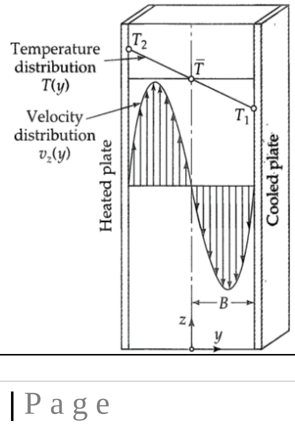
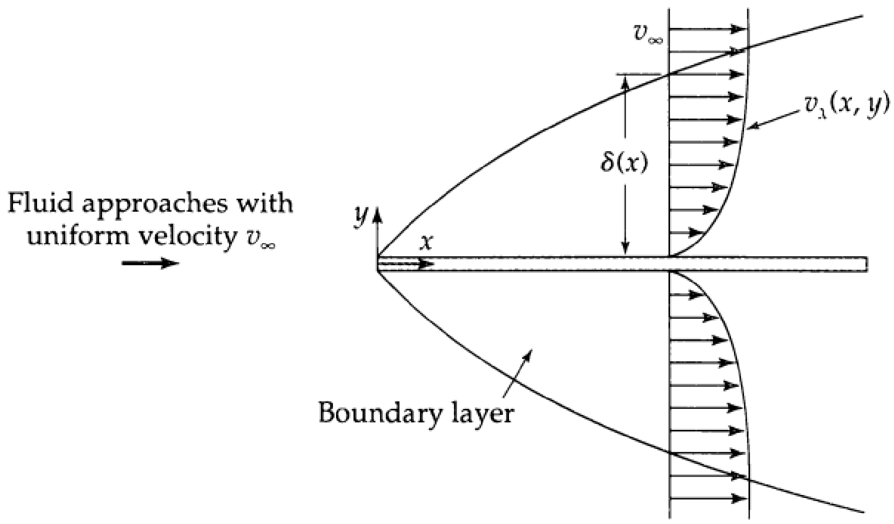
NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA
END-TERM EXAMINATION, 2023
SESSION: 2022 – 2023 (spring)
B. Tech. 6th Semester

Subject code: CH-3116 **Subject Name: Transport Phenomena** Dept. Code: **CH**
No. of pages: 02 Full Marks: 50 Duration: 3 ***Hours***

Figures at the right-hand margin indicate marks.
All parts of a question should be answered in one place.

All the terms have their usual meaning.

Q. No.	**Question**	**Marks**
1.	a. Show that the complex potential $w(z) = -v_\infty R\left(\frac{z}{R} + \frac{R}{z}\right)$ describes the potential flow around a circular cylinder of radius R, where the approach velocity is v_∞ in the positive x direction. b. Find the components of velocity vector. c. Find the pressure distribution on the cylinder surface when the modified pressure far from the cylinder is P_∞.	**4+3+3**
2.	(i) Discuss Boussinesq equation of motion for free convection. (ii) A viscous fluid with temperature-independent physical properties is in fully developed laminar flow between two vertical flat surfaces placed a distance 2B apart. The fluid flows in upward direction. At z = 0, the fully developed flow is achieved. For z < 0 the fluid temperature is uniform at T = T_1. For z > 0 heat is added at a constant, uniform flux q_0 at both walls. a. Make a **shell energy balance** to obtain the differential equation for $T(x, z)$ in the zone with z>0. b. Develop the non-dimensional equation in terms of the following variables: $\Theta = \frac{T - T_1}{q_0 B/k}$ $\sigma = \frac{x}{B}$ $\zeta = \frac{kz}{\rho \hat{C}_P v_{z,\max} B^2}$	**3+(4+3)**
3.	Two large flat porous horizontal plates are separated by a relatively small distance L. The upper plate at y = L is at temperature T_L, and the lower one at y = 0 is to be maintained at a lower temperature T_0. To reduce the amount of heat that must be removed from the lower plate, an ideal gas at T_0 is blown upward through both plates at a steady rate. Assuming negligible pressure distribution and viscous dissipation energy, and presence of both the convective and conductive energy transport in y direction, develop an expression for the temperature distribution and the amount of heat q_0 that must be removed from the cold plate per unit area as a function of the fluid properties and gas flow rate. Use abbreviation $\phi = \rho \hat{C}_P v_y L/\kappa$.	**7+3**
4.	 A fluid with density ρ and viscosity μ is located between two vertical walls a distance 2B apart. The heated wall at y = -B is maintained at temperature T_2 and the cooled wall at y = +B is maintained at T_1. It is assumed that the temperature difference is sufficiently small that the terms containing $(\Delta T)^2$ can be neglected. The system is closed at the top and bottom. Develop the expressions for the variations of (i) temperature, (ii) velocity and (iii) the expression of average velocity.	**3+4+3**

5.	Use the von Karman momentum balance to estimate the steady-state velocity profiles near a semi-infinite flat plate in a tangential stream with approach velocity v_∞. For this system the potential-flow solution is $v_e = v_\infty$. Find the expressions for the boundary layer thickness, velocity and drag force on the plate.  $$\mu \frac{\partial v_x}{\partial y}\bigg\rvert_{y=0} = \frac{d}{dx}\int_0^\infty \rho v_x(v_e - v_x)dy + \frac{dv_e}{dx}\int_0^\infty \rho(v_e - v_x)dy$$	**4+3+3**

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial y}(\rho v_y) + \frac{\partial}{\partial z}(\rho v_z) = 0$$

$$\rho\left(\frac{\partial v_z}{\partial t} + v_x\frac{\partial v_z}{\partial x} + v_y\frac{\partial v_z}{\partial y} + v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu\left[\frac{\partial^2 v_z}{\partial x^2} + \frac{\partial^2 v_z}{\partial y^2} + \frac{\partial^2 v_z}{\partial z^2}\right] + \rho g_z$$

$$\Phi_v = 2\left[\left(\frac{\partial v_x}{\partial x}\right)^2 + \left(\frac{\partial v_y}{\partial y}\right)^2 + \left(\frac{\partial v_z}{\partial z}\right)^2\right] + \left[\frac{\partial v_y}{\partial x} + \frac{\partial v_x}{\partial y}\right]^2 + \left[\frac{\partial v_z}{\partial y} + \frac{\partial v_y}{\partial z}\right]^2 + \left[\frac{\partial v_x}{\partial z} + \frac{\partial v_z}{\partial x}\right]^2 - \frac{2}{3}\left[\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z}\right]^2$$

$$\rho\hat{C}_p\left(\frac{\partial T}{\partial t} + v_x\frac{\partial T}{\partial x} + v_y\frac{\partial T}{\partial y} + v_z\frac{\partial T}{\partial z}\right) = k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] + \mu\Phi_v$$