Ref. No. PE/T222/2018

B. POWER 2ND YR. 2ND SEM. EXAMINATION, 2018

*SUBJECT: **HEAT TRANSFER***

Time: Three Hours **(Full Marks 100)**

Assume the following properties of air and water unless otherwise specified:

AIR: ρ = 1.16 kg m^{-3}, ν = 1.86×10^{-5} m^2 s^{-1}, C_p = 1.014 kJ kg^{-1} K^{-1}, Pr=0.7

WATER: ρ = 1000 kg m^{-3}, ν = 1.0×10^{-6} m^2 s^{-1}, C_p = 4.186 kJ kg^{-1} K^{-1}, Pr=7.0

Part I (10 marks)

1. A flat heater surface, having emissivity of 0.8, runs parallel to a blackbody surface at a separation of 5 mm. The blackbody surface is maintained at 273 K by keeping it in contact with ice-bath. Under steady state, 5 kW/m^2 heat is uniformly dissipated through the heater surface. If the gap between the plates is filled up by a heat transfer oil of thermal conductivity of 1 W/mK, what is the heater surface temperature? Heat transfer due to convection may be neglected. **10**

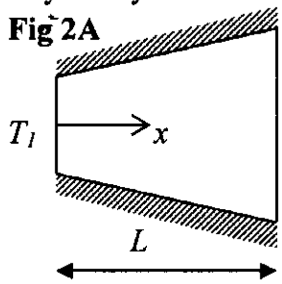
OR

A 1 cm diameter heated sphere (ρ_{solid}= 3000 kg/m^3, C_{solid}= 1000 J/kgK) at 150°C is dipped into an isothermal liquid (k_{liquid}= 1 W/mK) pool of 50°C. The liquid over the sphere does not have any relative velocity with respect to it. What is the rate of cooling of the sphere, right when it is dipped into the pool? How long does it take to cool the sphere to 100°C? Assume that $k_{solid} >> k_{liquid}$. Neglect radiation and free convection. **10**

Part II (Answer Q 2 and 3, total 30 marks)

2. A conical cylinder is insulated along its tapered surface. The cylinder has a length L and its radii at the smaller and larger ends are R_1 and R_2, respectively (see Fig 2A). The surfaces are maintained at temperatures T_1 and T_2 as shown in the figure. Considering 1-d steady heat conduction, find the expressions of temperature as a function of x and the overall thermal resistance offered by the cylinder. **20**

Fig 2A



OR

The inner surface at $r = a$ and the outer surface at $r = b$ of a hollow sphere are maintained at uniform temperatures T_1 and T_2, respectively. The thermal conductivity of the material is constant. (i) Develop an expression for the 1-dimensional steady-state temperature distribution $T(r)$ in the sphere. Also evaluate the expressions of (ii) heat flow rate and (iii) thermal resistance offered by the hollow sphere. (iv) Using the last expression, show that the Nusselt number for a spherical solid in a quiescent fluid medium is 2.

10 + 3+3+4 = 20

Ref. No. PE/T222/2018

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3. State the reciprocity and summation rules of view factors. Using them, derive an expressions of shape factors F_{12} and F_{13} of the following triangular prism of infinite length (See Fig 3A) , and evaluate them where W_1: W_2: W_3 = 6: 4: 3: **10**

OR

State Hottel's cross-string method, and deduce from it the view factors F_{11} and F_{12} for the pair of surfaces 1 and 2 of infinite length perpendicular to the plane of the paper, as shown in Fig 3B. **10**

Fig 3A

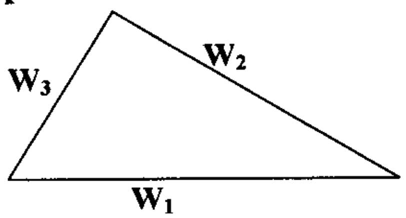
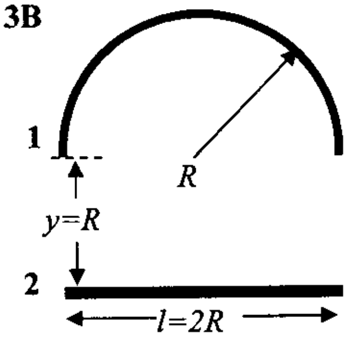


Fig 3B



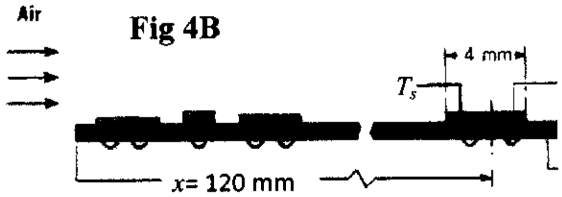
Part III (Answer Q 4 and 5; 20×2 = 40 Marks)

4. Hot air at atmospheric pressure and 80°C enters an 8 m long un-insulated square duct of cross section 0.2m × 0.2 m at a rate of 0.15 m^3/s. The duct loses heat to the surroundings which is at 15°C. The heat transfer coefficient between the outer surface of duct and the outside ambient is 20 W/m^2 while the duct wall thickness is negligible. Consider the flow through the duct fully developed and neglect the effect of thermal radiation. Estimate the outlet temperature of air and the heat loss from the duct. **20**

OR

Forced air at 25°C and and 10 m/s is used to cool electronic elements mounted on a circuit board (see Fig 4B). Consider a 4 mm×4 mm chip located 120 mm from the leading edge. Because the board has rough and irregular surface, the flow is disturbed, and the appropriate convection correlation is of the form $Nu_x = 0.04\, Re_x^{0.85} Pr^{0.33}$. Estimate the average surface temperature T_s of the chip for a 30 mW heat dissipation from it. **20**

Fig 4B



5. An incandescent spherical 100 W lightbulb of 8 cm diameter hung in a quiescent air of 27° C converts a fraction of its input to light energy and the remaining part is converted to heat, which is dissipated by radiation and free convection. If the surface temperature of the bulb is 177° C, find the fraction of the energy that is converted to light. Assume the walls of room where the bulb is housed are also at 27°C and the glass ε = 0.9. Assume the correlation $Nu_D = 2 + (0.589\, Ra_D^{0.25}) / [1+(0.469/Pr)^{9/16}]^{4/9}$ to hold good. **20**

OR

Consider a cylindrical furnace of diameter D = 5 m and height H = 5 m with a flat base and a roof. The curved side wall and the roof of the furnace may be approximated as blackbody surface, and are maintained at 600 K. The spectral hemispherical emissivity of the base, which is maintained at 1000 K is approximated as $\varepsilon_1 = 0.1$ (for $\lambda < 0.8\ \mu m$), $\varepsilon_2 = 0.9$ (for $0.8 < \lambda < 2\ \mu m$), and $\varepsilon_3 = 0.2$ (for $2\ \mu m < \lambda$). Determine the net rate of radiation heat transfer emanating from the base to the side wall during steady operation. Consider the blackbody *radiation fraction table* provided at the end of the question paper. **20**

Part IV (20 Marks)

6. A cylindrical pin fin of length L is to be mounted between two identical hot plates A and B, maintained at 100 °C, as shown in Fig 6A. The fin metal has a thermal conductivity of 100 W/mK, while the intervening fluid has a convective heat transfer coefficient of 10 W/m^{2}K and a temperature of 10 °C. What would be the highest practical length of the fin, and the total heat loss through the fin? **20**

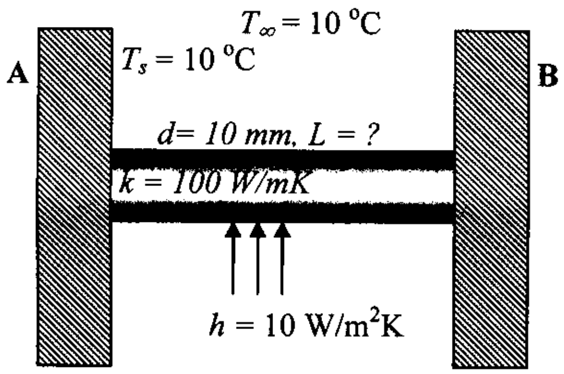


Fig 6A

OR

A shell-and-tube heat exchanger with 1-shell pass and 20-tube passes is used to heat glycerin (Cp = 2480 J/kgK) in the shell, with hot water in the tubes. The tubes are thin walled and have a diameter of 1.5 cm and length of 2 m per pass. The water enters the tubes at 100 °C at a rate of 5 kg/s and leaves at 55 °C. The glycerin enters the shell at 15 °C and leaves at 55 °C. Determine the mass flow rate of the glycerin and the overall heat transfer coefficient of the heat exchanger. Use the following Bowman chart provided at the end of the question paper. **20**

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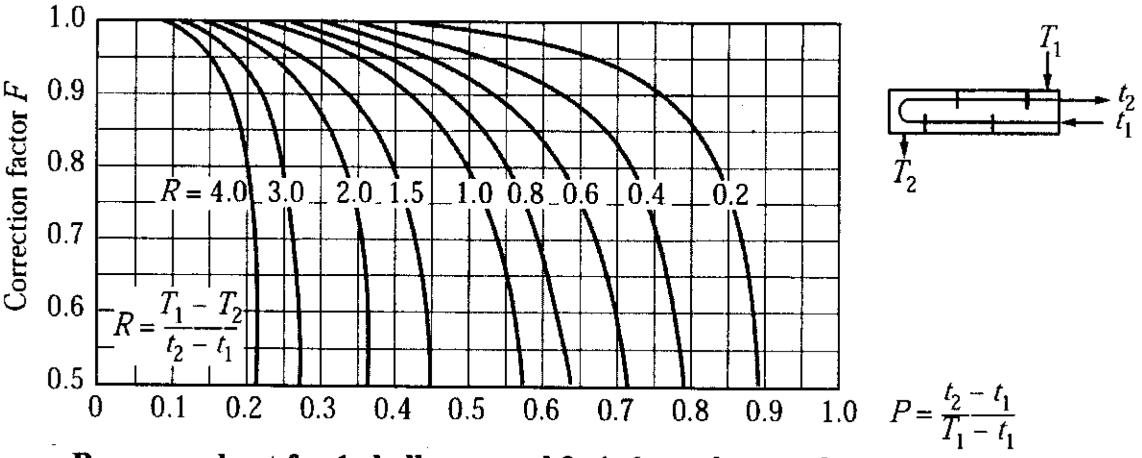
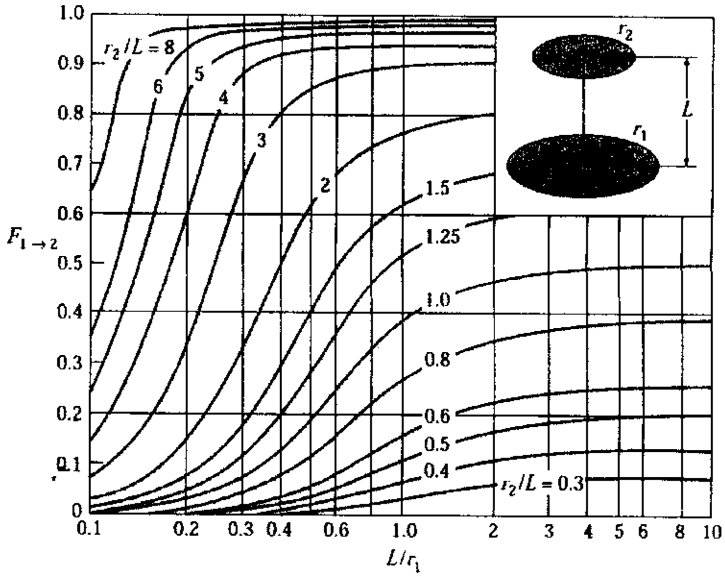


Bowman chart for 1 shell pass and 2, 4, 6... tube pass heat exchangers

Blackbody radiation functions f_λ

λT, μm · K	f_λ
200	0.000000
400	0.000000
600	0.000000
800	0.000016
1000	0.000321
1200	0.002134
1400	0.007790
1600	0.019718
1800	0.039341
2000	0.066728
2200	0.100888
2400	0.140256
2600	0.183120



View factor between two parallel circular discs of radii r_1 and r_2.