(vi) An increase in number of effects in a multiple effect evaporator system
(a) increases evaporator capacity
(b) increases evaporator economy
(c) decreases evaporator economy
(d) both (a) and (b).

(vii) Maximum Baffle space in a shell & tube heat exchanger as recommended by TEMA is
(a) ID of the shell (b) 1/5th ID of the shell
(c) twice ID of the shell (d) half ID of the shell.

(viii) Fins are provided on heat transferring surface to increase
(a) heat transfer area
(b) heat transfer coefficient
(c) mechanical strength of equipment
(d) efficiency of heat transferring surface.

(ix) With an increase in wavelength, the mono cromatic emissive power of a black body
(a) increases
(b) decreases
(c) increases, reaches a maximum and then decreases
(d) decreases, reaches a minimum and then increases.

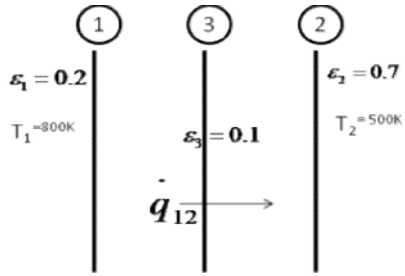
(x) Baffles are used in shell and tube heat exchanger to
(a) increase mechanical strength of the shell
(b) increase mechanical strength of the tubes
(c) account for uneven expansion between shell and tube bundle
(d) increase the magnitude of shell side film coefficient.

Group – B

2. (a) A small sphere of radius r_1 and at temperature T_1 is kept in a surrounding at temperature T_2 ($T_1 > T_2$). The sphere is covered with an insulating material of thermal conductivity k and radius r. Give a physical explanation for the fact that putting insulation up to certain thickness may increase the rate of heat loss from the sphere rather than decreasing it. Also prove that heat loss will be maximum when r = 2k/h, where h is the heat transfer co-efficient on the outer surface.

(b) Two slabs, each 100 mm thick and made of materials with thermal conductivities of 16 w/mK and 1600 w/mK are placed in contact which is not perfect. Due to roughness of surfaces only 40% of area is in contact and air fills 0.02 mm thick gap in remaining area. If the extreme surfaces of the arrangements are at temperatures of 250°C and 30°C, determine the heat flow through the composite system and temperature drop in contact. Assume half of the contact area is due to either metal. Given thermal conductivity of air is 0.032 w/mK.

(2 + 3) + (5 + 2) = 12



(2× 3) + 6 =12

Group – E

8. 0.5 kg/s of ethylene glycol flows through a thin walled copper tube of 1.25cm diameter and 0.35 kg/s of water flows in the opposite direction through annular space formed by this thin tube and tube of diameter 2 cm. The ethylene glycol which enters at 100°C is required to be cooled to 60°C while the water enters at 10°C. Calculate
(a) Heat load
(b) Water outlet temperature
(c) Driving force for heat transfer
(d) Heat transfer coefficient on ethylene glycol side
(e) Heat transfer coefficient on water side
(f) Overall heat transfer coefficient
(g) Length of the heat exchanger tube required.
Use the correlation:
$Nu = 0.023 (Re)^{0.8} (Pr)^{0.3}$
Take properties of ethylene glycol and water as listed below:

Property	Ethylene Glycol	Water
Density (kg/m^3)	1075	995
Viscosity (kg/ms)	3200 x 10^{-6}	850 x 10^{-6}
Specific heat (J/kgK)	2650	4180
Thermal conductivity (w/mK)	0.26	0.615

1 + 1 + 1 + 3 + 3 + 1 + 2 = 12

9. (a) 8000 kg/h of solution of non volatile non electrolyte solute is to be concentrated from 5% solid to 40% solid in a single effect evaporator. The evaporator will operate at a vacuum of 26 inch Hg and at this pressure water boils at 51.67°C and has a latent heat of 567 kcal/kg. Saturated steam is available at 4.76 kg/cm^2 pressure (saturation temperature 150.5°C and latent heat of condensation 540 kcal/kg). If the overall heat transfer coefficient is 2000 kcal/m^{2}hrK, calculate (i) steam economy and (ii) area of heat transfer.

(b) "Saturated steam is used as hot utility in chemical process industry but not superheated steam" – Justify.

5 + 2 + 3 + 2 = 12

(c) Define effectiveness of a heat exchanger and find an expression for it in terms of inlet and outlet temperatures of hot and cold fluid when (i) heat capacity flow rate of hot fluid and less than that of cold fluid and (ii) heat capacity flow rate of cold fluid is less than that of hot fluid.

(d) Why operating cost is higher with backward feed evaporator than that with forward feed evaporator?

5 + 2 + 3 + 2 = 12

PROCESS HEAT TRANSFER
(CHEN 2201)

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

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one 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) Thermal resistance for heat conduction through a hollow sphere of inner radius r_1 and outer radius r_2 is
(a) $\frac{r_2 - r_1}{4\pi k r_1 r_2}$ (b) $\frac{(r_2 - r_1) r_1 r_2}{4\pi k}$ (c) $\frac{4\pi k\,(r_2 - r_1)}{r_1 r_2}$ (d) $\frac{k(r_2 - r_1)}{4\pi\, r_1 r_2}$.
where k is the thermal conductivity of the material of the sphere.

(ii) Lumped parameter analysis for transient heat conduction is valid for
(a) Bi <0.1 (b) 0.1< Bi < 0.51 (c)< Bi < 100.5 (d)< Bi <1.

(iii) Prandtl number is a ratio between
(a) conduction to convection resistance
(b) momentum diffusivity to thermal diffusivity
(c) momentum diffusivity to mass diffusivity
(d) thermal diffusivity to momentum diffusivity.

(iv) Leiden-frost effect is associated with
(a) evaporation of a solution
(b) boiling of liquid on a hot surface
(c) exchange of heat between two liquids
(d) condensation of vapour on a cold surface.

(v) Dirt factor
(a) is a factor of safety
(b) accounts for additional resistance due to deposition of scale on heat transfer surface
(c) does not depend on nature of fluids handled
(d) is a degree of freedom to the design engineer.

3. (a) Define efficiency and effectiveness of fin.
Rate of heat dissipation from an infinitely long fin(Q) is given by
$Q = \sqrt{Phk\,A_c}\,(t_0 - t_a)$
Where,
P is the circumferential parameter of the fin
A_c is the cross sectional area of the fin
k is the thermal conductivity of the fin
h is the surrounding film co-efficient
t_0 is the base temperature
t_a is the ambient temperature
Derive an expression for effectiveness of the fin and comment on effect of (i) k (ii) h (iii) P/A_c ratio on effectiveness.

(b) A 12 mm diameter mild steel sphere is exposed to cooling air flow at 27°C resulting in convective co-efficient, h = 114 w/m²K.
Determine the time required to cool the sphere from 540°C to 95°C. Physical properties of mild steel are as follows:
Density = 7850 kg/m², specific heat = 475 J/kgK,
thermal conductivity = 45 W/mK.

(2 + 2 + 1 + 1 + 1) + 5 = 12

Group – C

4.(a) A steam pipe 50 mm diameter and 2.5 m long has been placed horizontally in still air at 25°C. If the pipe wall temperature is 295°C determine the rate of heat loss from the pipe. The physical properties of air at mean temperature of 160°C are as follows:
thermal conductivity = 3.64×10^{-2} W/mK
kinematic viscosity = 30.09×10^{-6} m²/s
Prandtl number = 0.682
Appropriate correlation for free convection from horizontal cylinder is
$Nu = 0.53\,(Gr.Pr)^{0.25}$.

(b) Air flows through a 10 cm internal diameter tube at a rate of 75 kg/hr. Average temperature of air may be taken as 325 K while the tube wall temperature is 375 K. Estimate air film heat transfer coefficient and rate of heat transfer from 1 m length of the tube.
If required the following correlation for turbulent flow through tube may be used:
$Nu = 0.023\,(Re)^{0.8}\,(Pr)^{0.4}$
Given the following property values of air:
viscosity = 1.967×10^{-5} kg/ms
thermal conductivity = 0.02792 W/mK
Prandtl number = 0.713

6 + 6 = 12

5. (a) Define hydrodynamic boundary layer and thermal boundary layer. Deduce Reynolds analogy to establish the interrelationship between skin friction coefficient and film heat transfer coefficient.

(b) State the advantages of counter flow arrangement over parallel flow arrangement. When would you prefer to use parallel flow arrangements? Under what conditions LMTD for parallel flow arrangement becomes exactly equal to that for counter flow arrangement?

(c) Show that the driving force for exchange of heat between two flowing fluids is logarithmic mean between two terminal temperature differences. Clearly mention the assumptions made.

(1 + 3) + (2 + 1 +1) + (3 + 1) = 12

Group – D

6. (a) Describe the boiling point curve of water at atmospheric pressure.

(b) The condenser of a steam power plant operates at a pressure of 7.38 Kpa. Steams at this pressure condense on the outer surfaces of horizontal pipes through which cooling water circulates. The outer diameter of the pipes is 0.03 m and the outer surface of the pipe is maintained at 30°C. Determine i) the rate of heat transfer to the cooling water circulating in the pipes and ii) the rate of condensation of steam per unit length of a horizontal pipe. Assume steady state operating condition exits and the tube is in isothermal condition.
Data given:
$h_{fg} = 2435 \times 10^3\,J/kg$, $\rho_1 = 994\,kg/m^3$, $\mu_1 = 0.720 \times 10^{-3}\,kg/m.s$
$c_{pl} = 4178\,J/kg\,°C$; $k_1 = 0.623\,W/m\,°C$, $\rho_v = 0.05\,kg/m^3$

6 + 6 = 12

7. (a) Write a short notes on
i) black body radiation
ii) Stefan-Boltzmann law
iii) Kirchoff's law

(b) A thin aluminum sheet with an emissivity of 0.1 on both sides is placed between two very large parallel plates that are maintained at uniform temperatures T_1= 800 K and T_2= 500 K and have emissivities $\varepsilon_1 = 0.2$ and $\varepsilon_2 = 0.7$ respectively, as shown in figure. Determine the net rate of radiation heat transfer between the two plates per unit surface area of the plates and compare the result to that without the shield.

(2× 3) + 6 =12

3. (a) Define efficiency and effectiveness of fin.
Rate of heat dissipation from an infinitely long fin(Q) is given by
$Q = \sqrt{Phk\,A_c}\,(t_0 - t_a)$
Where,
P is the circumferential parameter of the fin
A_c is the cross sectional area of the fin
k is the thermal conductivity of the fin
h is the surrounding film co-efficient
t_0 is the base temperature
t_a is the ambient temperature
Derive an expression for effectiveness of the fin and comment on effect of (i) k (ii) h (iii) P/A_c ratio on effectiveness.

(b) A 12 mm diameter mild steel sphere is exposed to cooling air flow at 27°C resulting in convective co-efficient, h = 114 w/m²K.
Determine the time required to cool the sphere from 540°C to 95°C. Physical properties of mild steel are as follows:
Density = 7850 kg/m², specific heat = 475 J/kgK,
thermal conductivity = 45 W/mK.

(2 + 2 + 1 + 1 + 1) + 5 = 12

Group – C

4.(a) A steam pipe 50 mm diameter and 2.5 m long has been placed horizontally in still air at 25°C. If the pipe wall temperature is 295°C determine the rate of heat loss from the pipe. The physical properties of air at mean temperature of 160°C are as follows:
thermal conductivity = 3.64×10^{-2} W/mK
kinematic viscosity = 30.09×10^{-6} m²/s
Prandtl number = 0.682
Appropriate correlation for free convection from horizontal cylinder is
$Nu = 0.53\,(Gr.Pr)^{0.25}$.

(b) Air flows through a 10 cm internal diameter tube at a rate of 75 kg/hr. Average temperature of air may be taken as 325 K while the tube wall temperature is 375 K. Estimate air film heat transfer coefficient and rate of heat transfer from 1 m length of the tube.
If required the following correlation for turbulent flow through tube may be used:
$Nu = 0.023\,(Re)^{0.8}\,(Pr)^{0.4}$
Given the following property values of air:
viscosity = 1.967×10^{-5} kg/ms
thermal conductivity = 0.02792 W/mK
Prandtl number = 0.713

6 + 6 = 12

5. (a) Define hydrodynamic boundary layer and thermal boundary layer. Deduce Reynolds analogy to establish the interrelationship between skin friction coefficient and film heat transfer coefficient.

(b) State the advantages of counter flow arrangement over parallel flow arrangement. When would you prefer to use parallel flow arrangements? Under what conditions LMTD for parallel flow arrangement becomes exactly equal to that for counter flow arrangement?

(c) Show that the driving force for exchange of heat between two flowing fluids is logarithmic mean between two terminal temperature differences. Clearly mention the assumptions made.

(1 + 3) + (2 + 1 +1) + (3 + 1) = 12

Group – D

6. (a) Describe the boiling point curve of water at atmospheric pressure.

(b) The condenser of a steam power plant operates at a pressure of 7.38 Kpa. Steams at this pressure condense on the outer surfaces of horizontal pipes through which cooling water circulates. The outer diameter of the pipes is 0.03 m and the outer surface of the pipe is maintained at 30°C. Determine i) the rate of heat transfer to the cooling water circulating in the pipes and ii) the rate of condensation of steam per unit length of a horizontal pipe. Assume steady state operating condition exits and the tube is in isothermal condition.
Data given:
$h_{fg} = 2435 \times 10^3\,J/kg$, $\rho_1 = 994 kg/m^3$, $\mu_1 = 0.720 \times 10^{-3}\,kg/m.s$
$c_{pl} = 4178 J/kg\,°C$; $k_1 = 0.623 W/m\,°C$, $\rho_v = 0.05 kg/m^3$

6 + 6 = 12

7. (a) Write a short notes on
i) black body radiation
ii) Stefan-Boltzmann law
iii) Kirchoff's law

(b) A thin aluminum sheet with an emissivity of 0.1 on both sides is placed between two very large parallel plates that are maintained at uniform temperatures T_1= 800 K and T_2= 500 K and have emissivities $\varepsilon_1 = 0.2$ and $\varepsilon_2 = 0.7$ respectively, as shown in figure. Determine the net rate of radiation heat transfer between the two plates per unit surface area of the plates and compare the result to that without the shield.