(c) Which non-dimensional number determines the transition from laminar to turbulent flow?

3 +(4 + 4) + 1 = 12

7. (a) A heat-treated steel plate measures $3m \times 1m$ and is initially at 30°C. It is then cooled by blowing air over both sides parallel to the $1m$ edge at $9\ km/hr$. If the air is at 10°C, calculate the heat transfer rate from both sides of the plate. Take the following properties of air at 20°C: $k = 0.0259\ W/mK$; $\nu = 15.06 \times 10^{-6}\ m^2/s$; $Pr = 0.703$ For $Re < 5 \times 10^5$, use the correlation $Nu = 0.664 Re^{0.5} Pr^{0.33}$.

(b) Derive the momentum equation for the hydrodynamic boundary layer over a flat plate. For laminar flow over a flat plate, the average value of Nusselt number $\overline{Nu}$ is prescribed by the relation $\overline{Nu} = 0.664 Re^{0.5} Pr^{0.33}$. In order to double the heat transfer coefficient, keeping all other parameters unchanged, the dynamic viscosity has to be decreased sixty four times - *Justify*.

5 + (5 + 2) = 12

Group – E

8. (a) Two horizontal steam mains with diameters $5cm$ and $15cm$ are so laid in a boiler house that any mutual heat effect is precluded. The mains are at the same surface temperature of 500°C, while the ambient air is at 50°C. Calculate (i) the ratio of heat transfer coefficients, and (ii) the ratio of convection losses per unit length of the mains. Assume $Nu \sim (Gr.Pr)^{0.25}$. Explain the physical significance of the bulk mean temperature in internal forced convection flow.

(b) A horizontal cylinder $25mm$ diameter and $500\ mm$ long is suspended in water at 20°C. Calculate the rate of heat transfer if the cylinder is at 60°C. Use the following correlation $Nu = 0.53(Gr.Pr)^{0.25}$. The relevant physical properties of water at the mean film temperature(40°C) are: $\rho = 992\ kg/m^3$; $k = 0.63\ W/mK$; $\mu = 6.527 \times 10^{-4}\ kg/ms$; $Pr = 4.3$.

(4 + 3) + 5 = 12

9. (a) In a food processing plant, a brine solution is heated from -12°C to -65°C in a double pipe parallel-flow heat exchanger, by water entering at 35°C and leaving at 20.5°C at the rate of $9\ \frac{kg}{min}$. Determine the heat exchanger area for an overall heat transfer coefficient of $860\ W/m^2K$. For water, take $c_p = 4.186 \times 10^3 \frac{J}{kgK}$.

(b) An oil cooler for a lubrication system has to cool $1000\ kg/h$ of oil ($c_p = 2.09\ kJ/kg$°C) from 80°C to 40°C by using cooling water flow of $1000\ kg/h$ ($c_p = 4.18\ kJ/kg$°C) at 30°C. Give your *choice* for a parallel flow or counter-flow heat exchanger, with reasons. Also calculate the surface area of the heat exchanger if the overall heat transfer coefficient is $U = 24\ W/m^2$°C.

6 + 6 = 12

HEAT TRANSFER
(MECH 3102)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and <u>any 5 (five)</u> from Group B to E, taking <u>at least one</u> from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) Heat transfer takes place according to
(a) First Law of Thermodynamics (b) Second Law of Thermodynamics
(c) Third Law of Thermodynamics (d) Zeroth Law of Thermodynamics.

(ii) Aluminium is used as a fin material because
(a) it has higher convection heat transfer coefficient
(b) it has higher thermal conductivity
(c) it has lower convection heat transfer coefficient
(d) it has lower thermal conductivity.

(iii) For a long thin fin with insulated tip, the fin efficiency is given by
(a) $\frac{\tanh(ml)}{ml}$ (b) $\frac{ml}{\tanh\ (ml)}$ (c) $\frac{\tan(ml)}{ml}$ (d) $\frac{ml}{\tan(ml)}$.

(iv) When does the general heat conduction equation reduce to the Laplace equation?
(a) if the body or element is in unsteady-state with heat generation
(b) if the body or element is in steady-state with heat generation
(c) if the body or element is in unsteady-state with no heat generation
(d) if the body or element is in steady-state with no heat generation.

(v) Gray body can emit radiation
(a) at higher rate than the black body (b) at lower rate than the black body
(c) at equal rate as the black body (d) cannot be predicted.

(vi) The Prandtl number Pr represents the ratio of
(a) dynamic viscosity & thermal conductivity (b) dynamic viscosity & specific heat
(c) kinematic viscosity & thermal diffusivity (d) kinematic viscosity & density.

(vii) In forced convection heat transfer, the Nusselt number is a function of fluid Prandtl number and
(a) Biot number (b) Reynolds number
(c) Grashoff number (d) Stanton number.

(viii) Which of the following represents dimensionless surface shear stress?
(a) Biot number (b) Grashoff number
(c) Coefficient of friction (d) Friction factor.

(ix) A heat exchanger with heat transfer surface area A and overall heat transfer coefficient U handles two fluids of heat capacities C_{max} and C_{min}. The parameter NTU is specified as
(a) AUC_{min} (b) $U/A\ C_{min}$ (c) $UA/\ C_{min}$ (d) $UA/\ C_{max}$.

(x) In a counter-flow heat exchanger, cold fluid enters at 30°C and leaves at 50°C. The hot fluid enters at 150°C and leaves at 130°C. The mean temperature difference for the set up is
(a) 20°C (b) 80°C (c) 60°C (d) 100°C.

Group – B

2. (a) An insulated steam pipe having outside diameter of 30mm is to be covered with two layers of insulation A and B each having thickness of 20mm. The thermal conductivity of A is 5 times that of B. Any of the insulation may be placed next to the pipe. Assuming that the inner and the outer surface temperature of the insulation to be fixed what arrangement would be better from the viewpoint of arresting heat loss?

(b) Thermal energy generated due to flow of current in a metallic rod of 6.5mm diameter and 1.25m length with the lateral surface perfectly insulated is to be limited such that nowhere in the rod, the temperature exceeds 180°C. The rod runs between two large bus bars which are at 25°C and one dimensional heat transfer along the length of the rod may be assumed. Determine the maximum current the rod can carry. For the material of rod, Electric resistivity (resistance × cross section per unit length) = 1.75×10^{-6} ohm-cm, Thermal conductivity = 250 W/m-K.

6 + 6 = 12

3. (a) A closed container with outside surface area of 0.36m^2 with a temperature of 3°C contains ice at 0°C. The container is placed in ambient air at 27°C. The convective heat transfer coefficient between the container surface and the surrounding air is estimated to be $6.25\ \text{W/m}^2\text{K}$. Calculate the mass rate of conversion of ice to liquid water. Given, the latent heat of fusion of ice is 340kJ/kg. Also estimate the thermal conductivity of the wall of thickness 20cm, if the inner surface temperature is 0°C. Assume the inner surface area same as the outside area for calculation.

(b) A certain material 200mm thick with a cross sectional area of 0.1m^2, has one side maintained at 35°C and the other at 95°C under steady state. The temperature of the central plane of the material is 62°C, and the heat flow through the material is 10kW. Assuming the thermal conductivity of the material as a linear function of temperature, find its expression.

6 + 6 = 12

Group – C

4. (a) Obtain an expression from the governing equation for the temperature distribution and heat transfer from an infinitely long fin with standard parameters. Given, the governing equation for a fin of uniform cross section is $\frac{d^2\theta}{dx^2} - m^2\theta = 0$ [symbols have usual meaning].

(b) Consider a hot boiled egg on a plate. The temperature of the egg is observed to drop by 5°C during the first minute. Will the temperature drop during the second minute be less than, equal to, or more than 5°C? Explain your answer with reasons. If t_f is the time required for a 'lumped system' to reach the average temperature $(T_i + T_\infty)/2$ where $T_i(> T_\infty)$ is the initial temperature and T_∞ is the temperature of the environment, express t_f in terms of the heat transfer coefficient h, thermal conductivity of the system k, and other thermo-physical properties.

6 + (3 + 3) = 12

5. (a) Consider an infinitesimal surface area dS_1 placed vertically below the centre of a large circular disc of diameter D, separated by a distance H and in a way parallel with the circular disc. Derive an expression of the shape factor of dS_1 with respect to the large disc.

(b) Consider two large parallel plates, one at $T_1 = 800$ K with emissivity $\varepsilon_1 = 0.9$ and the other at $T_2 = 300$ K with emissivity $\varepsilon_2 = 0.5$. A radiation shield is placed between the two plates. (i) Calculate the heat transfer rate per unit area without using the radiation shield in between. (ii) Calculate the emissivity of the radiation shield in order to reduce the radiative heat transfer to 10% of that without the shield. (iii) Calculate the temperature of the radiation shield.

6 + 6 = 12

Group – D

6. (a) The velocity distribution in a laminar boundary layer for flow over a flat plate is given by $\frac{u}{U_\infty} = \left(\frac{y}{\delta}\right)^2$ where $u(y) = u$ and $u(y = \delta) = U_\infty$. Calculate
(i) The ratio of displacement thickness to boundary layer thickness and
(ii) The ratio of momentum thickness to boundary layer thickness.

(b) Engine oil at 60°C flows over a 5 m long flat plate whose temperature is20°C. The free-stream velocity is 2 m/s. Determine the total drag force and the rate of heat transfer per unit width of the entire plate. The properties of air at film temperature of 40°C:
$\rho = 876\ kg/m^3$, $k = 0.144\ W/m.K$, $Pr = 2870$, $\nu = 242\times10^{-6}$. The *averaged* friction coefficient and he Nusselt number over the entire isothermal plate for *laminar* regime are: $Nu = 0.664\ Re_L^{0.5} Pr^{0.33}\ (Pr \geq 0.6)$ and $C_f = 1.328\ Re_L^{-0.5}$.