Ref. No: Ex/ME(M2)/PC/B/T/214/2025

B.E. MECHANICAL ENGINEERINGSECOND YEAR FIRST SEMESTER EXAM 2025
Heat Transfer

Time: Three hours **Full Marks 100**

All parts of the same question must be answered together. Assume any unfurnished data suitably
Use of Heat transfer Tables and Charts permitted

Group I (CO1) 10

Q:1. **Answer any five parts** 5x2 = 10

(a) Write the expressions for the three components of conduction heat flux in rectangular significance of the negative sign in the expression?

(b) Define spectral intensity of a black body. Does its value vary with temperature of emitting surface, wavelength and direction of propagation?

(c) Define radiosity for a real surface. How is it different from emissive power?

(d) A fluid at temperature T_∞ flows over a flat plate at temperature T_w. How is the convective heat transfer coefficient related to the rate of heat transfer between the plate and the fluid? If the temperature distribution in the fluid is known, how can we calculate the rate of heat transfer from the fluid?

(e) What is the basic difference between free and forced convection? Explain briefly with one example of each.

(f) What is a parallel flow heat exchanger? Sketch the variation of hot and cold fluid temperatures along the length of a parallel flow heat exchanger.

(g) The spectral distribution of the radiation emitted by a diffuse surface may be approximated as shown in Fig. Q1g. What is the total emissive power?

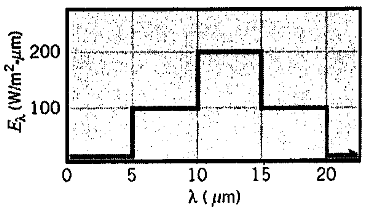

Fig. Q1g

Group II (CO2) 24

Q:2 **Answer any four parts:** 4 x 6

(a) Define fin effectiveness. Derive the expression of fin effectiveness for an infinitely long fin whose base is maintained at a constant temperature.

(b) Consider a sphere of diameter 10 mm completely enclosed in a cube of side length 15 mm. Calculate the view factor of the inner surface of the cube with respect to

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	itself.	
(c)	For a two-dimensional steady flow in rectangular coordinates, use scale analysis to simplify the energy equation applicable to the thermal boundary layer over an isothermal plate.	
(d)	How is bulk mean temperature defined in case of flow between two parallel plates? What is the mathematical condition for a thermally fully developed flow in terms of bulk mean temperature?	
(e)	Derive the expression for critical radius of insulation of a sphere made of a material of thermal conductivity k and exchanging heat with ambient by convection with a heat transfer coefficient h.	
(f)	Consider two gray diffuse infinite parallel plates 1 and 2 at temperatures T_1 and T_2 and having emissivities ε_1 and ε_2 respectively. Calculate the net radiative heat exchange per unit area from plate 1 to plate 2.	

	Group III (CO4)	30
Q:3	**Answer any three parts:**	3 x 10 =30
(a)	A steam-carrying pipe with an outer diameter of 25 cm and a length of 225 meters is insulated with two layers of thermal insulation: The first layer (high-temperature insulation) is 5 cm thick and has a thermal conductivity of k_1=0.095 W/mK, the second layer (low-temperature insulation) is 4 cm thick and has a thermal conductivity of k_2=0.065 W/mK. The inner surface of the high temperature insulation is at 400°C and the outer surface of the low temperature insulation is at 50°C. Assume steady-state conditions and heat transfer only in radial directions. (a) Calculate the total heat loss per hour through the pipe. (b) Determine the temperature at the interface between the two insulation layers.	
(b)	Consider a very long duct having the cross-section of an equilateral triangle. Each side of the triangle is 5 cm. One of the sides has emissivity of 0.7 and is at a temperature of 700 K while another side is a black surface at temperature 400 K. The third side is insulated. (i) Draw the radiation exchange network for this configuration after necessary simplifications. (ii) Calculate the temperature of the insulated surface. Neglect end effects.	
(c)	Engine oil for a large industrial gas turbine engine enters a circular tube (diameter, D =25 mm) at temperature of 87°C and leaves at 47°C. The flow rate of oil is 0.1 kg/s. Determine the convective heat transfer heat transfer coefficient between the oil and the tube. Use the property data for engine oil provided at the end. For flow through a duct, use the correlation	

(d)	$$Nu_D = 0.023\, Re_D^{0.8} Pr^{0.3}$$ A long cylindrical wood log, with a thermal conductivity of k=0.17 W/mK ° and thermal diffusivity $\alpha=1.28\times10^{-7}$ m²/s, has a diameter of 10 cm and is initially at a uniform temperature of 10°C. The log is placed in a fireplace, where it is exposed to hot gases at 500°C. The heat transfer coefficient on the surface of the log is h=13.6 W/m²·°C. Given that the ignition temperature of the wood is 420°C, calculate the time required for any part of the log to reach its ignition temperature using Heissler chart.	
	Group IV (CO5) **Answer any one question**	20
Q:4 (a)	In a counter flow double pipe heat exchanger, water is heated from 25°C to 65°C by oil with specific heat of 1.45 kJ/kg K and mass flow rate of 0.9 kg/s. The oil is cooled from 230°C to 160°C. If overall heat transfer coefficient is 420 W/m² °C. calculate following: a) The rate of heat transfer b) The mass flow rate of water considering specific heat of water to be 4.18 kJ/kgK, and c) The surface area of heat exchanger	15
(b)	Derive the expression for LMTD of a condenser.	5
Q:5.(a)	A hot water stream $(\dot{m}_h = 1\ kg/sec, c_h = 4.18\ kJ/kgK)$ is to cool from 95°C by transferring heat to oil stream $(\dot{m}_c = 2\ kg/sec, c_c = 2\ kJ/kgK)$. The oil enters at 25°C. The heat transfer area is 3.19 m². Calculate the exit temperature for water if $U = 1000\ W/m^2K$ for parallel flow geometry. For parallel flow heat exchangers $$\varepsilon = \frac{1 - exp[-NTU(1 + C_r)]}{1 + C_r}$$	15
(b)	Derive the expression for LMTD of an evaporator	5
	Group V (CO3)	16
Q:6	**Answer any two parts:**	8×2 =16
(a)	An object of volume V and surface area A is initially at temperature T_i. It loses heat to ambient at temperature T_∞ by convection with a constant heat transfer coefficient h. There is a constant heat generation Q per unit time within the object, Derive the unsteady energy balance equation, assuming lumped capacitance model to be valid. Determine the temperature of the object as a function of time.	
(b)	A thin flat plate of length L, thickness t, and width W >> L is thermally joined to two large heat sinks that are maintained at different temperatures, To and T_L (as shown in Fig. Q6b). Convection heat transfer is allowed to occur from the bottom surface to a fluid at T_∞, with a convection coefficient h, while the net heat flux to the top surface of the plate is known to have a uniform value of q_0. Derive the differential equation involving temperature of the thin plate using energy balance for an elemental control volume of length Δx in the thin plate. Write down	

the boundary conditions at the two ends of the plate (x=0 and x=L)

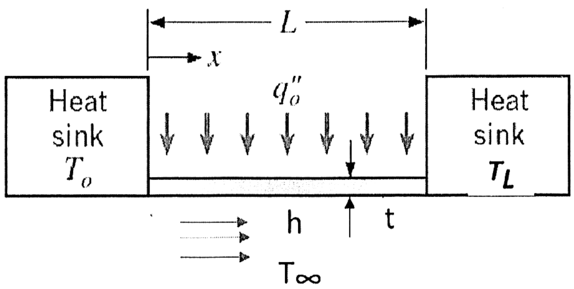

Fig. Q6b

(c) A 0.2 m thick infinite black plate having thermal conductivity 3.96 W/m K is exposed to two black surfaces, as shown in Fig. Q6c. The left surface is at a temperature of 300 K. At steady state, the left face of the plate is at a temperature of 350 K. Calculate

(i) Radiative heat exchange between the plate and the left surface

(ii) Temperature of the right face of the plate, T_1

(iii) Temperature of the black surface at the right, T_2

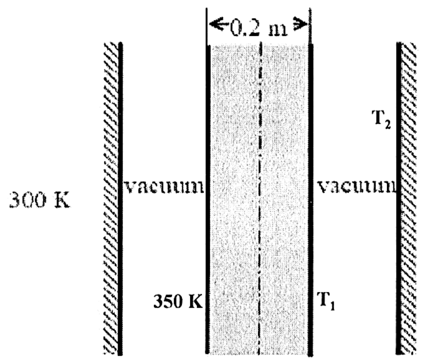

Fig. Q:6c

*Ref. No:*Ex/EE/ES/B/ME/T/216/2025

Properties for engine Oil:

Temperature, T (K)	Pressure, p (bar)[b]	Specific Volume (m^3/kg) $v_f \cdot 10^3$	v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	$c_{p,g}$	Viscosity (N · s/m^2) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	$k_g \cdot 10^3$
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3
295	0.02617	1.002	51.94	2449	4.181	1.868	959	8.89	606	19.5
300	0.03531	1.003	39.13	2438	4.179	1.872	855	9.09	613	19.6
305	0.04712	1.005	29.74	2426	4.178	1.877	769	9.29	620	20.1
310	0.06221	1.007	22.93	2414	4.178	1.882	695	9.49	628	20.4
315	0.08132	1.009	17.82	2402	4.179	1.888	631	9.69	634	20.7
320	0.1053	1.011	13.98	2390	4.180	1.895	577	9.89	640	21.0
325	0.1351	1.013	11.06	2378	4.182	1.903	528	10.09	645	21.3
330	0.1719	1.016	8.82	2366	4.184	1.911	489	10.29	650	21.7
335	0.2167	1.018	7.09	2354	4.186	1.920	453	10.49	656	22.0
340	0.2713	1.021	5.74	2342	4.188	1.930	420	10.69	660	22.3
345	0.3372	1.024	4.683	2329	4.191	1.941	389	10.89	664	22.6
350	0.4163	1.027	3.846	2317	4.195	1.954	365	11.09	668	23.0
355	0.5100	1.030	3.180	2304	4.199	1.968	343	11.29	671	23.3
360	0.6209	1.034	2.645	2291	4.203	1.983	324	11.49	674	23.7
365	0.7514	1.038	2.212	2278	4.209	1.999	306	11.69	677	24.1