B.E. POWER ENGINEERING SECOND YEAR SECOND SEMESTER - 2025

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}, $\nu = 1.8\times10^{-5}$ m^2 s^{-1}, $C_p = 1.014$ kJ kg^{-1} K^{-1}, Pr=0.7

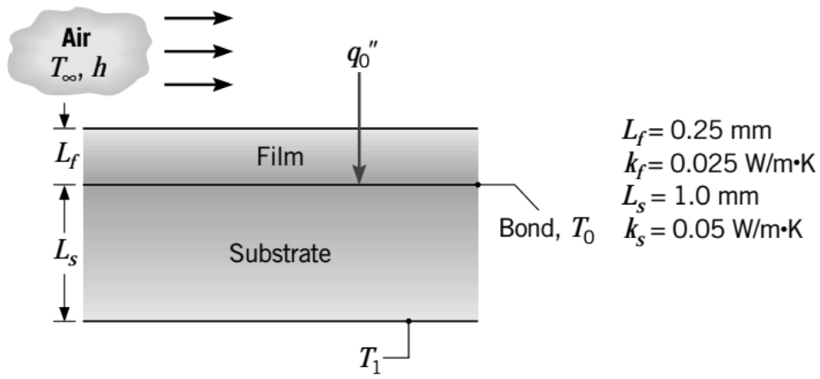
WATER: $\rho = 1000$ kg m^{-3}, $\nu = 1.0\times10^{-6}$ m^2 s^{-1}, $C_p = 4.186$ kJ kg^{-1} K^{-1}, Pr=7.0

Part I (CO1) (30 marks)

1. Answer ANY THREE **3×10=30**

a) A thermocouple is suddenly inserted in a furnace to measure the temperature of the hot gas stream. The junction may be approximated as a sphere having a thermal conductivity of 25 W/mK, density 8400 kg/m^3, and specific heat of 0.4 kJ/kgK. The heat transfer coefficient between the junction and the gas is 560 W/m^{2}K. Calculate the diameter of the junction if the thermocouple should be able to read 95% of the applied temperature difference in 3 s. Assume the lumped capacitance model to hold good.

b) In a manufacturing process, a transparent film is being bonded to a substrate as shown in the sketch below. To cure the bond at a temperature T_0, a radiant source is used to provide a heat flux q_0'' (W/m^2), all of which is absorbed ONLY at the bonded surface. The back of the substrate is maintained at T_1 while the free surface of the film is exposed to air at T_∞ and a convection heat transfer coefficient h. (a) Show the thermal circuit representing the steady-state heat transfer situation. (b) If T_∞ =20°C, h = 50 W/m^2 K, and T_1= 30°C, calculate the heat flux q_0'' that is required to maintain the bonded surface at T_0= 60°C.



c) The steady-state temperature distribution in a one-dimensional wall of thermal conductivity k and thickness L is of the form $T=ax^3+bx^2+cx+d$. Derive expressions for the heat generation rate per unit volume in the wall and the heat fluxes at the two wall faces (x= 0, and x=L) in terms of a, b, c and d.

d) A furnace is of cylindrical shape with R = H = 2 m. The base, top, and side surfaces of the furnace are all black and are maintained at uniform temperatures of 1500, 1000, and 500 K, respectively. Determine the net rate of radiation heat transfer to or from the curved surface during steady operation. Use view factor chart provide at the end of the question paper.

[Turn over

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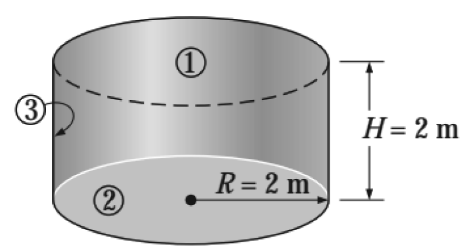


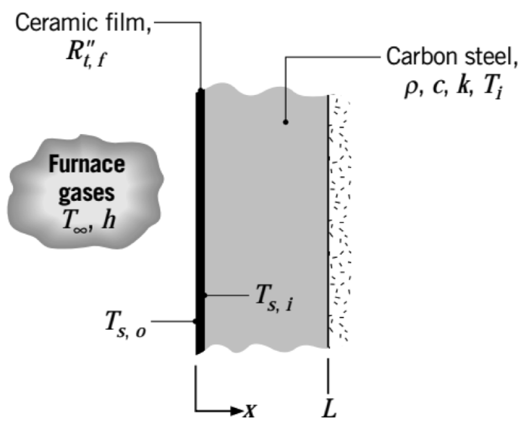
e) The spectral hemispherical absorptivity of an opaque surface at 1000 K, maintained in an enclosure of 2000 K, is approximated as α_1= 0.1 (for λ< 1 μm), α_2= 0.9 (for 1 < λ< 2 μm), and α_3= 0.2 (for 2 μm <λ). Determine the total hemispherical absorptivity and total hemispherical emissivity for the surface. Consult the *blackbody radiation fraction table* provided at the end of the question paper.

Part II (CO2) (20 marks)

2. A 500 mm long, cylindrical electrical resistance element of 2.5 mm diameter passes 40 A current through it homogeneously, while a voltage drop of 25 V is measured across its length. The thermal conductivity of the wire material is 25 W/mK. The wire is dipped in an evaporative cooling environment (h= *1000* W/m^2K, T_∞=30 °C). (a) Starting from the steady state conduction equation in the pertinent coordinates system, and the appropriate boundary conditions, deduce the expression of temperature as a function of radial position. (b) Estimate the maximum and the surface temperature of the wire. **10+10**

OR

A plane wall of a furnace is fabricated from plain carbon steel (k = 60 W/m K, ρ = 7850 kg/m^3, c = 430 J/kg K) and is of thickness L = 10 mm. To protect it from the corrosive effects of the furnace combustion gases, one surface of the wall is coated with a thin ceramic film that, for a unit surface area, has a thermal resistance of $R''_{t,f}$= 0.01 m^2 K/W. The opposite surface is well insulated from the surroundings. At furnace start-up the wall is at an initial temperature of T_i = 300 K, and combustion gases at T_∞ = 1300 K enter the furnace, providing a convection coefficient of h = 25 W/m2 K at the ceramic film. Assuming the film to have negligible thermal capacitance, how long will it take for the inner surface of the steel to achieve a temperature of $T_{s,i}$ = 1200 K? What is the temperature $T_{s,o}$ of the exposed surface of the ceramic film at this time?



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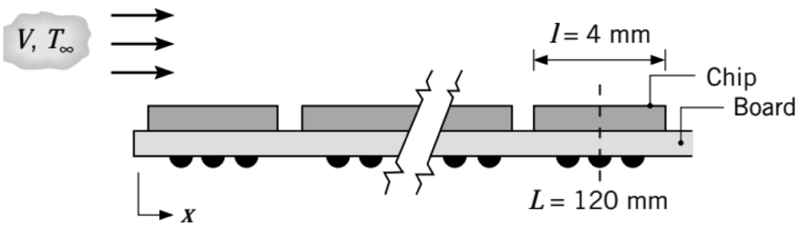
Part III (CO3) (25 Marks)

3. Forced air at 25ºC and and 10 m/s is used to cool electronic elements mounted on a circuit board. 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. Consider the properties of air as given in page 1. **25**



OR

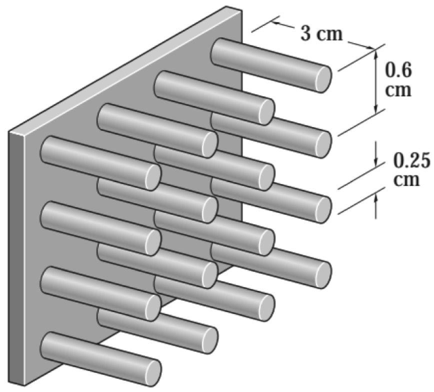
A 0.5m by 0.5 m diffuse vertical flat plate receives concentrated solar radiation G_i = 10000 W/m^2, while its spectral absorptivity of the plate surface varies as: $\alpha = 0.9$ for $0<\lambda<1$ μm and 0 for 1μm $<\lambda$. (a) How much heat does the plate absorb? (b) The plate is thermally insulated at its back, and under a steady state it rejects the heat by radiation and free-convection from the front which is at a temperature of 327 ºC. The free stream air and the surroundings are at 27 ºC. What is the emissivity of the surface? Consider solar radiation to mimic the radiation from a blackbody maintained at 5000 K. Also assume the air properties at the ambient temperature of 300 K. Assume the following correlation for Nu for free convection on a vertical flat plate: $Nu = 0.59\, Ra_L^{1/4}$. **25**

Part IV (CO4) (25 Marks)

4. Water (C_w=4.2 kJ/kg K)flowing at a rate of 1 kg/s enters a counterflow, double-pipe heat exchanger at 308K and is heated by an oil stream entering at 383K at a rate of 3 kg/s (C_o=1.9 kJ/kg K). The overall heat transfer coefficient of the heat exchanger is 300 W/(m^2 K) and the heat transfer area in the exchanger is 15.0 m^2. Calculate the heat-transfer rate and the exit water temperature. Use the charts/ expressions provided at the end of the question paper. **25**

OR

A hot surface at 100 ºC is to be cooled by attaching 3 cm-long, 0.25 cm-diameter aluminum pin fins (k = 237 W/m K) to it, with a center-to-center distance of 0.6 cm. The temperature of the surrounding medium is 30 ºC, and the heat transfer coefficient on the surfaces is 35 W/m^2·C. Determine the rate of heat transfer from the surface for a 1m ×1m section of the plate. Also determine the overall effectiveness of the fins. **25**



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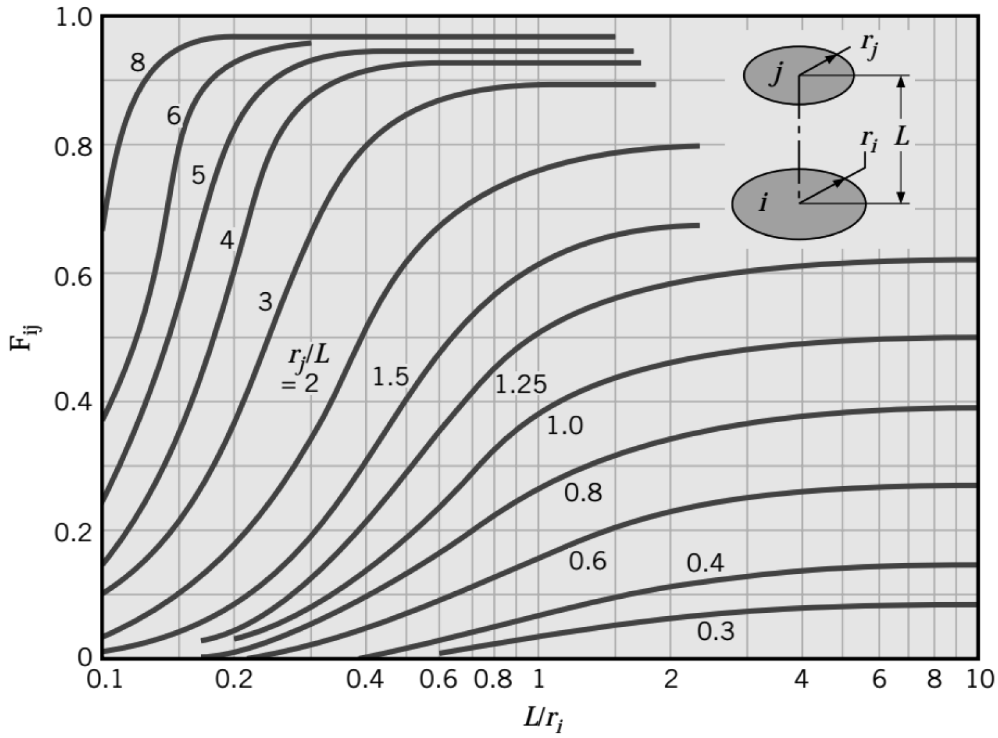
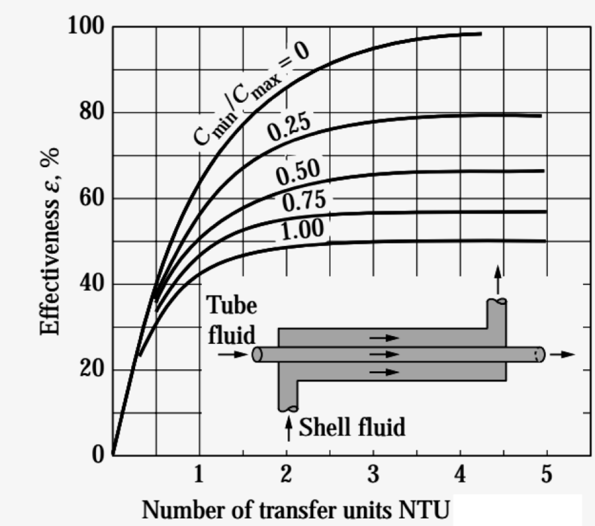
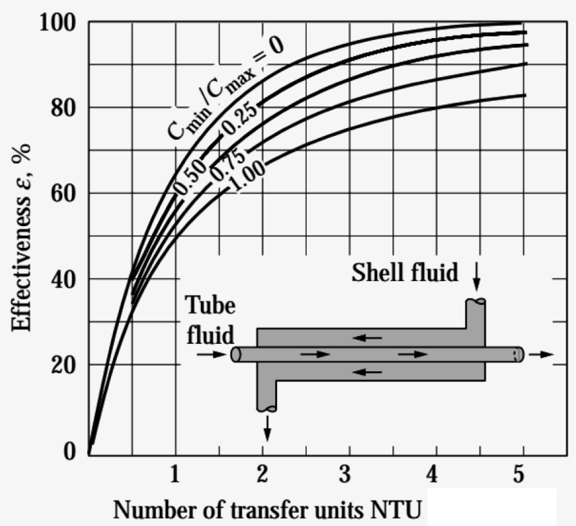
ADDITIONAL INFORMATION



View Factor Chart





ε-NTU plots for concentric tube heat exchangers

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$$\varepsilon_{PARALLEL} = \frac{1-exp\left[-NTU\left(1+C_r\right)\right]}{1+C_r}; \qquad \varepsilon_{COUNTER} = \frac{1-exp\left[-NTU\left(1-C_r\right)\right]}{1-C_r\,exp\left[-NTU\left(1-C_r\right)\right]} \quad \left(for\ C_r<1\right)$$

$$= \frac{NTU}{1+NTU} \qquad \left(for\ C_r=1\right)$$

Blackbody Radiation Function

λT (μm · K)	$F_{(0\to\lambda)}$	λT (μm · K)	$F_{(0\to\lambda)}$	λT (μm · K)	$F_{(0\to\lambda)}$
200	0.000000	4,400	0.548796	9,500	0.903085
400	0.000000	4,600	0.579280	10,000	0.914199
600	0.000000	4,800	0.607559	10,500	0.923710
800	0.000016	5,000	0.633747	11,000	0.931890
1,000	0.000321	5,200	0.658970	11,500	0.939959
1,200	0.002134	5,400	0.680360	12,000	0.945098
1,400	0.007790	5,600	0.701046	13,000	0.955139
1,600	0.019718	5,800	0.720158	14,000	0.962898
1,800	0.039341	6,000	0.737818	15,000	0.969981
2,000	0.066728	6,200	0.754140	16,000	0.973814
2,200	0.100888	6,400	0.769234	18,000	0.980860
2,400	0.140256	6,600	0.783199	20,000	0.985602
2,600	0.183120	6,800	0.796129	25,000	0.992215
2,800	0.227897	7,000	0.808109	30,000	0.995340
2,898	0.250108	7,200	0.819217	40,000	0.997967
3,000	0.273232	7,400	0.829527	50,000	0.998953
3,200	0.318102	7,600	0.839102	75,000	0.999713
3,400	0.361735	7,800	0.848005	100,000	0.999905
3,600	0.403607	8,000	0.856288		
3,800	0.443382	8,500	0.874608		
4,000	0.480877	9,000	0.890029		
4,200	0.516014				