Indian Institute of Technology Kanpur

Thermodynamics (ESO201A)

Semester: 2022-23-I

End-Semester Examination

Closed Notes, Closed Book

Time Limit: 3 hours **Full Marks: 100**

Note: Show all steps and calculations. 1 Pa = 1 N/m^2.

1. A constant volume tank contains 5 kg of air at 100 kPa and 327^{o}C. The temperature of the surroundings is 27^{o}C. The tank loses heat to the surroundings until the temperature of the former drops to 27^{o}C. Assume constant specific heats for air at 300 K. (a) Determine the entropy change of the air in the tank during the process, in kJ/K; and (b) determine the total entropy change of the universe due to this process, in kJ/K. Treat air as an ideal gas. For air, c_v = 0.718 kJ/kg K.

(5 + 5 =10)

2. A piston-cylinder device initially contains 0.5 m^3 of nitrogen gas at 400 kPa and 27^{o}C. An electric heater within the device is turned on and is allowed to pass a current at 2 amp for 5 min from a 120 volt source. Nitrogen expands at constant pressure, and a heat loss of 2800 J occurs during the process. Determine the final temperature of nitrogen (in ^{o}C). Treat nitrogen as an ideal gas with constant specific heats at room temperature. For nitrogen, c_p = 1.039 kJ/kg K, R = 0.297 kJ/kg K.

(15)

3. A 2-m^3 rigid uninsulated tank initially contains air at 100 kPa and 22^{o}C. The tank is connected to a supply line through a valve. Air is flowing in the supply line at 600 kPa and 22^{o}C. The valve is opened, and air is allowed to enter the tank until the pressure in the tank reaches the line pressure, at which point the valve is closed. A thermometer placed in the tank indicates that the air temperature at the final state is 77^{o}C. Determine (a) the mass of air (in kg) that has entered the tank and (b) the amount of heat transfer (kJ). Treat air as an ideal gas with variable specific heats. For air, $h_{@295K}$ = 295.17 kJ/kg, $u_{@295K}$ = 210.49 kJ/kg, $u_{@350K}$ = 250.07 kJ/kg. R = 0.287 kJ/kg K.

(6 + 9 = 15)

4. n-Octane gas (C_8H_{18}) is burned with 100% excess air in a constant pressure burner. The air and fuel enter this burner steadily at the standard reference state (25^{o}C, 1 atm) and the products of combustion leave at 257^{o}C. Calculate the heat transfer, in kJ/kg fuel, during the combustion. Assume air and the combustion products to be ideal gases. Use the property data from Table 1 given below.

Table 1 Property Data

Substance	$\bar{h}_f^o$ (kJ/kmol)	$\bar{h}_{298K}$ (kJ/kmol)	$\bar{h}_{530K}$ (kJ/kmol)
C_8H_{18} (g)	-208,450	---	---
O_2	0	8682	15,708
N_2	0	8669	15,469
H_2O (g)	-241,820	9904	17,889
CO_2	-393,520	9364	19,029

(15)

5. Consider a Carnot-cycle heat pump with R-410a as the working fluid. Heat is rejected from the R-410a at 40^{o}C, during which process the R-410a changes from saturated vapour to saturated liquid. The heat is transferred to the R-410a at -5^{o}C. (a) Show the cycle on a T-s diagram. Indicate all the state points in the diagram clearly and the flow direction; (b) Find the quality of the R-410a at the beginning and end of the isothermal heat addition process at -5^{o}C; and (c) Determine the COP for the cycle. At T = 40^{o}C, s_f = 0.4473 kJ/kg K, s_g = 0.9552 kJ/kg K. At T = -5^{o}C, s_f = 0.1989 kJ/kg K, s_{fg} = 0.8477 kJ/kg K.

(3 + 5 + 2 = 10)

6. A simple Rankine cycle uses water as the working fluid. The boiler operates at 6000 kPa and the condenser at 50 kPa. At the entrance to the turbine, the temperature is 450^{o}C. The isentropic efficiency of the turbine is 94%, pressure and pump losses are negligible, and the water leaving the condenser is subcooled by 6.3^{o}C. The boiler is sized for a mass flow rate of 20 kg/s. Draw the *T-s* diagram for this cycle. Indicate all state points on the diagram clearly and the flow direction. Determine the rate at which heat is added to the boiler (in kW), the power required to operate the pumps (in kW), the net power produced by the cycle (kW), and the thermal efficiency. At P_1 = 50 kPa, $T_1 = T_{sat@50kPa}$ - 6.3 = 81.3 - 6.3 = 75^{o}C: $h_1 \cong h_{f@75^oC}$ = 314.03 kJ/kg, $v_1 = v_{f@75^oC}$ = 0.001026 m^3/kg. At P_3 = 6000 kPa and T_3 = 450^{o}C: h_3 = 3302.9 kJ/kg, s_3 = 6.7219 kJ/kg. At P_4 = 50 kPa, $s_{4s} = s_3$: s_f = 1.0912 kJ/kg K, s_{fg} = 6.5019 kJ/kg K, h_f = 340.54 kJ/kg, h_{fg} = 2304.7 kJ/kg.

(5 + 4 + 4 + 4+ 3 = 20)

7. An engine operating on an ideal diesel cycle has a compression ratio of 20 and uses air as the working fluid. The state of air at the beginning of the compression process is 95 kPa and 20^{o}C. If the maximum temperature in the cycle is 2200 K, determine (a) the thermal efficiency and (b) the mean effective pressure (in kPa). Assume constant specific heats for air at room temperature. Also draw *P-v* diagram for this cycle. Indicate all state points on the diagram clearly and the direction of the processes. Treat air as an ideal gas. For air, c_p = 1.005 kJ/kg K, c_v = 0.718 kJ/kg K, R = 0.287 kJ/kg K and k = 1.4.

(3 + 7 + 5 =15)