100°C$, while the outer cylinder is maintained at $T_c = 30°C$. Estimate the rate of heat transfer from the inner cylinder to the outer cylinder per unit length of the cylinders. Use the following equations for estimating heat transfer rate

$$\text{Effective conductivity, } k_e = 0.386 k_f \left(\frac{\text{Pr}}{0.861+\text{Pr}}\right)^{1/4} \left(\text{Ra}^{\star}_{\text{cyl}}\right)^{1/4}$$

$$\text{where} \quad \left(\text{Ra}^{\star}_{\text{cyl}}\right)^{1/4} = \frac{\ln\left(\frac{d_o}{d_i}\right)}{\delta^{3/4}\left(d_i^{-3/5} + d_0^{-3/5}\right)^{5/4}} \left(\text{Ra}_\delta\right)^{1/4}$$

Rayleigh number Ra based on the gap between the cylinders (δ) is given by:

$$\text{Ra}_\delta = \frac{g\beta(T_h - T_c)\delta^3}{\nu^2} \times \text{Pr}$$

All the properties of air are evaluated at 65°C and 1 atm. given as; $\rho = 1.097$ kg/m^3, $\alpha = 19.75 \times 10^{-6}$ m^2/s, $k_f = 0.0291$ W/m.K; Pr = 0.7087.

[10] 8. In a shell-and-tube type condenser used in a small power plant, saturated steam condenses at 38°C by transferring heat to cooling water that enters the condenser at 24°C with a mass flow rate of 150 kg/s. The heat transfer area A is 420 m^2 and overall heat transfer coefficient U based on this area is 3600 W/m^2.K. Taking an average specific heat (c_p) of 4.18 kJ/kg.°C for liquid water, find the heat transfer rate in the condenser in MW. You may use the effectiveness-NTU (ϵ-NTU) relation given below for shell-and-tube type heat exchangers to estimate the heat transfer rate. In the expression, m is the mass flow rate of the fluid(s).

$$\epsilon = 2\left\{1 + c + \sqrt{(1+c^2)}\frac{1+\exp\left[-\text{NTU}\sqrt{1+c^2}\right]}{1-\exp\left[-\text{NTU}\sqrt{1+c^2}\right]}\right\}^{-1} \quad \text{where} \quad c = \frac{(mc_p)_{\text{min}}}{(mc_p)_{\text{max}}}; \text{NTU} = \frac{UA}{(mc_p)_{\text{min}}}$$