E : THERMODYNAMICS

Notation used:

P - pressure, V - volume, T - temperature, S - entropy, H - enthalpy, U - internal energy, A - Helmholtz free energy, C_p - specific heat capacity at constant pressure.
Specific properties are designated by lower case symbols.

Useful data:

Universal gas constant $R = 8.314$ kJ/(kmol.K)
C_p of air = 1.005 kJ/(kg.K)
Ratio of ideal gas specific heats for air: $\gamma = 1.4$
Molecular mass of hydrogen: 2 kg/kmol

Q. 1 – Q. 9 carry one mark each.

Q.1 Which of the following thermodynamic properties is NOT an intensive property of a thermodynamic system:

(A) Pressure
(B) Temperature
(C) Density
(D) Volume

Q.2 An U-tube manometer shows a height difference of z_1 between the two columns for a known gauge pressure P_1 (both z_1 and P_1 in appropriate units). If the height difference between the two columns is $2z_1$, then the corresponding gauge pressure will be:

(A) $P_1/2$ (B) $2P_1$ (C) P_1 (D) $4P_1$

Q.3 Water vapour can be treated as an ideal gas,

(A) for all temperature and pressure
(B) for sufficiently low pressure, regardless of its temperature
(C) for very high pressure only
(D) for sufficiently low temperature, regardless of its pressure

Q.4 The thermal efficiency of a Carnot engine is 0.5. If the temperature of the cold reservoir is 300 K, then the temperature of the hot reservoir is:

(A) 600 K (B) 1200 K (C) 900 K (D) 450 K

Q.5 In a reversible, constant-pressure, non-flow process, heat input is given by

(A) change in internal energy
(B) change in enthalpy
(C) change in entropy
(D) work output

Q.6 Moist air undergoes an adiabatic saturation process such that the relative humidity of air increases. For this process,

(A) Dry bulb temperature increases, specific humidity increases
(B) Dry bulb temperature increases, specific humidity decreases
(C) Dry bulb temperature decreases, specific humidity increases
(D) Dry bulb temperature decreases, specific humidity decreases

Q.7 A steadily flowing ideal gas undergoes adiabatic throttling, where
T_1: temperature before throttling
T_2: temperature after throttling
Assuming no change in kinetic and potential energy due to throttling, which of the following is correct:

(A) $T_1 = T_2$ (B) $T_1 > T_2$
(C) $T_1 < T_2$ (D) $T_1 = \gamma\ T_2$, γ: specific heat ratio

Q.8 For irreversible heat transfer from a hot body to a cold body, if Δ denotes the property change of both hot and cold bodies (i.e. difference between its final and initial values), then

(A) $\Delta S = 0$ (B) $\Delta U > 0$
(C) $\Delta S < 0$ (D) $\Delta S > 0$

Q.9 A closed system undergoes a cyclic process. For the net work done by the system on the surroundings, which of the following statements is FALSE:

(A) Net work is always zero
(B) Net work is $\oint P\ dV$ if the process is reversible
(C) Net work can be negative
(D) Net work can be positive

Q. 10 – Q. 22 carry two marks each.

Q.10 Consider the following statements related to the second law of thermodynamics:

P. A cyclic heat engine cannot produce net work by exchanging heat only with one reservoir.
Q. The efficiency of a reversible heat engine is dependent on the nature and amount of working substance undergoing the cycle.
R. It is impossible to have a cyclic device which will produce no effect other than the transfer of heat from a cold body to a hot body.
S. It is impossible to have heat engines operating between a heat source and sink to have a lower efficiency than that of a reversible heat engine operating between the same source and sink.

For which of the following options, BOTH the statements are inconsistent with the second law of thermodynamics:

(A) P and R (B) P and Q (C) R and S (D) Q and S

Q.11 Consider the following statements related to air-standard Otto, Diesel, and Brayton cycles:

P. Brayton cycle has at least one isentropic and one isobaric process.
Q. Otto cycle has at least one isentropic and one isochoric process.
R. Diesel cycle has at least one isentropic and one isothermal process.
S. At least one of the cycles has an isothermal process.

For which of the following options, BOTH the statements are consistent with the operation of the above cycles:

(A) P and R (B) P and Q (C) R and S (D) P and S

Q.12 Volumetric analysis of a hydrocarbon combustion product shows 8% CO_2, 15% H_2O (vapour), 5.5% O_2 and 71.5% N_2. The combustion product flows steadily through a heat exchanger at 200 kPa pressure. Assume each component in the mixture to be an ideal gas. In order to avoid the condensation of H_2O in the heat exchanger, the minimum allowable temperature (in ^oC) is _____.

Saturated H_2O Table:

P (kPa)	10	20	30	40	50
T (^oC)	45.83	60.09	69.12	75.82	81.35

Q.13 An equimolar mixture of two ideal gases (A, B) expands isentropically in a nozzle. The gas mixture enters the nozzle at 300 kPa, 400 K and exits at 100 kPa. Assuming the mixture to be an ideal gas, the exit temperature of the gas mixture (in K) is _____.

	Molar mass (kg/kmol)	C_p (kJ/kg-K)
Gas A	28.013	1.04
Gas B	2.016	14.21

Q.14 A rigid vessel of volume 10 m^3 is filled with hydrogen at 25^{o}C and 500 kPa. Due to leakage, some gas has escaped from the vessel until the pressure in the vessel drops down to 200 kPa, and the corresponding temperature of the gas inside the vessel is found to be 15^{o}C. The amount of gas leaked (in kg) from the vessel is _____.

Q.15 A hot ideal gas (C_p = 1.2 kJ/(kg.K)) steadily flows through a turbine with inlet and exit temperatures of 1500 K and 500 K respectively. The minimum mass flow rate (in kg/s) of the hot gas to achieve a power output of 12 MW is _____.

Q.16 Air pressure inside a spherical balloon is proportional to its diameter. The balloon undergoes a reversible, isothermal, non-flow process. During the process, the balloon maintains its spherical shape, and the air inside the balloon consumes 2 kJ of heat. Initial air pressure inside the balloon was 120 kPa, while the initial balloon diameter was 20 cm. Assuming air to be an ideal gas, the final diameter of the balloon (in cm) is _____.

Q.17 An air-standard diesel engine has a compression ratio of 18 (the ratio of the volume at the beginning of the compression process to that at the end of the compression process), and a cut-off ratio of 2 (the ratio of the volume at the end of the heat addition process to that at the beginning of the heat addition process). The thermal efficiency (in %) of the engine is _____.

Q.18 Compressed air, at 1 MPa pressure, 400 K temperature flows through a large pipe. An evacuated, insulated rigid tank of 0.5 m^3 volume is connected to the pipe through a valve. The valve is opened to fill the tank and the valve closes automatically when the tank pressure reaches 1 MPa. Assuming ideal gas behaviour, the final air temperature in the tank (in K) is _____.

Q.19 A 40 kg metal block (C_p = 0.5 kJ/(kg.K)) at T = 450^{o}C is quenched in 150 kg oil (C_p = 2.5 kJ/(kg. K)) at T = 25^{o}C. If the combined (metal block and oil) system is fully isolated from its surroundings, then the net change in the entropy (in kJ/K) of the combined system is _____.

Q.20 For phase change from solid (sol) to liquid (liq) state, if the slope of the solid-liquid coexistence line in the P-T diagram is negative, then:

(A) $v_{liq} < v_{sol}$ (B) $v_{liq} > v_{sol}$ (C) $s_{liq} < s_{sol}$ (D) $h_{liq} < h_{sol}$

Q.21 A house-hold refrigerator operates under steady state condition between an evaporator temperature of 263 K and a condenser temperature of 323 K. The heat load to the refrigerator is 3 kW. The actual COP of the refrigerator is half of that of a Carnot refrigerator operating between the same condenser and evaporator temperatures. The power required (in kW) to run the refrigerator is _____.

Q.22 The Maxwell relation that results from the expression for the Helmholtz free energy $A = U - TS$, is:

(A) $\left.\frac{\partial T}{\partial v}\right)_s = -\left.\frac{\partial P}{\partial s}\right)_v$

(B) $\left.\frac{\partial T}{\partial P}\right)_s = \left.\frac{\partial v}{\partial s}\right)_P$

(C) $\left.\frac{\partial P}{\partial T}\right)_v = \left.\frac{\partial s}{\partial v}\right)_T$

(D) $\left.\frac{\partial v}{\partial T}\right)_P = -\left.\frac{\partial s}{\partial P}\right)_T$

END OF THE QUESTION PAPER

Space for Rough Work

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