2022

Basic Thermodynamics

Subject Code: UME 301

Full Marks: 100

Time: Three hours

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

Use of property table is allowed

Answer all the questions

1. Answer *any ten* of the following questions. [2 x 10 = 20]
   a) What is a thermodynamic system? Distinguish between the closed system and the open system.
   b) Define 'thermodynamic state' and 'path of a process'.
   c) What is absolute pressure? Distinguish between the gauge pressure and vacuum pressure.
   d) State the internal energy of a system. Mentions any two forms of internal energy.
   e) Distinguish between the isobaric and isochoric processes.
   f) How will you establish that enthalpy is a function of temperature?
   g) What are the saturated liquid and saturated vapour of a pure substance?
   h) Define the degree of superheat. At what point the saturated liquid and saturated vapour states are identical?
   i) State Kelvin-Plank's statements of the second law of thermodynamics.
   j) Prove that a heat pump is more efficient than a refrigerator.
   k) What are the perpetual-motion machines (PMM)? Distinguish between the PMM1 and PMM2.
   l) What do you mean by an adiabatic process? Mention the three modes of heat transfer.

2. Answer *any five* of the following questions. [3 x 5 = 15]
   a) What do you mean by thermodynamic equilibrium? Distinguish between mechanical and chemical equilibriums.

b) Define the term latent heat. What are the liquid enthalpy (h_f) and enthalpy of vaporization (h_{fg}) of water?

c) Consider a rigid tank contains a saturated liquid–vapor mixture. If the specific volume occupied by saturated liquid is v_f and the specific volume occupied by the saturated vapor is v_g, prove that

$v = v_f + xv_{fg}$, where x is the quality of steam.

d) Show that enthalpy is a thermodynamic property.

e) Show that $C_p - C_v = R$, where C_p and C_v are the specific heat at constant pressure and constant volume, respectively, and R is a gas constant.

f) What are the 'source' and 'sink' of the thermal energy reservoirs? Write the characteristics of a heat engine.

g) Define 'irreversibilities'. Write any two important propositions regarding the efficiency of a Carnot cycle.

3. Answer *any three* of the following. [5 x 3 = 15]

a) Explain briefly the phase change process of water with (P-v) diagram.

b) Discuss the working cycle of the vapour compression refrigeration system.

c) Derive an expression for the variation of pressure with depth.

d) What is a polytropic process? Derive an expression for work done during a polytropic process.

4. Solve *any four* of the following. [4 x 5 = 20]

a) A piston-cylinder contains 0.1 kg air at 100 kPa, 400 K which goes through a polytropic compression process with n = 1.3 to a pressure of 300 kPa. How much work has the air done in the process?

b) The properties of a certain fluid are related as follows:

$u = 180 + 0.75\ t$

$Pv = 0.287\ (t + 273)$

Where u is the specific internal energy (kJ/K), t is in °C, P is pressure (kN/m^2), and v is the specific volume (m^3/kg). For this fluid, find C_V and Cp.

c) Find the specific volume, enthalpy and internal energy of wet steam at 1500 kPa, dryness fraction 0.85. *[Use steam tables to find unknown properties.]*

d) Steam at 4 MPa and 400 °C enters a nozzle steadily with a velocity of 60 m/s, and it leaves at 2 MPa and 300 °C. The inlet area of the nozzle is 50 cm^2, and heat is being lost at a rate of 75 kJ/s. Determine

i) The mass flow rate of the steam

ii) The exit velocity of the steam

[Use steam tables to find unknown properties.]

e) A household *refrigerator* with a COP of 1.5 removes heat from the refrigerated space at a rate of 80 kJ/min. Determine i) The electric power consumed by the refrigerator and ii) The rate of heat transfer to the kitchen air.

f) A heat pump is used to maintain a house at 24 °C by extracting heat from the outside air on a day when the outside air temperature is 8 °C. The house is estimated to lose heat at a rate of 120,000 kJ/h. Determine the minimum power required to operate this heat pump.

5. Solve *any three* of the following. [3 x 10 = 30]

a) A piston-cylinder device contains 0.2 kg of air initially at 2 MPa and 400 °C. The air is first expanded isothermally to 550 kPa, then compressed polytropically with a polytropic exponent of 1.3 to the initial pressure, and finally compressed at the constant pressure to the initial state. Determine the boundary work for each process and the net-work of the cycle. The gas constant for air is R=0.287 kJ/kg.K.

b) Steam enters a turbine steadily at 10 MPa and 600 °C with a velocity of 80 m/s and leaves at 30 kPa with a quality of 95%. A heat loss of 25 kJ/kg occurs during the process. The inlet area of the turbine is 150 cm^2, and the exit area is 1500 cm^2. Determine-

i) The mass flow rate of the steam,
ii) The exit velocity, and
iii) The power output

[*Use steam tables to find unknown properties.]*

c) A rigid tank of 0.05 m^3 volume contains a mixture of liquid water and water vapour at 100 kPa. The mass of the mixture in the tank is 20 kg. Calculate the heat added and the quality of the mixture when the pressure inside the tank is raised to 10 MPa. ***[****Use steam tables to find unknown properties.]*

d) A Carnot heat engine receives heat at 740 K and rejects the waste heat to the environment at 290 K. The entire work output of the heat engine is used to drive a Carnot refrigerator that removes heat from the cooled space at -16 °C at a rate of 410 kJ/min and rejects it to the same environment at 290 K. Determine

(i) The rate of heat supplied to the heat engine and
(ii) The total rate of heat rejection to the environment.

*******XXXX*******