Ref. No. PE/T222/2019

B. POWER 2ND YR. 2ND SEM. EXAMINATION, 2019

SUBJECT: **HEAT TRANSFER**

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

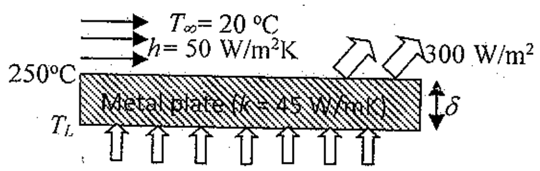
Assume the following properties of air and water unless otherwise specified:

AIR: $\rho = 1.16$ kg m^{-3}, $\nu = 1.86\times10^{-5}$ m^2 s^{-1}, $C_p = 1.014$ kJ kg^{-1} K^{-1}, Pr=0.7

WATER: $\rho = 1000$ kg m^{-3}, $\nu = 1.0\times10^{-6}$ m^2 s^{-1}, $C_p = 4.186$ kJ kg^{-1} K^{-1}, Pr=7.0

Part I (10 marks)

1. Air at 20°C with a convection heat transfer coefficient of 25 W/m^{2}K blows over a horizontal metal plate of k= 45 W/mK to maintain the plate temperature at 250° C, while the plate continuously loses a radiative heat flux of 300W/m^2 from the upper face. The plate has a thickness δ= 2 cm and area A = 0.4 m^2. Calculate the steady operating temperature T_L of the lower surface and the heat flux from below. **10**



OR

A 3-m internal diameter spherical tank made of 2-cm-thick stainless steel (k = 15 W/m K) is used to store iced water at T_1 = 0°C. The tank is housed in a room whose temperature is T_2 = 22°C. Heat transfer between the outer surface of the tank and the surroundings is by natural convection only. The convection heat transfer coefficients at the inner and the outer surfaces of the tank are h_1 = 80 W/m^{2}K and h_2 = 10 W/m^2 K, respectively. Determine the rate of heat transfer to the iced water in the tank. Also find the inner and outer surface temperatures of the tank. **10**

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

2. A 20 mm thick, infinitely spread, flat metal (k = 200 W m^{-1} K-1) plate carries electrical current so that it generates 80 MWm^{-3} of Joule heating (see Fig 2A). The left and right faces of the plates are maintained at 160 °C and 120 °C, respectively. (a) Starting from the energy equation, derive the expression for temperature distribution within the plate. Also evaluate (b) location and the value of maximum temperature within the plate and (c) the heat flux at the left and right faces of the plate. **20**

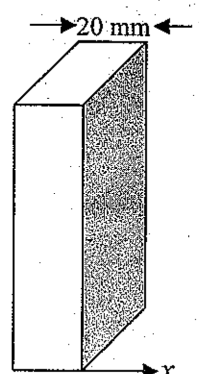


Fig 2A

OR

Glass wool insulation of thickness δ is wrapped over the main steam pipeline of a power plant. The metal pipe has an outer radius R maintained at temperature T_R. The insulation fits tightly on the metal pipe and has an outer radius r, while its thermal conductivity is k. The outer surface of the insulation is exposed to an ambient of T_∞. (a) Starting from the energy equation in cylindrical coordinates, deduce the expression of thermal resistance offered by a cylindrical insulation layer. (b) Do you think the thermal resistance increase with the insulation thickness $\delta =(R-r)$ monotonically? (c) Deduce an expression of δ for which the heat loss from the pipe will be maximum. What is it called? **20**

Ref. No. PE/T222/2019

B. POWER 2^{ND} YR. 2^{ND} SEM. EXAMINATION, 2019

SUBJECT: **HEAT TRANSFER**

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

3. Define bulk mean temperature for a forced convection through a circular pipe. The velocity and temperature profiles inside a circular pipe, of radius R=10 cm, vary as u=1 m/s and $T(r)$=[400 – 1000$(R-r)^2$] K. Calculate the centerline and bulk mean temperature inside the pipe. Also calculate the Nusselt number for the flow. **10**

OR

State the summation and reciprocity rules of view factor. A hollow cylinder of height L and diameter D has three inner surfaces A_1, A_2 and A_3, respectively denoting the bottom, side (curved) and the upper surface, respectively. The view factor $F_{12} = 2x[(1+x^2)^{1/2}-x]$, where $x=L/D$. Find the value of F_{21} and F_{22} in terms of x. Refer to Fig 3B. **10**

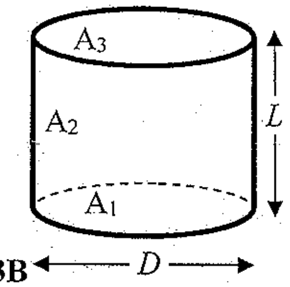


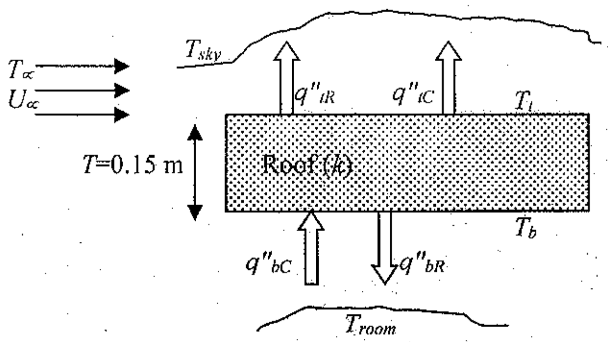
Fig 3B

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

4. In a boiler furnace, the hot flue gas, flowing out of the furnace region at a mean velocity of 10 m/s, temperature is measured by an R-type thermocouple inserted in the furnace space. What is the actual gas temperature if the thermocouple reads 1000 K? The bead of the thermocouple has a diameter of 800 micron, and the bead surface emissivity is 0.9. Consider the furnace walls to be blackbody at 700 K. Consider the expression for Nusselt number for forced flow over a sphere as $Nu_D = 2+(0.4Re_D^{0.5}+0.06Re_D^{2/3})Pr^{0.4}$. Also use the same fluid properties specified at the beginning of the question paper for the furnace gas. **20**

OR

The roof of a house consists of a 1.5 m × 1.5 m and 10 cm thick flat concrete slab (k= 2.5 W/mK). The convection heat transfer on the inner surface of the room is 4.5 W/m². The ambient air is reported to be at 7°C, while the night sky temperature is at 100K. Interior of the house and the internal surfaces of the walls are maintained at a constant temperature of 27°C. The emissivity of both surfaces of the concrete roof is 0.9.



Considering both radiation and forced convection heat transfer, determine the rate of heat transfer through the roof, when the ambient air is blowing at 3.6 km/h blowing over the roof. For laminar flow, $Nu_x=0.296\, Re_x^{0.8}\, Pr^{1/3}$. **20**

5. A heated metallic sphere of 8 cm diameter hung in a quiescent air of 27° C maintains surface temperature of 327° C. Assume the walls of room where the bulb is housed are also at 27°C and the surface of the sphere has a spectral hemispherical emissivity as $\varepsilon_\lambda = 0.3$ for $\lambda \le 4$ μm and $\varepsilon_\lambda = 0.9$ for $\lambda > 4$ μm. Assume the correlation $Nu_D = 2+(0.589\, Ra_D^{0.25})/[1+(0.469/Pr)^{9/16}]^{4/9}$ to hold for free convection over a sphere. Calculate the heat loss from the sphere, and the fraction lost by radiation. Use the blackbody radiation chart provided at the end of the question paper. **20**

OR

A long cylindrical metal rod (k =150 W/m K and α =5 $\times 10^{-5}$ m^2s) is 10 cm in diameter and is initially at a uniform temperature of 10°C. It is exposed to hot gases at 200°C in a furnace when the gases blow over the cylinder at 10 m/s velocity. Assume the same air properties prescribed in the beginning of the question paper to represent the furnace gas, and the following expression of Nusselt number for cross-flow over a cylinder. How long it will be before the metal is heated to 150 °C?

$Nu = A\, Re^m Pr^{1/3}$; where $A=0.95$and $m = 0.35$ for $0<Re<50$; $A=0.68$ and m = 0.46for $50<Re<5000$; $A=0.2$ and $m = 0.62$for $5000<Re<50000$. **20**

Part IV (20 Marks)

6. A hot surface at 100 °C is to be cooled by attaching an array of 10 cm-long, 2mm-diameter metal pin fins (k = 200 W/m K) to it, with a center-to-center distance of 1 cm. The temperature of the surrounding medium is 30 °C, and the heat transfer coefficient on the surfaces is 200 W/m^2 K. Determine the rate of heat transfer from the surface for a 1-m × 1-m section of the plate. Also determine the overall effectiveness of the finned surface. **20**

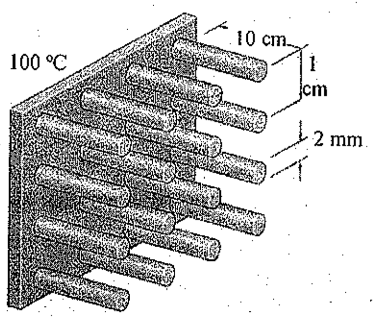


Fig 6A

OR

Water (c_{pw}=4.19 kJ/kg K) flowing at a rate of 0.667 kg/s enters a countercurrent, double-pipe heat exchanger at 308K and is heated by an oil stream entering at 383K at a rate of 2.85 kg/s (c_{po}=1.89 kJ/kg K). The heat transfer coefficients on the outer and inner sides of the of the inner pipe are 600 W/(m^2 K) and 400 W/m^2K, respectively, while the resistance due to fouling on the pipe is 0.004 K.m^2/W. Heat transfer area in the exchanger is 15.0 m^2. Calculate the heat-transfer rate and the exit water temperature. The effectiveness for a counterflow heat exchanger is

$$\varepsilon = \frac{1-exp\left[-NTU(1-C_r)\right]}{1-C_r\, exp\left[-NTU(1-C_r)\right]} \quad (for\ C_r<1); \quad \varepsilon = \frac{NTU}{1+NTU} \quad (for\ C_r = 1)$$ **20**

ADDITIONAL INFORMATION

Blackbody Radiation Function f_λ

λT (μm.K)	f_λ	λT (μm.K)	f_λ
200	0	1600	0.019718
400	0	1800	0.039341
600	0	2000	0.066728
800	0.000016	2200	0.100888
1000	0.000321	2400	0.140256
1200	0.002134	2600	0.18312
1400	0.00779	2800	0.227897