Total number of printed pages: 03 *UG/3rd Sem./UME 301*

Central Institute of Technology Kokrajhar

End Semester Examination 2023

Basic Thermodynamics (UME 301)

Full Marks: 100

Time: Three hours

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

Answer all the questions

1. Fill in the blanks. [1x 6 = 6]
   a) In a closed system, the heat absorbed is equal to the change in internal energy at constant................
   b) The amount of work done during the isochoric process is ....
   c) The portion of the internal energy of a system associated with the kinetic energies of the molecules is called the ....
   d) For a cyclic process, the initial and final internal energies of a system are ....
   e) The critical pressure of water (at critical point) is ....
   f) A heat engine that has a thermal efficiency of 100 percent necessarily violates the .... law of thermodynamics.

2. Answer in short ***any ten*** of the following [2 x 10 = 20]
   a) What are the 'thermodynamic system' and 'thermodynamic property'?
   b) Distinguish between the intensive and extensive properties.
   c) State the Zeroth law of thermodynamics.
   d) In what forms energy can cross the boundary of a closed system?
   e) Define 'internal energy' of a system.
   f) What are the specific heats at constant volume and constant pressure of a substance?
   g) State Clausius's statement of the second law of thermodynamics.
   h) What are the saturated temperature and saturated pressure of a pure substance?
   i) What do you mean by dryness fraction of a pure substance?
   j) State 'flow energy' of flowing fluid.
   k) Define coefficient of performance of a heat pump.
   l) What do you mean by an 'irreversible process' and 'irreversibilities'?

3. 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) Demonstrate '***enthalpy is a thermodynamic property***' by considering a closed system undergoing a quasi-equilibrium constant-pressure process.

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

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

e) Derive the expression for mass and energy balance equations of a single stream steady-flow system.

f) Mention the four processes of Carnot cycle. Draw its processes in ***P–v*** diagram.

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

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

b) Explain briefly the phase change process of water with ***(P–v)*** diagram.

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

d) What is a heat engine (HE) ? Write the four characteristics of a HE. Also derive the expression for thermal efficiency of a HE.

5. Solve ***any eight*** of the following. [3 x 8 = 24]

a) Consider a system whose temperature is *-12 °C*. Express this temperature in R, K, and °F.

b) A manometer containing oil (ρ=800 kg/m^3) is attached to a tank filled with air. If the oil-level difference between the two columns is 70 cm and the atmospheric pressure is 96 kPa, determine the absolute pressure of the air in the tank.

c) 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, determine the specific heats at constant volume and constant pressure

d) Air enters a ***nozzle*** steadily at 3.07 kg/m^3 and 47 m/s and leaves at 0.903 kg/m^3 and 183 m/s. If the outlet area of the nozzle is 500 cm^2, determine (*a*) the mass flow rate through the nozzle, and (*b*) the inlet area of the nozzle.

e) A piston-cylinder device 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 and temperature of 520 K. The gas constant for air is R=0.287 kJ/kg. K. How much work has the air done in the process?

f) Apples are to be cooled from 33 to 15 °C at a rate of 219 kg/h by a refrigeration system. The power input to the refrigerator is 1.7 kW. Determine the rate of cooling, in kJ/min, and the coefficient of performance of the refrigerator. The specific heat of apple above freezing is 3.77 kJ/kg·°C.

g) A Carnot refrigerator operates in a room in which the temperature is 35°C and consumes 3.5 kW of power when operating. If the food compartment of the refrigerator is to be maintained at 7°C, determine the rate of heat removal from the food compartment.

h) Determine the amount of heat to be removed from a refrigerated space if coefficient of performance of the refrigerator is 1.5 and power consumed by the refrigerator is 0.6 kW. Also determine the rate of heat transfer to the surrounding air.

i) A piston–cylinder device initially contains 0.07 m^3 of nitrogen gas at 130 kPa and 180 °C. The nitrogen is now expanded to a pressure of 80 kPa polytropically with a polytropic exponent of 1.3. Determine the final volume and final temperature for this process. The gas constant for nitrogen is 0.2968 kJ/kg.K.

6. Solve the following problems. [2 x 10 = 20]

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 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, and
   iii) The exit area of the nozzle

Use the following data:

$$\left.\begin{array}{l} P_1 = 4\text{ MPa} \\ T_1 = 400°\text{C} \end{array}\right\} \begin{array}{l} v_1 = 0.07343\text{ m}^3/\text{kg} \\ h_1 = 3214.5\text{ kJ/kg} \end{array} \qquad \left.\begin{array}{l} P_2 = 2\text{ MPa} \\ T_2 = 300°\text{C} \end{array}\right\} \begin{array}{l} v_2 = 0.12551\text{ m}^3/\text{kg} \\ h_2 = 3024.2\text{ kJ/kg} \end{array}$$

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