1. Write the Poisson’s equation for heat conduction.

2. What is lumped heat capacity analysis?

3. Define thermal boundary layer thickness.

4. What do you understand by free and forced convection?

5. What is effectiveness of a heat exchange?

6. Give the expression for NTU.

7. Find the temperature of the sun assuming as a black body, if the intensity of radiation is maximum at the wave length of \(0.5 \mu\).

8. State Kirchhoff’s law.

9. Define molar concentration.

10. What is mass average velocity?
PART B — (5 × 16 = 80 Marks)

11. (a) Derive the general heat conduction equation in cylindrical coordinates. (16)

Or

(b) Derive the general heat conduction equation for a hollow cylinder. (16)

12. (a) Air at 20°C at 3m/s flows over a thin plate of 2m long and 1m wide. Estimate the boundary layer thickness at the trailing edge, total drag force, mass flow of air between $x=30\text{cm}$ and $x=80\text{cm}$. Take $\nu = 15 \times 10^6$ and $\rho = 1.17 \text{kg/m}^3$. (16)

Or

(b) Calculate the convective heat transfer from a radiator 0.5m wide and 1m high at 84°C in a room at 20°C. Treat the radiator as a vertical plate. (16)

13. (a) Dry steam at 2.45 bar condenses on a vertical tube of height of 1m at 117°C. Estimate the thickness of the condensate film and the local heat transfer coefficient at a distance 0.2 m from the upper end of the plate. (16)

Or

(b) Derive the LMTD for a parallel flow heat exchanger stating the assumptions. (16)

14. (a) Derive the radiation exchange between

(i) Large parallel gray surfaces and

(ii) Small gray bodies. (16)

Or

(b) Two large parallel plates of 1m×1m spaced 0.5m apart in a very large room whose walls are at 27°C. The plates are at 900°C and 400°C with emissivities 0.2 and 0.5 respectively. Find the net heat transfer to each plate and to the room. (16)

15. (a) The temperature recorded by a thermometer whose bulb covered by a wet wick in dry air at atmospheric pressure is 22°C. Estimate the true air temperature. (16)

Or

(b) Dry air at 27°C and 1 bar flows over a wet plate of 50cm at 50m/s. Calculate the mass transfer coefficient of water vapour in air at the end of the plate. (16)


3. What is lumped system analysis? When is it used?

4. In which mode of heat transfer is the convection heat transfer coefficient usually higher, natural or forced convection? Why?

5. Define bulk temperature.

6. List the various promoters used for maintaining dropwise condensation.

7. Define LMTD of a heat exchanger.

8. What do you understand by thermal radiation?

9. What does the view factor represent? When the view factor from a surface to itself is zero?

10. What is the physical meaning of Schmidt number?
PART B — (5 × 16 = 80 marks)

11. (a) (i) Define thermal conductivity. How does it vary with temperature for gases? (4)

(ii) Derive the general 3-dimensional heat conduction equation in cylindrical coordinates. Assume the material as homogeneous isotropic continues. (12)

Or

(b) A cold storage room has walls made of 23 cm of brick on the outside, 8 cm of plastic foam and finally 1.5 cm of wood on the inside. The outside and inside air temperatures are 22°C and –2°C respectively. The inside and outside heat transfer coefficients are respectively 29 and 12 W/m².K. The thermal conductivities of brick, foam and wood are 0.98, 0.02 and 0.12 W/m.K respectively. If the total wall area is 90 m², determine the rate of heat removal by refrigeration and the temperature of the inside surface of the brick.

12. (a) (i) Define the velocity boundary layer and thermal boundary layer thicknesses for flow over a flat plate. (4)

(ii) Atmospheric air at 150°C flows with a velocity of 1.25 m/s over a 2 m long flat plate whose temperature is 25°C. Determine the average heat transfer coefficient and the rate of heat transfer for a plate width of 0.5 m. (12)

Or

(b) A 6 – m long section of an 8 cm diameter horizontal hot water pipe passes through a large room in which the air and walls are at 20°C. The pipe surface is at 70°C and the emissivity of the pipe surface is 0.7. Find the rate of heat loss from the pipe by natural convection and radiation.

13. (a) Consider laminar film condensation of a stationary vapour on a vertical flat plate of length L and width b. Derive an expression for the average heat transfer coefficient. State the assumptions made.

Or

(b) (i) Explain briefly fouling in heat exchangers. (6)

(ii) Hot gases enter a finned tube, cross flow heat exchanger with a flow rate of 1.5 kg/s and a temperature of 250°C. The gases are used to heat water entering the exchanger at a flow rate of 1 kg/s and an inlet temperature of 35°C. On the gas side, the overall heat transfer coefficient and the area are 100 W/m².K and 40 m² respectively. What is the rate of heat transfer by the exchanger and what are the gas and water exit temperatures? Assume $C_p$ of gas as 1.0 kJ/kg.K. (10)
14. (a) (i) Distinguish between irradiation and radiosity. (4)

(ii) Consider a cylindrical furnace with outer radius = height = 1 m. The top (surface 1) and the base (surface 2) of the furnace have emissivities 0.8 & 0.4 and are maintained at uniform temperatures of 700 K and 500 K respectively. The side surface closely approximates a black body and is maintained at a temperature of 400 K. Find the net rate of radiation heat transfer at each surface during steady state operation. Assume the view factor from the base to the top surface as 0.38. (12)

Or

(b) (i) Considering radiation in gases, derive the exponential-decay formula. (6)

(ii) Two very large parallel planes exchange heat by radiation. The emissivities of the planes are respectively 0.8 and 0.3. To minimize the radiation exchange between the planes, a polished aluminium radiation shield is placed between them. If the emissivity of the shield is 0.04 on both sides, find the percentage reduction in heat transfer rate. (10)

15. (a) (i) With neat sketches, explain the different types of fins. (4)

(ii) Air at 1.01 bar and 30°C flows past a tray full of water with a velocity of 2 m/s. The partial pressure of water vapour is 0.7 kPa and the saturation pressure is 3.17 kPa. The tray measures 40 cm along the flow direction and has a width of 20 cm. Calculate the evaporation rate of water if the temperature on the water surface is 25°C. Assume the following properties for air: density, \( \rho \approx 1.2 \text{ kg/m}^3 \), kinematic viscosity, \( \nu = 15 \times 10^{-6} \text{ m}^2/\text{s} \), and diffusivity, \( D = 0.145 \text{ m}^2/\text{h} \). (12)

Or

(b) Write short notes on the following: (8 + 8)

(i) Analogy between heat and mass transfer

(ii) Evaporation process in the atmosphere.

Sixth Semester

(Regulation 2004)

Mechanical Engineering

ME 1351 — HEAT AND MASS TRANSFER

(Common to B.E. (Part-Time) Fifth Semester, Regulation-2005)

Time : Three hours
Maximum : 100 marks

Heat and Mass Transfer Data Handbook is permitted.

Answer ALL questions.

PART A — (10 x 2 = 20 marks)

1. Distinguish between Fin Efficiency and Fin Effectiveness.

2. What is the use of Heislers chart?

3. What is overall heat transfer co-efficient?

4. What is the significance of Dimensional number?

5. What is condensation process?

6. What is Fouling factor?

7. Explain electrical analogy.

8. What is grey body?


PART B — \((5 \times 16 = 80\) marks)

11. (a) (i) Derive the heat conduction equation in cylindrical co-ordinates using an elemental volume for a stationary isotropic solid. 

(ii) A 3 cm OD steam pipe is to be covered with two layers of insulation each having a thickness of 2.5 cm. The average thermal conductivity of one insulation is 5 times that of the other. Determine the percentage decrease in heat transfer if better insulating material is next to pipe than it is the outer layer. Assume that the outside and inside temperatures of composite insulation are fixed.

(b) (i) Explain briefly the concept of critical thickness of insulation and state any two applications of the same.

(ii) A 6 cm long copper rod \((k = 300 \text{ W/mK})\) 6mm in diameter is exposed to an environment at 20°C. The base temperature of the rod is maintained at 160°C. The heat transfer coefficient is 20 W/m²K. Calculate the heat given by the rod and efficiency and effectiveness of the rod.

12. (a) (i) Explain for fluid flow along a flat plate:

1. Velocity distribution in hydrodynamic boundary layer
2. Temperature distribution in thermal boundary layer
3. Variation of local heat transfer coefficient along the flow.

(ii) The water is heated in a tank by dipping a plate of 20 cm X 40 cm in size. The temperature of the plate surface is maintained at 100°C. Assuming the temperature of the surrounding water is at 30°C, Find the heat loss from the plate 20 cm side is in vertical plane.

(b) (i) Define the Biot and Fourier numbers.

(ii) What is meant by lumped capacity? What are the physical assumptions necessary for a lumped capacity unsteady state analysis to apply?

(iii) A slab of Aluminum 5 cm thick initially at 200°C is suddenly immersed in a liquid at 70°C for which the convection heat transfer coefficient is 525 W/m²K. Determine the temperature at a depth of 12.5 mm from one of the faces 1 minute after the immersion. Also calculate the energy removed per unit area from the plate during 1 minute of immersion.

Take \(p = 2700\) bar, \(C_p = 0.9 \text{ kJ/kg.}^\circ\text{K},\)
\(k=215 \text{ W/mK}, \alpha = 8.4X10^{-5} \text{ m}^2/\text{s}.\)
13. (a) (i) With a neat and labeled sketch explain the various regimes in boiling heat transfer. (8)

(ii) A vertical plate 0.5 m² in area at temperature of 92°C is exposed to steam at atmospheric pressure. If the steam is dry and saturated estimate the heat transfer rate and condensate mass per hour. The vertical length of the plate is 0.5 m. Properties of water at film temperatures of 96°C can be obtained from tables. (8)

Or

(b) (i) Compare LMTD and NTU method of heat exchanger analysis. (6)

(ii) Hot exhaust gases which enters a finned tube cross flow heat exchanger at 300°C and leave at 100°C, are used to heat pressurized water at a flow rate of 1 kg/s from 35 to 125°C. The exhaust gas specific heat is approximately 1000 J/kg.K, and the overall heat transfer co-efficient based on the gas side surface area is \( U_h = 100 \text{W/m}^2\text{K} \). Determine the required gas side surface area \( A_h \) using the NTU method.

Take \( C_p,c \) at \( T_c = 80^\circ \text{C} \) is 4197 kJ/kg.K and \( C_p,h = 1000 \text{J/kg.K} \). (10)

14. (a) (i) State and prove the following laws:

(1) Kirchoff's law of radiation

(2) Stefan — Boltzmann law (8)

(ii) Show from energy balance consideration that the radiation heat transfer from a plane composite surface area \( A_1 \) and made up of plane surface areas \( A_2 \) and \( A_3 \) to a plane surface area \( A_t \) is given by:

\[
A_4 F_{41} = A_3 F_{31} + A_2 F_{21}
\]

and

\[
F_{14} = F_{12} + F_{13}
\] (8)

Or

(b) (i) Using the definition of radiosity and irradiation prove that the radiation heat exchange between two grey bodies is given by the relation:

\[
Q_{net} = \frac{\sigma (T_1^4 - T_2^4)}{1 - \varepsilon_1 + 1 + \varepsilon_2}
\]

\[
A_1 \varepsilon_1 A_2 F_{1-2} + A_2 \varepsilon_2
\] (8)

(ii) A surface at 100K with emissivity of 0.10 is protected from a radiation flux of 1250 W/m² by a shield with emissivity of 0.05. Determine the percentage cut off and the shield temperature. Assume shape factor as 1. (8)

3 C 3306
15.  (a) (i) Explain Fick's first and second laws of diffusion.  
(ii) Explain the phenomenon of equimolar counter diffusion. Derive an expression for equimolar counter diffusion between two gases or liquids.  

Or

(b) (i) Define the Schmidt, Sherwood and Lewis numbers. What is the physical significance of each?  
(ii) Dry air at 27°C and 1 atm flows over a wet flat plate 50 cm long at a velocity of 50 m/s. Calculate the mass transfer coefficient of water vapour in air at the end of the plate. Take the diffusion coefficient of water vapour in air is $D_{AB} = 0.26 \times 10^{-4}$ m$^2$/s.
Of

through 65 meters, determine the work done during the process.
100 kJ/kg of heat, through the system and that passes through the system and leaves
internal energy 750 kJ/kg, the fluid leaves the system with a final pressure of 7.2 bar, velocity 180 m/s,
7 kg/min with an initial pressure of 2 bar, initial velocity 15 m/s,
7 kg/min with an initial pressure of 2 bar, initial velocity 15 m/s,

A steady flow thermodynamic system receives fluid at the rate of

Various terms:

11. (a) (i) Write down the steady flow energy equation clearly indicating the

PART B — (6 x 16 = 96 marks)

10. Distinguish between free convection and forced convection.
9. What do you understand by convection and convection heat transfer?
8. What is sensible cooling and sensible heating?
7. List down any four advantages of multistage compression.
6. Mention the principle of an impulse turbine and a reaction turbine.
5. Define wet steam and dry steam, fraction of steam.
4. Mention the process involved in diesel cycle.
3. What do you understand by two stroke and four stroke cycle engines?
2. Distinguish between a refrigerator and a heat pump.
1. Define path and point functions.

PART A — (10 x 2 = 20 marks)

Answer all questions.

Use of Steam tables, HTL Data Book, Refrigeration tables permitted.

Time: Three hours

Regulation 2014

Control & Instrumentation (Common to Electronics and Instrumentation, Electrical and Instrumentation and

ME 121 I — APPLIED THERMODYNAMICS

Electrical and Electronics Instrumentation

Third Semester


D 4063
Length of pipe.

The atmosphere is at 20°C. Find the rate of heat loss from a 60 m pipe.

Inside and outside heat transfer coefficients are 60 and 12 W/m²°C. The corresponding thermal conductivities are 0.24 and 0.4 W/m°C. The insulating material of thickness 60 mm and 40 mm and their thermal conductivity materials of thickness 60 mm and 40 mm and their different layers are considered with two layers of different materials.

Heat at a temperature of 65°C is flowing through a steel pipe of 120 mm diameter. The pipe is covered with two layers of different materials.

Obtain an expression for heat conduction through a plane wall.

List down the different types of air conditioning systems.

Describe the operation of a vapour compression refrigeration system with a neat sketch.

Or

A centrifugal compressor.

With a neat sketch explain the construction and principle of operation of a centrifugal compressor.

Draw the layout of a steam power plant and explain the principle of operation.

Explain very briefly compounded impulse turbine with a neat sketch.

Or

Clearly the function of each.

List down the various boiler mountings and accessories indicating their working and interconnections.

Show the Brayton cycle on P-V and T-s diagrams indicating the sketch.

Explain the operation of a closed cycle gas turbine with a neat sketch.

Or

Discuss the construction of two stroke compression ignition engine with a sketch.

Explain the principle of operation of a four stroke cycle spark ignition engine with a neat sketch.

Discuss the concept of entropy and the principle of entropy increase.
(8) Difficulty: block body, gray body, radiation shape factor, and in

(60°C) take K = 0.66 W/mK, λ = 0.475 x 10^-6 m²/s and Pr = 2.98.

Determine whether the flow is laminar or turbulent. For water at
water temperature is 50°C and the wall is isothermal at 80°C.

Dilution – Boelter equation and the rate of heat transfer if the mean
velocity 0.8 m/s. Determine the heat transfer coefficient using
water flows inside a tube 5 cm in diameter and 5 m long at a
1. What is a thermodynamic property? How are they classified?

2. What is a heat pump?

3. List down any two differences between two stroke and four stroke I.C. engines.

4. What is meant by regeneration in gas turbine cycle?

5. What are boiler mountings and accessories?

6. What is meant by governing of steam turbines?

7. Name the factors on which the volumetric efficiency of a reciprocating compressor depends on.

8. What is sub cooling with respect to refrigeration cycles?

9. What is critical thickness of insulation?

10. Define radiation shape factor.
11. (a) (i) What is a thermodynamic system? Explain the classification of thermodynamic system with suitable examples. 

(ii) An air compressor draws in air at 1 bar pressure, 0.5 m³/kg specific volume and 5 m/sec velocity and delivers at 7 bar pressure, 0.15 m³/kg specific volume and 7.5 m/sec velocity. If the enthalpy of air at delivery is 170 kJ/kg greater than that at inlet and the rate of airflow is 15 kg/min. Estimate the power of the compressor in kW and the ratio of pipe diameters at inlet and outlet. Assume a heat loss of 7300 kJ/min to the cooling water and surrounding air. 

Or 

(b) (i) Establish the inequality of Clausius.

(ii) A heat pump uses water in a river at 6°C as an energy source and it delivers heat at 65°C to a building. It operates at 65% of its maximum possible COP between these temperatures and is powered by a 1.5 kW motor. What is the heat output to the building?

12. (a) (i) Compare the efficiency of Otto, Diesel and Dual cycles for the same compression ratio and heat rejection with the help of p-V and T-s diagrams.

(ii) Explain the working of four-stroke spark ignition engine with suitable sketches.

Or 

(b) (i) What are the effects of reheat, intercooling and regeneration in Brayton cycle efficiency?

(ii) Differentiate clearly between a closed cycle gas turbine and open cycle gas turbine.
13. (a) (i) Explain the process of steam formation with the help of temperature-total heat graph. (8)

(ii) The following observations were made in a boiler trial:
Coal used 250 kg of calorific value 29,800 kJ/kg, water evaporated 2000 kg, steam pressure 11.5 bar, dryness fraction of steam 0.95 and feed water temperature 34°C.
Calculate the equivalent evaporation “from and at 100°C” per kg of coal and the efficiency of the boiler. (8)

(b) (i) What are the different compounding methods of steam turbines? Explain velocity compounding. (10)

(ii) Draw the velocity diagram of an impulse turbine and indicate the various components. (6)

14. (a) (i) Differentiate between centrifugal compressor and axial flow compressor. (5)

(ii) A single stage reciprocating air compressor takes in 7.5 m³/min of air at 1 bar and 30°C and delivers it at 5 bar. The clearance is 5 percent of the stroke. The expansion and compression are polytropic with n = 1.3. Calculate the temperature of air delivered, volumetric efficiency and power of the compressor. (11)

(b) (i) With the help of p-h diagram explain the effect of sub cooling and super heating on vapour compression refrigeration cycle. (8)

(ii) With the help of a neat sketch explain summer air-conditioning system. (8)

15. (a) (i) Derive an expression for the quantity of heat flow through a hollow sphere. (10)

(ii) Hot air at a temperature of 60°C is flowing through a steel pipe of 10 cm diameter. The pipe is covered with two layers of different insulating materials of thicknesses 5 cm and 3 cm, and their corresponding thermal conductivities are 0.23 and 0.37 W/m K. The inside and outside heat transfer coefficients are 58 and 12 W/m²K. The atmosphere is at 25°C. Find the rate of heat loss from a 50 m length of pipe. Neglect the resistance of the steel pipe. (6)

Or
(b) (i) Write a note on thermoelectric cooling.

(ii) Water flows inside a tube 5 cm in diameter and 3 m long at a velocity 0.8 m/s. Determine the heat transfer coefficient and the rate of heat transfer if the mean water temperature is 50°C and the wall is isothermal at 70°C.

For water at 60°C, take $k = 0.66 \text{ W/m K}$, $\nu = 0.478 \times 10^{-6} \text{ m}^2/\text{s}$, and $Pr = 2.98$. (8)
PART A — (10 × 2 = 20 Marks)

1. What do you understand by lumped capacity analysis?
2. Define fin efficiency and effectiveness.
3. Distinguish between free and forced convection.
4. State Buckingham’s \( \Pi \) theorem. What are \( \Pi \) terms?
5. Indicate the difference between boiling and condensation.
6. What is fouling? Why are fouling factors taken into account in the design of heat exchangers?
7. State the Stefan-Boltzmann and Wien’s displacement laws of radiation.
8. Calculate the total rate of energy emission of a body having an area of 0.12 m\(^2\) maintained at a temperature of 527°C.
10. Define equimolar counter diffusion.

PART B — (5 × 16 = 80 Marks)

11. (a) (i) State Fourier’s law of heat conduction. Give Fourier’s, Poisson’s and Laplace equation from the general heat conduction equation. (8)

(ii) A steel rod of diameter 12 mm and 60 mm long with an insulated end that has a thermal conductivity of 32 W/(m.°C) is to be used as a spine. It is exposed to surroundings with a temperature of 60°C and a heat transfer coefficient of 55 W/(m\(^2\).°C). The temperature at the base of the fin is 95°C. Calculate the fin efficiency, the temperature at the edge of the spine and the heat dissipation. (8)

Or

(b) (i) Two slabs each of 120 mm thick have thermal conductivities of 14.5 W/m°C and 210 W/m°C. These are placed in contact but due to roughness only 30% of area is in contact and the gap in the remaining area is 0.025 mm thick and is filled with air. If the temperature of the face of the hot surface is at 220°C and the outside surface of other slab is at 30°C, calculate the heat flow through the composite system. Assume that the conductivity of air is 0.032 W/m°C and that half of the contact (of the contact area) is due to either metal. (8)
(ii) A 60 mm thick large steel plate \([k = 42.6 \text{ W/m.°C}], \alpha = 0.043 \text{ m}^2/\text{h}\) initially at 440°C is suddenly exposed on both sides to an ambient with convective heat transfer coefficient 235 W/(m².°C) and temperature 50°C. Determine the centre line temperature and the temperature inside the plate 15 mm from the mid plane after 4.3 minutes.

12. (a) (i) Define Reynold's, Prandtl, Nusselt and Grashoff number and give their expressions. (8)

(ii) Air is flowing over a flat plate 5 m long and 2.5 m wide with a velocity of 4 m/s at 15°C. If \(\rho = 1.208 \text{ kg/m}^3\) and \(\nu = 1.47 \times 10^{-5} \text{ m}^2/\text{s}\), calculate the length of plate over which the boundary layer is laminar and thickness of the boundary layer (laminar), shear stress at the location where boundary layer ceases to be laminar and the total drag force on the both sides on that portion of the plate where boundary layer is laminar. (8)

Or

(b) (i) Draw the profile of a boundary layer on a flat plate showing the velocity profiles and explain the significance of boundary layer. Define thermal boundary layer. (6)

(ii) A vertical cylinder 1.5 m high and 180 mm in diameter is maintained at 100°C in an atmosphere of 20°C. Calculate the heat loss by free convection from the surface of the cylinder. Assume properties of air at mean temperature as \(\rho = 1.06 \text{ kg/m}^3\) and \(\nu = 18.97 \times 10^{-7} \text{ m}^2/\text{s}\), \(c_p = 1.004 \text{ kJ/kg°C}\) and \(k = 0.1042 \text{ kJ/m.h.°C}\). (10)

13. (a) (i) Explain briefly the various regimes of pool boiling. (10)

(ii) A vertical cooling fin approximating a flat plate 40 cm in height is exposed to saturated steam at atmospheric pressure \((T_{\text{sat}} = 100°C, h_{fg} = 2257 \text{ kJ/kg})\). The fin is maintained at a temperature of 90°C. Calculate the thickness of the film at the bottom of the fin and overall heat transfer coefficient.

The relevant fluid properties are \(\rho_i = 965.3 \text{ kg/m}^3\), \(k_i = 0.68 \text{ W/m°C}\) and \(\mu_i = 3.153 \times 10^{-4} \text{ Ns/m}^2\). (6)

Or

(b) (i) Explain how heat exchangers are classified? (6)

(ii) The flow rates of hot and cold water streams running through a parallel flow heat exchanger are 0.2 kg/s and 0.5 kg/s respectively. The inlet temperatures on the hot and cold sides are 75°C and 25°C respectively. The exit temperature of hot water is 45°C. If the individual heat transfer coefficients on both sides are 650 W/m°C, calculate the area of the heat exchanger. (10)

14. (a) (i) Calculate the following for an industrial furnace in the form of a black body and emitting radiation at 2500 °C:

1. Monochromatic emissive power at 1.2 \(\mu\) m length
2. Wavelength at which the emission is maximum
3. Maximum emissive power
4. Total emissive power
5. Total emissive power of the furnace if it is assumed as a real surface with emissivity equal to
0.9. (10)

(ii) Define the following:
(1) Black body
(2) Grey body
(3) Opaque body
(4) White body
(5) Specular reflection
(6) Diffuse reflection.

Or

(b) (i) Calculate the net radiant heat exchange per m² area for two large parallel plates at temperatures of 427°C and 27°C respectively. The emissivity of hot and cold plate is 0.9 and 0.6 respectively. If a polished aluminium shield is placed between them, find the percentage reduction in the heat transfer. The emissivity of shield is 0.4.

(ii) The radiation shape factor of the circular surface of a thin hollow cylinder of 10 cm diameter and 10 cm length is 0.1716. What is the shape factor of the curved surface of the cylinder with respect to itself? (10)

15. (a) (i) Define mass concentration, molar concentration, mass fraction and mole fraction. (4)

(ii) Derive the general mass transfer equation in Cartesian coordinates. (12)

Or

(b) (i) A vessel contains binary mixture of O₂ and N₂ with partial pressures in the ratio 0.21 and 0.79 at 15°C. The total pressure of the mixture is 1.1 bar. Calculate the following:

(1) Molar concentrations,
(2) Mass densities,
(3) Mass fractions and
(4) Molar fractions of each species. (10)

(ii) Air at 1 atm and 25°C containing small quantities of iodine, flows with a velocity of 6.2 m/s inside a 35 mm diameter tube. Calculate the mass transfer coefficient for iodine. The thermo-physical properties of air are \( \nu = 15.5 \times 10^{-6} \text{m}^2/\text{s} \); \( D = 0.82 \times 10^{-5} \text{m}^2/\text{s} \). (6)
1. What are the two mechanisms of heat conduction in solids?

2. What is the purpose of attaching fins to a surface? What are the different types of fin profiles?

3. In what medium is the lumped system analysis more likely to be applicable? An aluminum or wood? Why?

4. List the parameters that influence the heat transfer coefficient.

5. Physically, what does the Grashof number represent and how does it differ from Reynolds number?

6. How does boiling differ from evaporation?

7. What are the different types of fouling in heat exchangers?

8. What is total hemispherical emissivity?

9. What are radiation shields?

10. What is the physical meaning of Lewis number?
PART B — (5 × 16 = 80 marks)

11. (a) (i) Explain Newton’s law of cooling and Stefan-Boltzmann’s law of thermal radiation. 

(ii) A composite wall consists of 2.5 cm thick Copper plate, a 3.2 cm layer of asbestos insulation and a 5 cm layer fibre plate. Thermal conductivities of the materials are respectively 355, 0.110 and 0.0489 W/m.K. The temperature difference across the composite wall is 560°C (560°C on one side and 0°C on the other side. Find the heat flow through the wall per unit area and the interface temperature between asbestos and fibre plate. 

(12)

Or

(b) The cylinder of a 2-stroke SI engine is constructed of aluminum alloy \( k = 186 \text{ W/m.K} \). The height and outside diameter of the cylinder are respectively 15 cm and 5 cm. Under steady operating conditions, the outer surface of the cylinder is at 500 K and is exposed to the ambient air at 300 K, with a convection heat transfer coefficient of 50 \( \text{W/m}^2\text{K} \). Equally spaced annular fins are attached with the cylinder to increase the heat transfer. There are five such fins with uniform thickness, \( t = 6 \text{ mm} \) and length, \( L = 20 \text{ mm} \). Calculate the increase in heat transfer due to the addition of fins.

(12)

12. (a) (i) Explain the development of velocity boundary layer for flow over a flat plate.

(ii) Engine oil at 60°C flows with a velocity of 2 m/s over a 5 m long flat plate whose temperature is 20°C. Determine the drag force exerted by oil on the plate and the rate of heat transfer for a plate width of 1 m.

(12)

Or

(b) (i) Define bulk temperature and thermal entry length for tube flows.

(ii) A metallic cylinder of 12.7 mm diameter and 94 mm length is heated internally by an electric heater and its surface is cooled by air. The free stream air velocity and temperatures are respectively 10 m/s and 26.2°C. Under steady operating conditions, heat dissipated by the cylinder is 39.1 W and its average surface temperature is 128.4°C. Determine the
convection heat transfer coefficient from the above experiment. Also find the convection heat transfer coefficient from an appropriate correlation and compare both.

13. (a) (i) Discuss critical heat flux and Leidenfrost point. (4)

(ii) A 10 by 10 array of horizontal tubes of 1.27 cm diameter is exposed to pure steam at atmospheric pressure. If the tube wall temperature is 98°C, estimate the mass of steam condensed assuming a tube length of 1.5 m. (12)

Or

(b) (i) List the assumptions made in the analysis of heat exchangers. (4)

(ii) In a cross flow heat exchanger, air is heated by water. Air enters the exchanger at 15°C and a mass flow rate of 2 kg/s while water enters at 90°C and a mass flow rate of 0.25 kg/s. The overall heat transfer coefficient is 250 W/m².K. If the exchanger has a heat transfer area of 8.4 m², find the exit temperatures of both the fluids and the total heat transfer rate. (12)

14. (a) (i) What is a black body? Find the energy emitted by a black body at 700°C. (4)

(ii) A furnace is approximated as an equilateral triangular duct of sufficient length so that end effects can be neglected. The hot wall of the furnace is maintained at 900 K and has an emissivity of 0.8. The cold wall is at 400 K and has the same emissivity. Find the net radiation heat flux leaving the wall. Third wall of the furnace may be assumed as a reradiating surface. (12)

Or

(b) (i) Considering radiation in gases, obtain the exponential-decay formula. (6)

(ii) Consider two concentric cylinders having diameters 10 cm and 20 cm and a length of 20 cm. Designating the open ends of the cylinders as surfaces 3 and 4, estimate the shape factor, F_{3-4}. (10)

15. (a) (i) How does mass transfer differ from bulk fluid motion? State Fick's law of diffusion. (4)

(ii) An open pan of 20 cm diameter and 8 cm depth contains water at 25°C and is exposed to dry atmospheric air. Assuming the rate of diffusion of water as $8.54 \times 10^{-4}$ kg/h, find the diffusion coefficient. (12)

Or
(b) Discuss briefly the following:
(i) Analogy between heat and mass transfer (8)
(ii) Mass convection. (8)
1. Calculate the rate of heat transfer per unit area through a copper plate 45 mm thick whose one face is maintained at 350°C and the other face at 50°C. Take thermal conductivity of copper as 370 W/m°C.

2. What do you understand by critical radius of insulation and give its expression?

3. Define total emissive power and Radiosity.

4. Mention the physical significance of view factor.

5. Define Reynolds number and Grashoff number.

6. What is the importance of boundary layer?

7. Draw the film growth, velocity and temperature profiles when laminar film condensation takes place on a vertical plate.

8. Why fouling factors are considered in the design of heat exchangers?

9. What are the mechanisms of mass transfer by diffusion and convection?

10. A vessel contains a binary mixture of O₂ and N₂ with partial pressures in the ratio 0.21 and 0.79 at 15°C. The total pressure of the mixture is 1.1 bar. Calculate the mass densities of O₂ and N₂.
11. (a) (i) Obtain an expression for the general heat conduction equation in Cartesian coordinates.  

(ii) An exterior wall of a house is covered by a 0.1 m layer of common brick \((k = 0.7 \text{ W/m}^\circ \text{C})\) followed by a 0.04 m layer of gypsum plaster \((k = 0.48 \text{ W/m}^\circ \text{C})\). What thickness of loosely packed rock wool insulation \((k = 0.065 \text{ W/m}^\circ \text{C})\) should be added to reduce the heat loss or gain through the wall by 80%? 

Or

(b) (i) Find out the amount of heat transferred through an iron fin of length 50 mm, width 100 mm and thickness 5 mm. Assume \(k = 58 \text{ W/m}^\circ \text{C}\) and \(h = 12 \text{ W/m}^2\text{C}\) for the material of the fin and the temperature at the base of the fin as 80\(^\circ\)C. Also determine the temperature at tip of the fin if the atmosphere temperature is 20\(^\circ\)C.

(ii) An electrical wire of 10 m length and 1 mm diameter dissipates 200 W in air at 25\(^\circ\)C. The convection heat transfer coefficient between the wire surface and air is 15 \(\text{W/m}^2\text{K}\). Calculate the critical radius of insulation and also determine the temperature of the wire if it is insulated to the critical thickness of insulation.

12. (a) (i) Write a note on black body and grey body. 

(ii) Find the shape factor \(F_{1-2}\) and \(F_{2-1}\) for the figure shown below. 

Or
(b) (i) Discuss how the radiation from gases differ from that of solids. (6)

(ii) Two very large parallel plates with emissivities 0.5 exchange heat. Determine the percentage reduction in the heat transfer rate if a polished aluminium radiation shield of $\varepsilon = 0.04$ is placed in between the plates. (10)

13. (a) (i) Consider laminar hydrodynamically fully developed couette flow (that is flow between parallel plates) fluid being viscous. The upper plate at temperature $T_2$ moves with a velocity $U$ while the lower plate at $T_1$ less than $T_2$ is stationary. The distance between the plates is $w$. Write the appropriate governing flow and energy equations for the above and obtain expressions for the velocity and temperature profiles across the flow. (12)

(ii) Air at $20^\circ \text{C}$ is flowing along a heated plate at $134^\circ \text{C}$ at a velocity of $3 \text{ m/s}$. The plate is $2 \text{ m}$ long and $1.5 \text{ m}$ wide. Calculate the thickness of the hydrodynamic boundary layer and the skin friction coefficient at $40 \text{ cm}$ from the leading edge of the plate. The kinematic viscosity of air at $20^\circ \text{C}$ is $15.06 \times 10^{-6} \text{ m}^2/\text{s}$. (4)

(b) A hot plate $1.2 \text{ m}$ wide, $0.35 \text{ m}$ high and at $115^\circ \text{C}$ is exposed to the ambient still air at $25^\circ \text{C}$. Calculate (i) the maximum velocity at $180 \text{ mm}$ from the leading edge of the plate, (ii) the boundary layer thickness at $180 \text{ mm}$ from the leading edge of the plate, (iii) the local heat transfer coefficient at $180 \text{ mm}$ from the leading edge of the plate, (iv) the average heat transfer coefficient over the surface of the plate, (v) the heat loss from the plate and rise in temperature of the air passing through the boundary. (16)

14. (a) (i) Discuss the various regimes of boiling. (8)

(ii) An aluminium pan of $15 \text{ cm}$ diameter is used to boil water and the water depth at the time of boiling is $2.5 \text{ cm}$. The pan is placed on an electric stove and the heating element raises the temperature of the pan to $110^\circ \text{C}$. Calculate the power input for boiling and the rate of evaporation. Take $C_{sf} = 0.0132$. (8)
(b) (i) Describe the principle of parallel flow and counter flow heat exchangers showing the axial temperature distribution. (8)

(ii) In a counter flow double pipe heat exchanger water is heated from 25°C to 60°C by an oil with a specific heat of 1.45 kJ/kg K and mass flow rate of 0.9 kg/s. The oil is cooled from 230°C to 160°C. If the overall heat transfer coefficient is 420 W/m² °C, calculate (1) the rate of heat transfer, (2) the mass flow rate of water and (3) the surface area of the heat exchanger. (8)

15. (a) Atmospheric air at 40°C flows over a wet bulb thermometer and it shows 25°C. Calculate the concentration of water vapour in the free stream and also its relative humidity. Take D (air-water) = 0.256 × 10⁻⁴ m²/s. If temperatures of dry and wet bulb are 30°C and 25°C respectively, what would be the corresponding values? (16)

Or

(b) (i) The molecular weights of the two components A and B of a gas mixture are 24 and 28 respectively. The molecular weight of gas mixture is found to be 30. If the mass concentration of the mixture is 1.2 kg/m³, determine (1) molar fractions, (2) mass fractions and (3) total pressure if the temperature of the mixture is 290 K. (8)

(ii) An open pan 20 cm in diameter and 8 cm deep contains water at 25°C and is exposed to dry atmospheric air. If the rate of diffusion of water vapour is $8.54 \times 10^{-4}$ kg/h estimate the diffusion coefficient of water in air. (8)
IH


Sixth Semester

Mechanical Engineering

ME 340 — HEAT AND MASS TRANSFER

Time : Three hours  Maximum : 100 marks

(Use of Steam Tables, Mollier Chart and HMT Data Book is permitted)

Answer ALL questions.

PART A — (10 x 2 = 20 marks)


2. Write down the three-dimensional heat conduction equation in rectangular coordinate system.

3. What do you understand by a graybody and blackbody?


5. An electrically heated plate dissipates heat by convection at a rate of 8000 W/m² into the ambient air at 25°C. If the surface of the hot plate is at 125°C, calculate the heat transfer coefficient for convection between the plate and the air.

6. Define Reynolds number and Prandtl number.

7. What do you understand by free and forced convection?

8. State the difference between filmwise and dropwise condensation.


10. Describe the two mechanisms of mass transfer.
11. (i) Discuss how the radiation from gases differ from that of solids. (6)

(ii) Two very large parallel plates with emissivities 0.5 exchange heat. Determine the percentage reduction in the heat transfer rate if a polished aluminium radiation shield of $\varepsilon = 0.04$ is placed in between the plates. (10)

12. (a) (i) A furnace wall consists of three layers. The inner layer of 10 cm thickness is made of firebrick ($k = 1.04 \text{ W/mK}$). The intermediate layer of 25 cm thickness is made of masonry brick ($k = 0.69 \text{ W/mK}$) followed by a 5 cm thick concrete wall ($k = 1.37 \text{ W/mK}$). When the furnace is in continuous operation the inner surface of the furnace is at 800°C while the outer concrete surface is at 50°C. Calculate the rate of heat loss per unit area of the wall, the temperature at the interface of the firebrick and masonry brick and the temperature at the interface of the masonry brick and concrete. (8)

(ii) An electrical wire of 10 m length and 1 mm diameter dissipates 200 W in air at 25°C. The convection heat transfer coefficient between the wire surface and air is $15 \text{ W/m}^2\text{K}$. Calculate the critical radius of insulation and also determine the temperature of the wire if it is insulated to the critical thickness of insulation. (8)

(b) (i) An aluminium rod ($k = 204 \text{ W/mK}$) 2 cm in diameter and 20 cm long protrudes from a wall which is maintained at 300°C. The end of the rod is insulated and the surface of the rod is exposed to air at 30°C. The heat transfer coefficient between the rod's surface and air is $10 \text{ W/m}^2\text{K}$. Calculate the heat lost by the rod and the temperature of the rod at a distance of 10 cm from the wall. (7)

(ii) A large iron plate of 10 cm thickness and originally at 800°C is suddenly exposed to an environment at 0°C where the convection coefficient is 50 W/m²K. Calculate the temperature at a depth of 4 cm from one of the faces 100 seconds after the plate is exposed to the environment. How much energy has been lost per unit area of the plate during this time? (9)

13. (a) (i) Write down the momentum equation for a steady, two dimensional flow of an incompressible, constant property newtonian fluid in the rectangular coordinate system and mention the physical significance of each term. (6)

(ii) A large vertical plate 5 m high is maintained at 100°C and exposed to air at 30°C. Calculate the convection heat transfer coefficient. (10)

Or

(ii) A large iron plate of 10 cm thickness and originally at 800°C is suddenly exposed to an environment at 0°C where the convection coefficient is 50 W/m²K. Calculate the temperature at a depth of 4 cm from one of the faces 100 seconds after the plate is exposed to the environment. How much energy has been lost per unit area of the plate during this time?
(b) (i) Sketch the boundary layer development of a flow over a flat plate and explain the significance of the boundary layer. (6)

(ii) Atmospheric air at 275 K and a free stream velocity of 20 m/s flows over a flat plate 1.5 m long that is maintained at a uniform temperature of 325 K. Calculate the average heat transfer coefficient over the region where the boundary layer is laminar, the average heat transfer coefficient over the entire length of the plate and the total heat transfer rate from the plate to the air over the length 1.5 m and width 1 m. Assume transition occurs at $Re_c = 2 \times 10^5$. (10)

14. (a) (i) It is desired to boil water at atmospheric pressure on a copper surface which is electrically heated. Estimate the heat flux from the surface to the water, if the surface is maintained at 110°C and also the peak heat flux. (8)

(ii) A tube of 2 m length and 25 mm OD is to be used to condense saturated steam at 100°C while the tube surface is maintained at 92°C. Estimate the average heat transfer coefficient and the rate of condensation of steam if the tube is kept horizontal. The steam condenses on the outside of the tube. (8)

Or

(b) (i) Give the classification of heat exchangers. (4)

(ii) It is desired to use a double pipe counter flow heat exchanger to cool 3 kg/s of oil ($C_p = 2.1 \text{ kJ/kgK}$) from 120°C. Cooling water at 20°C enters the heat exchanger at a rate of 10 kg/s. The overall heat transfer coefficient of the heat exchanger is 600 W/m$^2$K and the heat transfer area is 6 m$^2$. Calculate the exit temperatures of oil and water. (12)

15. (a) (i) Define mass concentration, molar concentration, mass fraction and mole fraction. (4)

(ii) The diffusivity of CCl$_4$ in air is determined by observing the steady state evaporation of CCl$_4$ in a tube of 1 cm diameter exposed to air. The CCl$_4$ liquid level is 10 cm below the top level of the tube. The system is held at 25°C and 1 bar pressure. The saturation pressure of CCl$_4$ at 25°C is 14.76 kPa. If it is observed that the rate of evaporation of CCl$_4$ is 0.1 g/hour determine the diffusivity of CCl$_4$ into air. (12)

Or
Dry air at 20°C ($\rho = 1.2 \text{ kg/m}^3$, $v = 15 \times 10^{-6} \text{ m}^2/\text{s}$, $D = 4.2 \times 10^{-5} \text{ m}^2/\text{s}$) flows over a flat plate of length 50 cm which is covered with a thin layer of water at a velocity of 1 m/s. Estimate the local mass transfer coefficient at a distance of 10 cm from the leading edge and the average mass transfer coefficient.

Discuss the analogy between heat and mass transfer.
1. A temperature difference of 500°C is applied across a fire-clay brick. 10 cm thick having a thermal conductivity of 1.0 W/m.K. Find the heat transfer rate per unit area.

2. Write the general 3-D heat conduction equation in cylindrical coordinates.

3. Biot number is the ratio between _______ and _______.

4. Define bulk temperature.

5. A vertical flat plate is maintained at a temperature lower than the surrounding fluid. Draw the velocity and temperature profiles assuming natural convection.

6. What is burnout point? Why is it called so?

7. What is a compact heat exchanger? Give examples.
8. What is thermal radiation and what is its wavelength band?

9. What are radiation shields?

10. Explain the physical meaning of Schmidt number.

PART B — (5 x 16 = 80 marks)

11. (a) A composite wall is formed of a 2.5 cm copper plate \((k = 355 \text{ W/m.K})\), a 3.2 mm layer of asbestos \((k = 0.110 \text{ W/m.K})\) and a 5 cm layer of fiber plate \((k = 0.049 \text{ W/m.K})\). The wall is subjected to an overall temperature difference of 560°C (560°C on the Cu plate side and 0°C on the fiber plate side). Estimate the heat flux through this composite wall and the interface temperature between asbestos and fiber plate.

Or

(b) When a thermocouple is moved from one medium to another medium at a different temperature, sufficient time must be given to the thermocouple to come to thermal equilibrium with the new conditions before a reading is taken. Consider a 0.1-cm-diameter copper thermocouple wire originally at 150°C. Find the temperature response (i.e. an approximate plot of temperature Vs time for intervals of 0, 40 and 120 seconds) when this wire is suddenly immersed in

(i) water at 40°C \((h = 80 \text{ W/m}^2\text{.K})\)

(ii) air at 40°C \((h = 40 \text{ W/m}^2\text{.K})\).

Assume unit length of wire.

12. (a) Air at 400 K and 1 atm pressure flows at a speed of 1.5 m/s over a flat plate of 2 m long. The plate is maintained at a uniform temperature of 300 K. If the plate has a width of 0.5 m, estimate the heat transfer coefficient and the rate of heat transfer from the air stream to the plate. Also estimate the drag force acting on the plate.

Or

(b) Cylindrical cans of 150 mm length and 65 mm diameter are to be cooled from an initial temperature of 20°C by placing them in a cooler containing air at a temperature of 1°C and a pressure of 1 bar. Determine the cooling rates when the cans are kept in

(i) horizontal position

(ii) vertical position.
13. (a) Water is to be boiled at atmospheric pressure in a mechanically polished stainless steel pan placed on top of a heating unit. The inner surface of the bottom of the pan is maintained at 108°C. The diameter of the bottom of the pan is 30 cm. Assuming Cs = 0.0130, calculate

(i) the rate of heat transfer to the water, and

(ii) the rate of evaporation of water.

Or

(b) Define effectiveness of a heat exchanger. Derive an expression for the effectiveness of a double pipe parallel flow heat exchanger. State the assumptions made.

14. (a) (i) Discuss briefly the variation of black body emissive power with wavelength for different temperatures. (8)

(ii) The spectral emissivity function of an opaque surface at 800 K is approximated as

\[
e_\lambda = \begin{cases} 
  0.30 & 0 \leq \lambda < 3 \mu m \\
  0.80 & 3 \mu m \leq \lambda < 7 \mu m \\
  0.10 & 7 \mu m \leq \lambda < \infty 
\end{cases}
\]

Calculate the average emissivity of the surface and its emissive power. (8)

Or

(b) Explain briefly the following: (5 + 5 + 6)

(i) Specular and diffuse reflection

(ii) Reflectivity and transmissivity

(iii) Reciprocity rule and summation rule.

15. (a) Discuss briefly the following: (4 + 6 + 6)

(i) Fick's law of diffusion

(ii) Equimolar counter diffusion

(iii) Evaporation process in the atmosphere.

Or
(b) (i) What are the assumptions made in the 1-D transient mass diffusion problems? (4)

(ii) An open pan, 20 cm diameter and 8 cm deep contains water at 25°C and is exposed to dry atmospheric air. Estimate the diffusion coefficient of water in air, if the rate of diffusion of water is $8.54 \times 10^{-4}$ kg/h. (12)
1. Write down the three dimensional heat conduction equation in rectangular coordinates.

2. Define fin efficiency.

3. What do you understand by specular and diffuse reflection?

4. State the Kirchoff's law of radiation.

5. What is velocity and thermal boundary layer?

6. Define Nusselt and Prandtl number.

7. How the filmwise condensation is different from dropwise condensation.

8. Draw the temperature distribution of a counterflow heat exchanger.

9. Define mole fraction and mass concentration.

11. (a) (i) The inner surface at \( r = a \) and the outer surface at \( r = b \) of a hollow cylinder are maintained at uniform temperatures \( T_1 \) and \( T_2 \), respectively. The thermal conductivity \( k \) of the solid is constant. Develop an expression for the one-dimensional, steady-state temperature distribution \( T(r) \) in the cylinder. Develop an expression for the radial heat flow rate \( Q \) through the cylinder of length \( H \). Develop an expression for the thermal resistance of a hollow cylinder of length \( H \). (8)

(ii) A steel rod of diameter \( D = 2 \) cm, length \( L = 25 \) cm, and thermal conductivity \( k = 50 \text{ W/(m°C)} \) is exposed to ambient air at \( T_\infty = 20°C \) with a heat transfer coefficient \( h = 64 \text{ W/(m}^2\text{°C)} \). If one end of the rod is maintained at a temperature of 120°C, calculate the heat loss from the rod. (8)

(b) (i) Consider one-dimensional, steady-state heat flow along two stainless-steel bars, each of diameter \( D = 2 \) cm, length \( L = 3 \) cm and pressed together with a pressure of 10 atm. The surface has a roughness of about 2.5 \( \mu \text{m} \). An overall temperature difference of \( T = 100°C \) is applied across the bars. The interface temperature is about 90°C. Calculate the heat flow rate along the bars and the temperature drop at the interface. (8)

(ii) A 5-cm-thick iron plate \([k = 60 \text{ W/(m°C)}, C_p = 460 \text{ J/(kg°C)}, \rho = 7850 \text{ kg/m}^3, \text{ and } \alpha = 1.6 \times 10^{-5} \text{ m}^2/\text{s}]\) is initially at \( T_1 = 225°C \). Suddenly, both surfaces are exposed to an ambient at \( T_\infty = 25°C \) with a heat transfer coefficient \( h = 500 \text{ W/(m}^2\text{°C)} \). Calculate the centre temperature at \( t = 2 \) min after the start of the cooling, the temperature at a depth 1 cm from the surface at \( t = 2 \) min after the start of the cooling and the energy removed from the plate per square meter during this time. (8)
12. (a) Two square plates, each 1 m by 1 m, are parallel to and directly opposite to each other at a distance 1 m. The hot plate is at $T_1 = 800 \text{ K}$ and has an emissivity $\varepsilon_1 = 0.8$. The colder plate is at $T_2 = 600 \text{ K}$ and also has an emissivity $\varepsilon_2 = 0.8$. The radiation heat exchange takes place between the plates as well as with a large ambient at $T_3 = 300 \text{ K}$ through the opening between the plates. Calculate the net heat transfer rate by radiation at each plate and to the ambient. (16)

Or

(b) (i) Two parallel plates are temperatures $T_1$ and $T_2$ and have emissivities $\varepsilon_1 = 0.8$ and $\varepsilon_2 = 0.5$. A radiation shield having the same emissivity $\varepsilon_3$ on both sides is placed between the plates. Calculate the emissivity $\varepsilon_3$ of the shield in order to reduce the radiation loss from the system to one-tenth of that without the shield. (8)

(ii) Distinguish between solid and gas radiation. (8)

13. (a) (i) Atmospheric air at $T_w = 400 \text{ K}$ flows with a velocity of $u_w = 4 \text{ m/s}$ along a flat plate $L = 1 \text{ m}$ long maintained at a uniform temperature $T_w = 300 \text{ K}$. The average heat transfer coefficient is determined to be $h_m = 7.75 \text{ W/(m}^2\text{C)}$. Using the Reynolds-Colburn analogy, estimate the drag force exerted on the plate per 1 m width. (8)

(ii) Write down the momentum equation and explain the various terms. (8)

Or

(b) (i) Atmospheric air at 300 K at a velocity of 1 m/s flows over a flat plate. Calculate the boundary-layer thickness $\delta(x)$ and the local drag coefficient $c_x$ at $x = 0.75 \text{ m}$ from the leading edge of the plate. What is the drag force $F$ acting on the plate over the length $x = 0$ to $x = 0.75 \text{ m}$ and width $w = 0.5 \text{ m}$ of the plate? (8)

(ii) A vertical plate $L = 5 \text{ m}$ high and $w = 1.5 \text{ m}$ wide has one of its surfaces insulated; the other surface, maintained at a uniform temperature $T_w = 400 \text{ K}$, is exposed to quiescent atmospheric air at $T_w = 300 \text{ K}$. Calculate the total rate of heat loss from the plate. (8)
(a) (i) Discuss the various regimes of pool boiling. (8)
(ii) Water at atmospheric pressure and saturation temperature is boiled in a 25 cm diameter, electrically heated, mechanically polished, stainless-steel pan. The heated surface of the pan is maintained at a uniform temperature $T_w = 116^\circ C$. Calculate the surface heat flux, the rate of evaporation from the pan and the peak heat flux. (8)

Or

(b) Air-free saturation steam at $T_v = 65^\circ C$ ($P = 25.03$ kPa) condenses on the outer surface of a 2.5 cm OD, 3 m long vertical tube maintained at a uniform temperature $T_J = 35^\circ C$ by the flow of cooling water through the tube. Assuming film condensation, calculate the average heat transfer coefficient over the entire length of the tube and the rate of condensate flow at the bottom of the tube. Also determine the average heat transfer coefficient $h_m$ and the total condensation rate when the tube is horizontal. (16)

15. (a) (i) Consider two large vessels, each containing uniform mixtures of nitrogen and carbon dioxide at 1 atm, $T = 288.9$ K, but at different concentrations. Vessel 1 contains 90 mole percent $N_2$ and 10 mole percent $CO_2$, whereas vessel 2 contains 20 mole percent $N_2$ and 80 mole percent $CO_2$. The two vessels are connected by a duct of $d = 0.1524$ m inside diameter and $L = 1.22$ m long. Determine the rate of transfer of nitrogen between the two vessels by assuming that steady-state transfer takes place in view of the large capacity of the two reservoirs. The mass diffusivity for the $N_2$—$CO_2$ mixture at 1 atm and 288.9 K can be taken as $D = 0.16 \times 10^{-4}$ m$^2$/s. (8)
(ii) Discuss the analogy between heat and mass transfer. (8)

Or

(b) Atmospheric air at $T_w = 40^\circ C$ flows over a wet-bulb thermometer. The reading of the thermometer, which is called the wet-bulb reading, is $T_\omega = 20^\circ C$. Calculate the concentration of water vapor $c_\omega$ in the free stream. Also determine the relative humidity of the air stream (i.e., the ratio of the concentration $c_\omega$ of water vapor free stream to the saturation concentration at the free-steam temperature $T_\omega = 40^\circ C$ obtained from the steam table). (16)
Question Paper Code: E3133

B.E./B.Tech. DEGREE EXAMINATION, APRIL/MAY 2010

Fourth Semester

Mechanical Engineering

ME2251 — HEAT AND MASS TRANSFER

(Regulation 2008)

Time: Three hours  Maximum: 100 Marks

Heat and mass transfer tables, steam tables are permitted for use.

Answer ALL Questions

PART A — (10 × 2 = 20 Marks)

1. Write the Poisson’s equation for heat conduction.

2. What is lumped heat capacity analysis?

3. Define thermal boundary layer thickness.

4. What do you understand by free and forced convection?

5. What is effectiveness of a heat exchange?

6. Give the expression for NTU.

7. Find the temperature of the sun assuming as a black body, if the intensity of radiation is maximum at the wave length of 0.5µm.

8. State Kirchhoff’s law.

9. Define molar concentration.

10. What is mass average velocity?
PART B — \((5 \times 16 = 80\) Marks)

11. (a) Derive the general heat conduction equation in cylindrical coordinates. \(\text{(16)}\)

Or

(b) Derive the general heat conduction equation for a hollow cylinder. \(\text{(16)}\)

12. (a) Air at 20°C at 3m/s flows over a thin plate of 2m long and 1m wide. Estimate the boundary layer thickness at the trailing edge, total drag force, mass flow of air between \(x=30\)cm and \(x=80\) cm. Take \(\nu = 15 \times 10^6\) and \(\rho = 1.17\text{kg/m}^3\). \(\text{(16)}\)

Or

(b) Calculate the convective heat transfer from a radiator 0.5m wide and 1m high at 84°C in a room at 20°C. Treat the radiator as a vertical plate. \(\text{(16)}\)

13. (a) Dry steam at 2.45 bar condenses on a vertical tube of height of 1m at 117°C. Estimate the thickness of the condensate film and the local heat transfer coefficient at a distance 0.2 m from the upper end of the plate. \(\text{(16)}\)

Or

(b) Derive the LMTD for a parallel flow heat exchanger stating the assumptions. \(\text{(16)}\)

14. (a) Derive the radiation exchange between
   
   (i) Large parallel gray surfaces and
   
   (ii) Small gray bodies. \(\text{(16)}\)

Or

(b) Two large parallel plates of 1m×1m spaced 0.5m apart in a very large room whose walls are at 27°C. The plates are at 900°C and 400°C with emissivities 0.2 and 0.5 respectively. Find the net heat transfer to each plate and to the room. \(\text{(16)}\)

15. (a) The temperature recorded by a thermometer whose bulb covered by a wet wick in dry air at atmospheric pressure is 22°C. Estimate the true air temperature. \(\text{(16)}\)

Or

(b) Dry air at 27°C and 1 bar flows over a wet plate of 50cm at 50m/s. Calculate the mass transfer coefficient of water vapour in air at the end of the plate. \(\text{(16)}\)

Sixth Semester

Mechanical Engineering

ME 340 — HEAT AND MASS TRANSFER

Time: Three hours  Maximum: 100 marks

(Use of Steam Tables, Mollier Chart and HMT Data Book is permitted)

Answer ALL questions.

PART A — (10 x 2 = 20 marks)

1. Write down the three dimensional heat conduction equation in rectangular coordinates.

2. Define fin efficiency.

3. What do you understand by specular and diffuse reflection?

4. State the Kirchoff's law of radiation.

5. What is velocity and thermal boundary layer?

6. Define Nusselt and Prandtl number.

7. How the filmwise condensation is different from dropwise condensation.

8. Draw the temperature distribution of a counterflow heat exchanger.

9. Define mole fraction and mass concentration.

11. (a) (i) The inner surface at $r = a$ and the outer surface at $r = b$ of a hollow cylinder are maintained at uniform temperatures $T_1$ and $T_2$, respectively. The thermal conductivity $k$ of the solid is constant. Develop an expression for the one-dimensional, steady-state temperature distribution $T(r)$ in the cylinder. Develop an expression for the radial heat flow rate $Q$ through the cylinder of length $H$. Develop an expression for the thermal resistance of a hollow cylinder of length $H$. 

(ii) A steel rod of diameter $D = 2$ cm, length $L = 25$ cm, and thermal conductivity $k = 50 \text{ W/(m°C)}$ is exposed to ambient air at $T_m = 20°C$ with a heat transfer coefficient $h = 64 \text{ W/(m}^2\text{°C)}$. If one end of the rod is maintained at a temperature of $120°C$, calculate the heat loss from the rod.

Or

(b) (i) Consider one-dimensional, steady-state heat flow along two stainless-steel bars, each of diameter $D = 2$ cm, length $L = 3$ cm and pressed together with a pressure of 10 atm. The surface has a roughness of about $2.5 \mu$m. An overall temperature difference of $T = 100°C$ is applied across the bars. The interface temperature is about $90°C$. Calculate the heat flow rate along the bars and the temperature drop at the interface.

(ii) A 5-cm-thick iron plate [$k = 60 \text{ W/(m°C)}$, $C_p = 460 \text{ J/(kg°C)}$, $\rho = 7850 \text{ kg/m}^3$, and $\alpha = 1.6 \times 10^{-6} \text{ m}^2/\text{s}$] is initially at $T_1 = 225°C$. Suddenly, both surfaces are exposed to an ambient at $T_m = 25°C$ with a heat transfer coefficient $h = 500 \text{ W/(m}^2\text{°C)}$. Calculate the centre temperature at $t = 2$ min after the start of the cooling, the temperature at a depth 1 cm from the surface at $t = 2$ min after the start of the cooling and the energy removed from the plate per square meter during this time.
12. (a) Two square plates, each 1 m by 1 m, are parallel to and directly opposite to each other at a distance 1 m, The hot plate is at $T_1 = 800$ K and has an emissivity $\varepsilon_1 = 0.8$. The colder plate is at $T_2 = 600$ K and also has an emissivity $\varepsilon_2 = 0.8$. The radiation heat exchange takes place between the plates as well as with a large ambient at $T_3 = 300$ K through the opening between the plates. Calculate the net heat transfer rate by radiation at each plate and to the ambient. 

Or

(b) (i) Two parallel plates are temperatures $T_1$ and $T_2$ and have emissivities $\varepsilon_1 = 0.8$ and $\varepsilon_2 = 0.5$. A radiation shield having the same emissivity $\varepsilon_3$ on both sides is placed between the plates. Calculate the emissivity $\varepsilon_3$ of the shield in order to reduce the radiation loss from the system to one-tenth of that without the shield. 

(ii) Distinguish between solid and gas radiation.

13. (a) (i) Atmospheric air at $T_w = 400$ K flows with a velocity of $u_w = 4$ m/s along a flat plate $L = 1$ m long maintained at a uniform temperature $T_w = 300$ K. The average heat transfer coefficient is determined to be $h_m = 7.75$ W/(m$^2$C). Using the Reynolds-Colburn analogy, estimate the drag force exerted on the plate per 1 m width. 

(ii) Write down the momentum equation and explain the various terms.

Or

(b) (i) Atmospheric air at 300 K at a velocity of 1 m/s flows over a flat plate. Calculate the boundary-layer thickness $\delta(x)$ and the local drag coefficient $c_x$ at $x = 0.75$ m from the leading edge of the plate. What is the drag force $F$ acting on the plate over the length $x = 0$ to $x = 0.75$ m and width $w = 0.5$ m of the plate? 

(ii) A vertical plate $L = 5$ m high and $w = 1.5$ m wide has one of its surfaces insulated: the other surface, maintained at a uniform temperature $T_w = 400$ K, is exposed to quiescent atmospheric air at $T_w = 300$ K. Calculate the total rate of heat loss from the plate.
14. (a) (i) Discuss the various regimes of pool boiling. (8)

(ii) Water at atmospheric pressure and saturation temperature is boiled in a 25 cm diameter, electrically heated, mechanically polished, stainless-steel pan. The heated surface of the pan is maintained at a uniform temperature $T_w = 116^\circ$C. Calculate the surface heat flux, the rate of evaporation from the pan and the peak heat flux. (8)

Or

(b) Air-free saturation steam at $T_v = 65^\circ$C ($P = 25.03$ kPa) condenses on the outer surface of a 2.5 cm OD, 3 m long vertical tube maintained at a uniform temperature $T_w = 35^\circ$C by the flow of cooling water through the tube. Assuming film condensation, calculate the average heat transfer co-efficient over the entire length of the tube and the rate of condensate flow at the bottom of the tube. Also determine the average heat transfer coefficient $h_m$ and the total condensation rate when the tube is horizontal. (16)

15. (a) (i) Consider two large vessels, each containing uniform mixtures of nitrogen and carbon dioxide at 1 atm, $T = 288.9$ K, but at different concentrations. Vessel 1 contains 90 mole percent $N_2$ and 10 mole percent $CO_2$, whereas vessel 2 contains 20 mole percent $N_2$ and 80 mole percent $CO_2$. The two vessels are connected by a duct of $d = 0.1524$ m inside diameter and $L = 1.22$ m long. Determine the rate of transfer of nitrogen between the two vessels by assuming that steady-state transfer takes place in view of the large capacity of the two reservoirs. The mass diffusivity for the $N_2$–$CO_2$ mixture at 1 atm and 288.9 K can be taken as $D = 0.16 \times 10^{-4}$ m$^2$/s. (8)

(ii) Discuss the analogy between heat and mass transfer. (8)

Or

(b) Atmospheric air at $T_w = 40^\circ$C flows over a wet-bulb thermometer. The reading of the thermometer, which is called the wet-bulb reading, is $T_w = 20^\circ$C. Calculate the concentration of water vapor $c_w$ in the free stream. Also determine the relative humidity of the air stream (i.e., the ratio of the concentration $c_w$ of water vapor free stream to the saturation concentration at the free-steam temperature $T_w = 40^\circ$C obtained from the steam table). (16)
PART A — (10 x 2 = 20 marks)

1. Distinguish between Fin Efficiency and Fin Effectiveness.

2. What is the use of Heislers chart?

3. What is overall heat transfer co-efficient?

4. What is the significance of Dimensional number?

5. What is condensation process?

6. What is Fouling factor?

7. Explain electrical analogy.

8. What is grey body?


11. (a) (i) Derive the heat conduction equation in cylindrical co-ordinates using an elemental volume for a stationary isotropic solid. (8)

(ii) A 3 cm OD steam pipe is to be covered with two layers of insulation each having a thickness of 2.5 cm. The average thermal conductivity of one insulation is 5 times that of the other. Determine the percentage decrease in heat transfer if better insulating material is next to pipe than it is the outer layer. Assume that the outside and inside temperatures of composite insulation are fixed. (8)

Or

(b) (i) Explain briefly the concept of critical thickness of insulation and state any two applications of the same. (8)

(ii) A 6 cm long copper rod (k = 300 W/mK) 6mm in diameter is exposed to an environment at 20°C. The base temperature of the rod is maintained at 160°C. The heat transfer co-efficient is 20 W/m²K. Calculate the heat given by the rod and efficiency and effectiveness of the rod. (8)

12. (a) (i) Explain for fluid flow along a flat plate:

1. Velocity distribution in hydrodynamic boundary layer
2. Temperature distribution in thermal boundary layer
3. Variation of local heat transfer co-efficient along the flow. (8)

(ii) The water is heated in a tank by dipping a plate of 20 cm X 40 cm in size. The temperature of the plate surface is maintained at 100°C. Assuming the temperature of the surrounding water is at 30°C, Find the heat loss from the plate 20 cm side is in vertical plane. (8)

Or

(b) (i) Define the Biot and Fourier numbers. (4)

(ii) What is meant by lumped capacity? What are the physical assumptions necessary for a lumped capacity unsteady state analysis to apply? (4)

(iii) A slab of Aluminum 5 cm thick initially at 200°C is suddenly immersed in a liquid at 70°C for which the convection heat transfer co-efficient is 525 W/m²K. Determine the temperature at a depth of 12.5 mm from one of the faces 1 minute after the immersion. Also calculate the energy removed per unit area from the plate during 1 minute of immersion.

Take p = 2700 bar, Cp = 0.9 kJ/kg°C, k=215 W/mK, α = 8.4X 10⁻⁵ m²/s. (8)
13. (a) (i) With a neat and labeled sketch explain the various regimes in boiling heat transfer. (8)

(ii) A vertical plate 0.5 m$^2$ in area at temperature of 92°C is exposed to steam at atmospheric pressure. If the steam is dry and saturated estimate the heat transfer rate and condensate mass per hour. The vertical length of the plate is 0.5 m. Properties of water at film temperatures of 96°C can be obtained from tables. (8)

Or

(b) (i) Compare LMTD and NTU method of heat exchanger analysis. (6)

(ii) Hot exhaust gases which enters a finned tube cross flow heat exchanger at 300°C and leave at 100°C, are used to heat pressurized water at a flow rate of 1 kg/s from 35 to 125°C. The exhaust gas specific heat is approximately 1000 J/kg.K, and the overall heat transfer coefficient based on the gas side surface area is $U_h = 100$ W/m$^2$K. Determine the required gas side surface area $A_h$ using the NTU method.

Take $C_p,c$ at $T_c = 80°C$ is 4197 kJ/kg.K and $C_p,h = 1000$ J/kg.K. (10)

14. (a) (i) State and prove the following laws:

(1) Kirchoff's law of radiation

(2) Stefan — Boltzmann law (8)

(ii) Show from energy balance consideration that the radiation heat transfer from a plane composite surface area $A_4$ and made up of plane surface areas $A_2$ and $A_3$ to a plane surface area $A_1$ is given by:

$$A_4 F_{41} = A_3 F_{31} + A_2 F_{21}$$

and

$$F_{14} = F_{12} + F_{13}$$ (8)

Or

(b) (i) Using the definition of radiosity and irradiation prove that the radiation heat exchange between two grey bodies is given by the relation:

$$Q_{net} = \frac{\sigma(T_1^4 - T_2^4)}{1 - \varepsilon_1 + 1 + \varepsilon_2}$$

$$A_1 \varepsilon_1 A_1 F_{1-2} A_2 \varepsilon_2$$ (8)

(ii) A surface at 100K with emissivity of 0.10 is protected from a radiation flux of 1250 W/m$^2$ by a shield with emissivity of 0.05. Determine the percentage cut off and the shield temperature. Assume shape factor as 1. (8)
15. (a) (i) Explain Fick’s first and second laws of diffusion. (8)

(ii) Explain the phenomenon of equimolar counter diffusion. Derive an expression for equimolar counter diffusion between two gases or liquids. (8)

Or

(b) (i) Define the Schmidt, Sherwood and Lewis numbers. What is the physical significance of each? (8)

(ii) Dry air at 27°C and 1 atm flows over a wet flat plate 50 cm long at a velocity of 50 m/s. Calculate the mass transfer co-efficient of water vapour in air at the end of the plate. Take the diffusion co-efficient of water vapour in air is \( D_{AB} = 0.26 \times 10^{-4} \text{ m}^2/\text{s} \). (8)