Ref. No.: Ex/PG/MEC/PE/T/113F/2025

M.E. MECHANICAL ENGINEERING FIRST YEAR FIRST SEMESTER EXAM 2025

COMPUTATIONAL HEAT TRANSFER

Time: Three hours **Full Marks 100**

Use separate answer script for PART A and B. Assume any unfurnished data suitably

PART – A (50 MARKS)

Q1 is compulsory, and you must solve any two among Q2, Q3, and Q4.

Q:1.

(a) Why is the Finite Volume Method (FVM) preferred for solving heat transfer problems in fluid flow simulations? 5

(b) Solve the 1D unsteady-state heat conduction equation using the explicit and implicit finite difference methods and derive the corresponding numerical formulations. 5

(c) Why is the Crank-Nicholson method considered a good choice for transient heat conduction problems? 5

(d) What is the significance of the Peclet number in computational heat transfer, and how does it influence discretization schemes? 5

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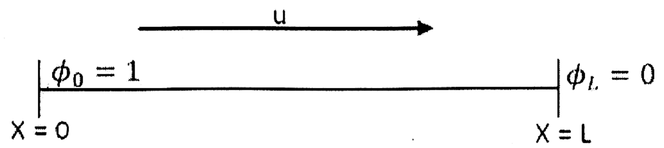
Q:2

A property Φ is transported by means of convection and diffusion through the one-dimensional domain sketched in figure below. Boundary conditions are $\Phi_0 = 1$ at $x = 0$ and $\Phi_L = 1$ at $x = L$. Calculate the value of Φ for $u = 2.0$ m/s with central differencing scheme and suggest which differencing scheme would be more appropriate and why. The following data apply: Length $L = 1.0$ m, $\rho = 1.0$ kg/m^3, $\Gamma = 0.1$ kg/m/s.

Boundary conditions for convection-diffusion problem are given in figure below 15



Q. 3

Figure 1 shows a large plate of thickness L = 1 cm with constant thermal conductivity k = 0.5 W/mK and uniform heat generation q = 2000 kW/m^3. The faces A and B are maintained at temperatures of 100 °C and 200° C respectively. Assuming that the dimensions in the y and z directions are so large that temperature gradients are significant in the x – direction only. Calculate the steady state temperature distribution

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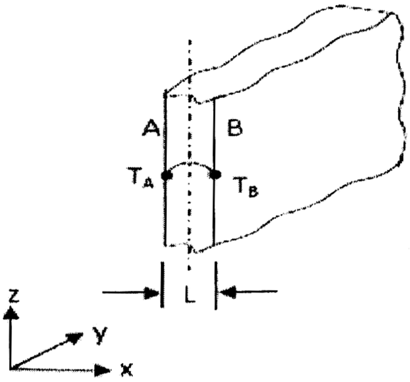
	using finite volume method (FVM). Compare the numerical results with the analytical solution. The governing equation is given by $$\frac{d}{dx}\left(k\frac{dT}{dx}\right) - q = 0$$  Fig.1 heat conduction through a plate with heat generation. The analytical solution is given by: $$T(x) = ((T_B - T_A)\, x/L) + qLx/2K - qx^2/2K + T_A$$	15
Q.4.	(a) What are the different types of partial differential equations? Explain the physical behaviour of PDE (b) Discuss the factors which contribute to errors in finite difference formulation. (c) Why is the Gauss-Seidel iterative solver preferred over the Jacobi method for solving the discretized system in 2D conduction? (d) Explain the features of TDMA method?	4 3 4 4 = 15
	PART B (50 MARKS)	
	Q1 is compulsory, answer any two (2) from the rest.	
Q.1	**a)** In the discretized equation using finite difference formulation of a differential equation, the coefficients for the neighboring four points are 2,4,2,2 respectively. If the values at these points are 10,12,12,10 respectively, find out the value of the variable at the central node. b) Calculate the allowable time step size for calculation of duct flow with inlet velocity of 10 m/s. The duct has been meshed with 50 cells along diameter of 30 cm. c) Explain the concept of turbulent Prandtl number d) You are solving thermal field in a metal rod with thermal diffusivity of $0.05 m^2/s$ The rod is 10 cm in length where 50 cells are considered. What is the maximum allowable time step size?	2 2 4 2

	e) The size of the smallest eddies (i.e. Kolmorov scale) of flow depends on viscosity and dissipation rate. Using dimensional analysis, derive a formula for Kolmogorov length scale.	4
Q.2	a) Using central difference, derive the finite volume coefficients for a 1-D problem, for the equation $$\rho u \frac{\partial \phi}{\partial x} = \Gamma \frac{\partial^2 \phi}{\partial x^2}$$	8
	b) Sketch the function Q(Pe) and state the limiting values. Show the approximations for central difference, upwinding and hybrid scheme (write the expressions separately). Use Graph paper.	10
Q.3	a) What do you mean by transportive property?	2
	b) Show if transportive property is satisfied for (i) central difference and (ii) upwinding scheme for the given equation $$\frac{\partial \emptyset}{\partial t} + u\frac{\partial \emptyset}{\partial x} = 0$$	16
Q.4	a) Derive the time-averaged turbulent continuity equation for two dimensional flow	4
	b) Explain turbulent stress - write down the terms of turbulent stress for three dimensional flow. How it is connected to turbulent viscosity?	8
	b) Temperature and velocity values at 11instances were found to be (10.9, 10.7,10.6,10.2,10.1,10.0,9.8,9.6,9.5,9.4,9.2) and (0.1,0.2,0,3,0.4,0.5,0.6,0.7,.0.8. 0.9, 1.0,1.1) Find out the value of $\overline{T'^2}$ and turbulent kinetic energy	6