Total number of printed pages–9

53 (FPT 403) TPEN

2012 C
2013
(May)

TRANSFER PROCESS ENGINEERING

Paper : FPT 403

Full Marks : 100

Pass Marks : 30

Time : Three hours

The figures in the margin indicate full marks for the questions.

*Answer **all** the questions.*

1. Answer ***any seven*** of the following :

   (a) State Newton's law of viscosity. Explain different types of Non-Newtonian fluids. 2+3=5

   (b) What do you mean by the term "convective momentum transport" ? What are the boundary conditions commonly used from the physical concepts in order to solve the differential equations formed for velocity and momentum flux ? 2+3=5

Contd.

(c) Explain the different regions of a velocity profile flow over a wall. 5

(d) Distinguish between the laminar and turbulent flow. Explain Prandtl's length theory. 2+3=5

(e) What are the modes of heat transfer ? Define them. 1½+3½=5

(f) What is buoyancy force ? Physically, what does the Grashof number represent ? How does the Grashof number differ from the Reynolds number ? 2+2+1=5

(g) Define thermal boundary layer. Explain in short the formation of laminar boundary layer of free convection on a vertical flat plate. 2+3=5

(h) "The mechanisms of heat transfer and mass transfer are analogous to each other" — explain this sentence. 5

(i) What is the driving force of mass transfer ? Define mass fraction and mole fraction. 1+4=5

2. Answer ***any five*** of the following : 5×7=35

(a) The parabolic velocity distribution of a liquid of density ρ flowing over a vertical flat plate of length L and weight W is shown in the following :

$$v_z = \frac{\rho g \delta^2}{2\mu}\left[1-\left(\frac{x}{\delta}\right)^2\right]$$

where, v_z = Velocity of fluid in the z-direction,

δ = Thickness of the liquid film forming over the flat plate,

x = Distance of a shell of the liquid,

μ = Viscosity of liquid.

Calculate —

(i) Maximum velocity of the fluid

(ii) Average velocity of the fluid

(iii) Mass flow rate.

(b) A cold storage room is constructed of inner layer of 12.7*mm* of pinewood, a middle layer of 101.6*mm* of cork board and outer layer of 76.2*mm* of concrete. The wall surface temperature is $255°K$ inside the cold room and $297.1K$ at the outside surface of the concrete. The thermal conductivities are given below. Calculate the heat loss in watts for $1m^2$ and the temperature at the interface between the pinewood and cork board.

Data : The thermal conductivities of the materials used are as follows :

Sl. No.	Material	Thermal Conductivities, W/m. K
1	Pinewood	0.151
2	Cork Board	0.0433
3	Concrete	0.762

(c) A hollow sphere, $10cm$ I.D. (Inner diameter) and $30cm$ O.D. (outer diameter) of a material having thermal conductivity 50 W/mK is used as a container for a liquid chemical mixture. Its inner and outer surface temperatures are $300°C$ and $100°C$ respectively.

Determine —

(i) The heat flow rate through the sphere

(ii) The temperature at a point a quarter of the way between the inner and the outer surfaces.

(d) Nichrome, having a resistivity of $100\mu\Omega\text{-}cm$ is to be used as a heating element in a $10kW$ heater. The Nichrome surface temperature should not exceed $1220°C$. Other design features include :

Surrounding air temperature $= 20°C$

Outside surface coefficient $= 1.15\ kW/m^2K$

Thermal conductivity of Nichrome $= 17\ W/mK$

Find out what diameter Nichrome wire is necessary for a I-*meter* long heater. Also find the rate of current flow.

(e) One end of a very aluminium rod is connected to a wall at $140°C$, while the other end protrudes into a room whose air temperature is $15°C$. The rod is $3mm$ in diameter and the heat transfer coefficient between the rod surface and environment is $300\ W/m^2K$. Estimate the total heat dissipated by the rod taking its thermal conductivity as $150\ W/mK$.

(f) Consider a $0.6m \times 0.6m$ thin square plate in a room at $30°C$. One side of the plate is maintained at a temperature of $90°C$, while the other side insulated. Determine the rate of heat transfer from the plate by natural convection if the plate is vertical. The properties of air at the film temperature $\left(T_f\right)$ of 60°C and 1 *atm* are :

$k = 0.02808\ W/m\,°C$

Prandtl Number, Pr = 0.7202

Kinematic viscosity, $\nu = 1.896 \times 10^{-5}\ m^2/s$

$$\beta = \frac{1}{T_f}$$

Nusselt Number for natural convection,

$$Nu = \left\{ 0.825 + \frac{0.387\, Ra_L^{1/6}}{\left[1 + \left(\frac{0.492}{Pr}\right)^{9/16}\right]^{8/27}} \right\}^2$$

(g) A thin plastic membrane separates hydrogen from air. The molar concentrations of hydrogen in the membrane at the inner and outer surfaces are determined to be 0.045 and 0.002 $Kmol/m^3$ respectively. The binary diffusion coefficient of the hydrogen in plastic at the operation temperature is $5.3 \times 10^{-10}\ m^2/s$. Compare the mass flow rate of hydrogen by diffusion through the membrane under steady conditions if the thickness of the membrane is $2mm$ and $0.5mm$.

3. Answer ***any three*** of the following : 10×3=30

(a) Prove that the velocity profile for laminar, incompressible flow of a Newtonian fluid of constant viscosity μ flowing through a circular tube of radius R and length L in the Z-direction is

$$v_z = \frac{\rho g}{4\mu} R^2 \left[1 - \left(\frac{r}{R}\right)^2\right]$$

where, v_z = Velocity of fluid in the z-direction

ρ = Density of fluid

g = Acceleration due to gravity

r = Radius of fluid at any shell.

(b) Derive the general form of time-smoothed Navier-Stoke equation of the turbulent flow in vector form as shown in below :

$$\frac{\partial}{\partial t}\left(\rho \overline{V}\right) = -\nabla p - \nabla.\left(\rho \overline{V}\overline{V}\right) - \left[\nabla.\left(\tau^{-v} + \tau^{-t}\right]\right. + \rho \overline{g}$$

where, the symbols have their usual meanings.

(c) How will you define thermal resistance of a plane wall ?

Derive an expression for the radial heat conduction through a hollow cylinder whose inside and outside surfaces are held at constant temperature, T_i and T_0 respectively and hence prove that the temperature distribution of the hollow cylinder in radial direction is

$$T = T_i + (T_0 - T_i)\frac{ln\left(\frac{r}{r_i}\right)}{ln\left(\frac{r_0}{r_i}\right)}$$

where, $T =$ Temperature at any radius (r)

$r_i =$ Inner radius of hollow cylinder

$r_0 =$ Outer radius of hollow cylinder

(d) Show that the expression for the isothermal evaporation of a liquid (A) from a surface and its subsequent diffusion through a stagnant gas (B) layer above is

$$\left(\frac{1-y_A}{1-y_{A1}}\right) = \left(\frac{1-y_{A2}}{1-y_{A1}}\right)^{\frac{x-x_1}{x_2-x_1}}$$

where, the symbols have their usual meanings.

(e) Prove that the temperature distribution at any radius in a solid cylindrical rod due to the passage of an electric current is

$$T = T_0 + \frac{\dot{q}}{4K} r_0^2 \left[1 - \left(\frac{r}{r_0} \right)^2 \right]$$

and hence show that the following relation

$$\frac{T - T_0}{T_c - T_0} = \left[1 - \left(\frac{r}{r_0} \right)^2 \right]$$

where, $\dot{q}$ = Heat generation within the rod due to the passage of an electric current

T_0 = Surface temperature of the rod

r_0 = Radius of rod

T_c = Temperature at the centre of the cylinder

K = Coefficient of thermal conductivity.

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