Ref. No. Ex/PG/PE/T/111A/2024

M. POWER ENGINEERING FIRST SEMESTER EXAMINATION 2024

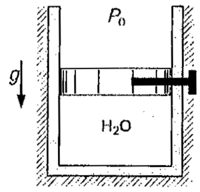
SUBJECT: **APPLIED THERMODYNAMICS**

Time: Three Hours **Full Marks 100**

CO 1 Answer any two questions

1.

(a) A piston held by a pin in an insulated cylinder, shown in the Figure, contains 2 kg of water at 100°C, with a quality of 98%. The piston has a mass of 100 kg, with cross-sectional area of 100 cm^2, and the ambient pressure is 100 kPa. The pin is released, which allows the piston to move. Determine the final state of the water, assuming the process to be adiabatic. Assume g = 10 m/s^2. Is the process reversible or irreversible? Explain from the perspective of entropy. **13**



(b) The internal energy of a certain substance is given by u=3.56 pv+84, where u is in kJ/kg, p in kPa and v is in m^3/kg. As system comprising of 3 kg of this substance expands from an initial pressure of 500 kPa and volume of 0.22 m^3 to a final pressure of 100 kPa in a process in which pressure and volume are related by $pv^{1.2}$=constant. **12**

2.

(a) Derive the Maxwell relations from the definitions of u, h, a and g. Also, deduce the Clausius Clapeyron's equation from Maxwell relations. **5+5=10**

(b) Show that, for a pure fluid,

$$\left(\frac{\partial u}{\partial v}\right)_T = T^2\left(\frac{\partial (p/T)}{\partial T}\right)_v \text{ and } \left(\frac{\partial h}{\partial p}\right)_T = -T^2\left(\frac{\partial (v/T)}{\partial T}\right)_p$$

Hence, show that, for a pure fluid, whose internal energy and enthalpy are functions of temperature only, (p/T) and (v/T) are sole functions of volume and pressure respective. **Do not assume the ideal gas equation of state.** Use this result to show that pv/T = Constant is a necessary condition for internal energy and enthalpy to be functions of temperature only. **15**

3.

(a) Define Joule Thomson effect and discuss its practical utility with the temperature inversion diagram. **5+5=10**

(b) Show that for a pure substance, the Joule-Thomson coefficient can be written as $\mu_J = \frac{T^2}{C_p}\left(\frac{\partial(v/T)}{\partial T}\right)_p$ **7**

(c) From the above expression, deduce the Joule Thompson coefficient for a van der Waals gas. **8**

CO 2: Answer any one

4.

(a) Two rigid, insulated tanks of 1 m^3 volume each are connected by a valve. One tank contains CO_2 at 10 bar and 400 K while the other tank contains N_2 at 1 bar and 300 K. Both the tank and the valve assembly are insulated from the surrounding. If the valve is now suddenly opened, find the final pressure and temperature of the gas mixture and the irreversibility. Assume the two gases to follow ideal gas behavior with C_{p,CO_2}= 0.8 kJ/kgK, and C_{p,N_2} = 1.04 kJ/kgK, and an ambient temperature of 300 K. **13**

(b) A combination air cooler and dehumidification unit receives outside ambient air at 30°C, 100 kPa, and 90% relative humidity. The moist air is first cooled to a low temperature T_2 to condense the proper amount of water; assume all the liquid leaves at T_2. The moist air is then heated and leaves the unit at 20°C, 100 kPa, and 30% relative humidity with a volume flow rate of 0.01 m^3/s. Find the temperature T_2, the mass of liquid

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per kilogram of dry air, and the heat transfer rates at the cooler and the heater sections. You may use the psychrometric chart attached with the question paper. **12**

5

(a) A reversible steady-state device receives a flow of 1 kg/s air at 400 K, 450 kPa, and the air leaves at 600 K, 100 kPa (see Fig 5(a)). Heat transfer of 800 kW is added from a 1000 K reservoir, 100 kW is rejected at 350 K, and some heat transfer takes place at 500 K. Find the heat transferred at 500 K and the rate of work produced. **10**

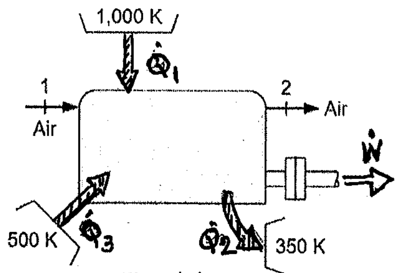

Fig 5(a)

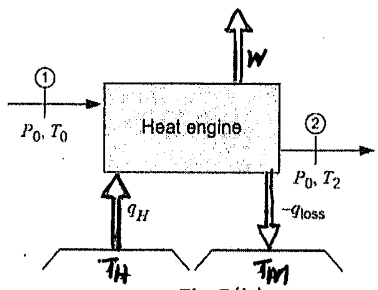

Fig 5(b)

(b) Air flows into a heat engine at ambient conditions 100 kPa, 300 K (stream 1), as shown in Fig. 5(b). Energy is supplied as 1200 kJ/kg air from a T_H = 1500 K source, and in some part of the process a heat loss of 300 kJ/kg air occurs at T_M=750 K. The air leaves the engine at 100 kPa, 800 K (stream 2). Find the first- and second-law efficiencies of the engine. **15**

CO 3: Answer any <u>one</u>

6.

(a) Consider a 5 mm thick infinitely large and wide copper plate, one surface of which is steadily maintained at 427 °C and the other at the ambient temperature of 27 °C. The specific heat and thermal conductivity of copper are known to be, respectively, 0.385 kJ kg^{-1} K^{-1} and 0.401 kW m^{-1} K^{-1}. Determine the entropy at fluxes at the hot and the cold planes, and the entropy generation rate. Also find the exergy destruction. **12**

(b) A semiconductor chip consumes 5 kJ of electric work over time and rejects that as heat dissipation from its 77° C surface to the surrounding air at 27° C. How much entropy is generated within the chip, and how much outside? **8**

(c) During the isothermal heat rejection process of a Carnot cycle, the working fluid experiences an entropy change of -0.6 kJ/K. If the temperature of the energy sink remains at 30° C, determine (a) the amount of heat transfer to the sink, (b) the entropy change of the sink, and (c) the total entropy generated. **5**

7.

(a) Write down the Availability transfer equation for an open system, and label what each term means. **5**

(b) Steam enters a turbine operating under steady state at a pressure of 3MPa, temperature of 400°C, and a velocity of 160 m/s. Steam exits as saturated vapor at 100°C with a velocity of 100 m/s. There is no significant change in elevation. Heat transfer from the turbine at the rate of 30 kJ per kg of steam flowing takes place at an average surface temperature of 400K. For the turbine, determine, per kg of steam flow (i) the work developed, (ii) magnitude and direction of availability transfer accompanied by heat and work transfers, (iii) the irreversibility. Assume ambient to be at 300 K and 1 bar. **20**

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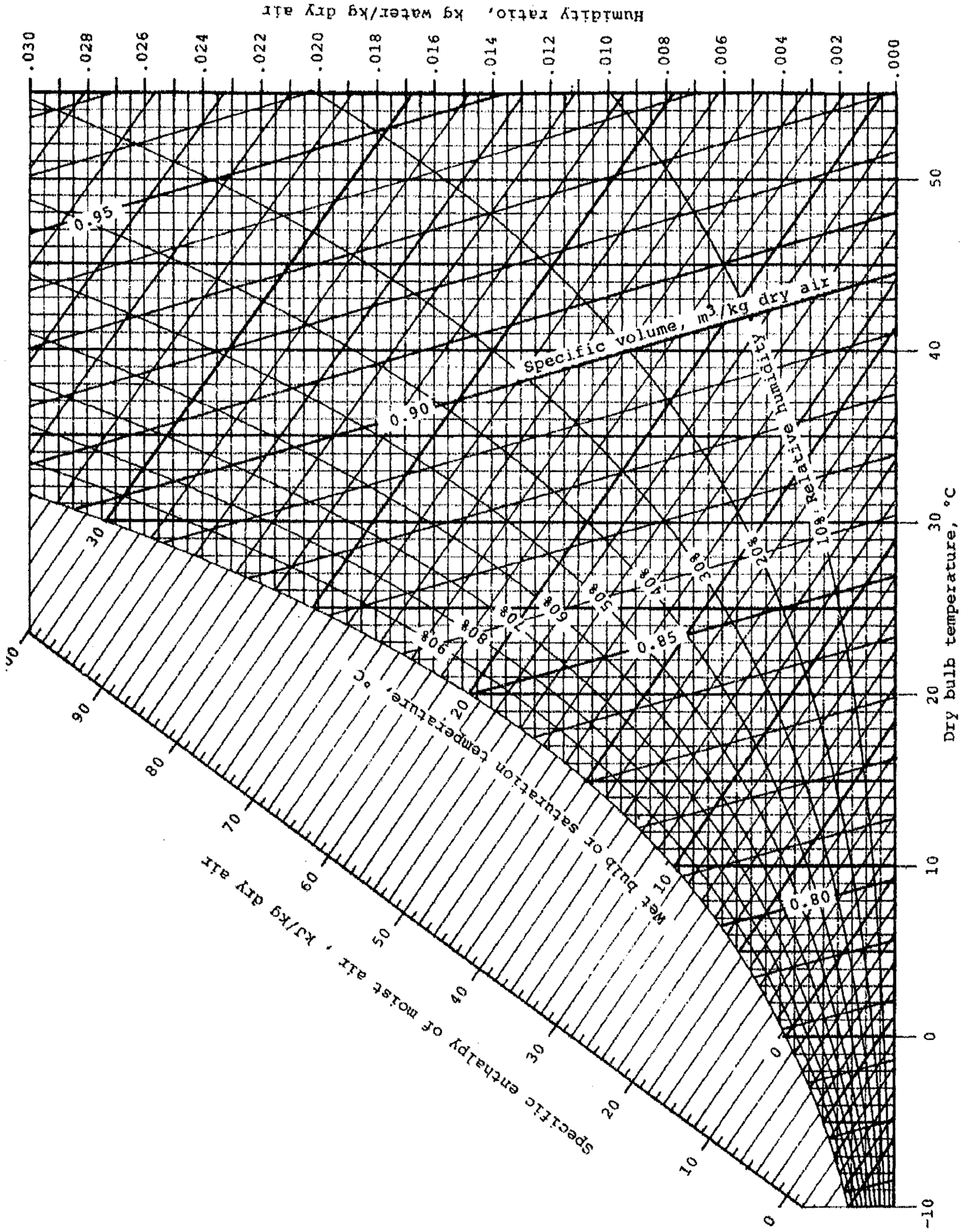

Psychrometric Chart