

E : THERMODYNAMICS

Notation used:

P-pressure, V-volume, T-temperature, S-entropy, H-enthalpy, U-internal energy, C_p , C_v – specific heats.

Specific properties are designated by lower case symbols.

Subscript 'f' refers to saturated liquid and subscript 'g' refers to saturated vapor.

Useful data:

Universal gas constant = 8.314 kJ/kmol K

Molecular mass of air in kg/kmol = 29

Specific heat ratio of air (γ_{air}) = 1.4

Q. 1 – Q. 9 carry one mark each.

- Q.1 A gas expands following the relation $PV^n = \text{constant}$, from the initial state P_1, V_1 to final volume $V_2 = 2V_1$. For the values of 'n' mentioned below, maximum displacement work is obtained for
 (A) $n = -1$ (B) $n = 0$ (C) $n = 1$ (D) $n = 1.4$
- Q.2 A 100 Ω electrical resistor is heated steadily by passing a current of 20 A. If heating is performed in the ambient at 30°C, the rate of increase in entropy of the universe in kW/K is _____.
- Q.3 As per Clausius inequality, a system operating on an irreversible cycle transfers
 (A) more entropy to the sink than what it receives from the source
 (B) as much entropy to the sink as it receives from the source
 (C) less entropy to the sink than what it receives from the source
 (D) less entropy to the sink than that corresponding to a reversible cycle
- Q.4 The critical point of a substance corresponds to the state
 (A) at which the solid, liquid and vapor phases are in equilibrium
 (B) beyond which liquid will require very large amount of heat to become vapor
 (C) beyond which solid sublimates directly to the vapor state
 (D) beyond which the distinction between liquid and vapor phases disappears
- Q.5 Consider the process of sensible cooling of air with 60% relative humidity at constant pressure. Which one of the following statements is **TRUE** for this process?
 (A) Both humidity ratio and relative humidity increase during the process.
 (B) The humidity ratio decreases continuously due to condensation.
 (C) The dry bulb temperature decreases but the wet bulb temperature increases.
 (D) The humidity ratio remains constant.
- Q.6 The coefficient of performance (COP) of a reversible refrigerator operating between two thermal reservoirs is 4.0. The efficiency (in percentage) of a reversible heat engine operating between the same temperature limits is _____.

Q.7 Differential change in specific enthalpy of a superheated vapor for which ideal gas approximation does not hold, is given by the expression

(A) $dh = C_p dT$

(B) $dh = C_p dT + \left. \frac{\partial h}{\partial v} \right|_T dv$

(C) $dh = C_p dT + \left. \frac{\partial h}{\partial p} \right|_T dp$

(D) $dh = C_v dT + \left. \frac{\partial h}{\partial p} \right|_T dp$

Q.8 An ideal gas mixture of oxygen (molecular weight = 32 kg/kmol) and carbon dioxide (molecular weight = 44 kg/kmol) has a mass composition of 40% and 60% respectively. If the total pressure is 200 kPa, the partial pressure of oxygen (in kPa) is _____.

Q.9 In an ideal Rankine cycle, increase in superheat of vapor at the exit of boiler leads to

- (A) decrease in net work output from the cycle
- (B) increase in cycle efficiency
- (C) decrease in cycle efficiency
- (D) decrease in quality of steam at the exit of the turbine

Q. 10 – Q. 22 carry two marks each.

Q.10 Two moles of air at 1 atm, 21.1°C goes through an adiabatic device and separates into a hot stream of 0.4 moles at 1 atm, 176.3°C and a cold stream of 1.6 moles at 1 atm, -17.7°C, without any external work. It can be concluded that

- (A) the total entropy change is zero
- (B) the total entropy change for the process is positive
- (C) the device violates Second Law of Thermodynamics
- (D) the device violates First Law of Thermodynamics

Q.11 For a real gas undergoing volume expansion through a porous plug with $\alpha = \left. \frac{1}{v} \frac{\partial v}{\partial T} \right|_p$, the Joule-Thomson cooling effect is observed if

- (A) $0 < \alpha T < 1$ (B) $\alpha T = 1$ (C) $\alpha T > 1$ (D) $\alpha T = 0$

Q.12 A lead bullet at 100°C traveling at 500 m/s, strikes a target and adiabatically comes to rest. If the specific heat of lead is 92 J/kg °C, melting temperature is 327.5 °C and heat of fusion is 108 kJ/kg, the percentage mass of lead in the bullet that is melted by collision is _____.

Q.13 An air-water vapor mixture with volume 100 m³ at 100 kPa, 35°C is at 75 % relative humidity. Taking saturation pressure of vapor at 35°C as 5.63 kPa, the mass of vapor in the mixture in kg is _____.

Q.14 An ideal gas of 1 kg mass enclosed inside a rigid vessel at the initial temperature 1200 K is employed as a heat source. The specific heat C_v of the gas is 718 J/kg K. The maximum work in kJ that can be developed by operating a heat engine between the ideal gas and the ambient at 300 K is

- (A) 646.2 (B) 484.7 (C) 387.7 (D) 347.6

- Q.15 The boiling point of water changes from 99.62°C to 105.99°C when the system pressure is changed from 1 bar to 1.25 bar. The boiling point value (in $^{\circ}\text{C}$) corresponding to a pressure of 1.5 bar is _____.
- Q.16 An ideal gas expands in an adiabatic frictionless nozzle from the inlet conditions of 31 bar, 800 K to the ambient pressure of 1 bar at the outlet. The specific heat C_p for the gas is 1 kJ/kg K and the specific heat ratio $\gamma = 1.4$. Neglecting inlet kinetic energy, the velocity of the gas (in m/s) at the nozzle exit is
- (A) 32 (B) 500 (C) 707 (D) 1000
- Q.17 One kmol of hydrogen (molecular weight = 2 kg/kmol , specific heat ratio $\gamma = 1.4$) at 1 bar, 300 K mixes with one kmol of nitrogen (molecular weight = 28 kg/kmol , specific heat ratio $\gamma = 1.4$) at 1 bar, 300 K in an adiabatic vessel. The final mixture is also at 1 bar, 300 K. The entropy change (in kJ/K) for the process is
- (A) -5.76 (B) zero (C) 5.76 (D) 11.53
- Q.18 A cycle 1-2-3-1 is proposed with the following processes:
1-2: Constant pressure expansion, 2-3: Reversible adiabatic expansion, 3-1: Irreversible adiabatic compression. Which one of the following statements is **TRUE**?
- (A) The net work of the cycle is zero because there is no heat transfer.
(B) The cycle is feasible and can deliver net positive work.
(C) The cycle is impossible according to Kelvin-Planck statement.
(D) The cycle is impossible in accordance with First Law of Thermodynamics.
- Q.19 One kg of saturated liquid-vapor mixture of water at 150 kPa ($u_f = 467 \text{ kJ/kg}$, $v_f = 0.001053 \text{ m}^3/\text{kg}$; $u_g = 2520 \text{ kJ/kg}$ and $v_g = 1.159 \text{ m}^3/\text{kg}$) with quality of 0.7 is enclosed in a piston cylinder assembly. Heat is added at constant pressure to this system while a paddle wheel transfers a work of 50 kJ. The mixture eventually attains saturated vapor state. The amount of heat added to the mixture (in kJ) is _____.
- Q.20 Air enters a pipe at 1 bar and flows isothermally at the rate of 1 kg/s. Due to pipe friction, the pressure drop between two sections of the pipe is 7 % of the pressure at inlet section. For ambient temperature, $T_0 = 300 \text{ K}$, the rate of irreversibility (in W) between the two sections is _____.
- Q.21 A pump raises pressure of saturated liquid water at 100 kPa (density $\rho = 959 \text{ kg/m}^3$) to 2 MPa. The isentropic efficiency of the pump is 0.92. The work done by the pump (in J/kg) is _____.
- Q.22 In a Brayton cycle with air ($\gamma = 1.4$) as working fluid, $T_{\min} = 300 \text{ K}$ and $T_{\max} = 1000 \text{ K}$. The pressure ratio corresponding to maximum net work per cycle is _____.

END OF THE QUESTION PAPER