Ref. No. Ex/PG/POW/PE/T/121A/2025

M. POWER ENGINEERING FIRST SEMESTER EXAMINATION 2025

SUBJECT: ***ADVANCED THERMODYNAMICS***

Time: Three Hours **Full Marks 100**

CO 1 Answer any <u>two</u> questions 2x25 = 50 Marks

1.

(a) 4.4 kg of CO_2 gas is expanded quasi-statically in a piston cylinder device at constant pressure of 1.0 MPa until its volume increases from 0.4 m^3 to 0.8 m^3. Then the piston is pinned (fixed) and the gas is cooled until its pressure drops to half of the initial value. Finally, the gas is compressed quasi-statically following a polytropic process back to the initial state. Find the (i) exponent of the polytrope, and (ii) the work done by the gas during the cycle. Also, identify the process(es) during which heat rejection will take place, and calculate the heat rejection(s). Assume $C_p/C_v = 1.26$ for CO_2. **12**

(b) A 0.5 m^3 rigid tank containing hydrogen at 20°C and 600 kPa is connected by a valve to another 0.5 m^3 rigid tank that holds hydrogen at 30°C and 150 kPa **(Fig P1(b))**. Now the valve is opened and the system is allowed to reach thermal equilibrium with the surroundings, which are at 15°C. Determine the final pressure in the tank and the amount of heat transferred in the process.

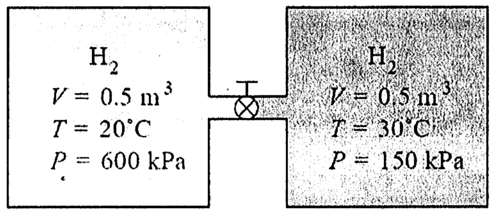

Fig. P1(b) **13**

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) Calculate the density of N_2 at 260 bar and 15°C by using the compressibility chart (see the end of the question paper). The critical pressure and temperature for N_2 are 34 bar and 126 K. **7**

(b) Show that for a pure substance, the Joule-Thomson coefficient can be written as $\mu_J = \frac{T^2}{C_p}\left(\frac{\partial (v/T)}{\partial T}\right)_p$ **8**

(c) From this, deduce the Joule Thompson coefficient for a van der Waals gas. **10**

CO 2: Answer any <u>one</u>

4

(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 P4(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**

[Turn over

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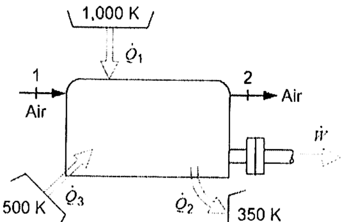

Fig P4(a)

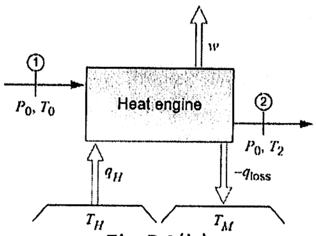

Fig P4(b)

(b) Air flows into a heat engine at ambient conditions 100 kPa, 300 K, as shown in **Fig. P4(b)**. Energy is supplied as 1200 kJ/kg air from a 1500 K source, and in some part of the process a heat-transfer loss of 300 kJ/kg air occurs at 750 K. The air leaves the engine at 100 kPa, 800 K. Find the first- and second-law efficiencies. **15**

5.

(a) Four ideal gases of molecular weights 44, 32, 2 and 16, respectively are mixed in equal volumes at p = 1 bar and T=300 K in an adiabatic chamber. Find out the entropy generated in mixing. **10**

(b) A wet cooling tower **(See Fig. P5b)** is to cool 60 kg/s of water from 40 to 26°C. Atmospheric air enters the tower at 1 atm with dry- and wet-bulb temperatures of 22 and 16°C, respectively, and leaves at 33°C with a relative humidity of 90 percent. Using the psychrometric chart, determine (a) the volume flow rate of air into the cooling tower and (b) the mass flow rate of the required makeup water, which also enters at 26°C. **15**

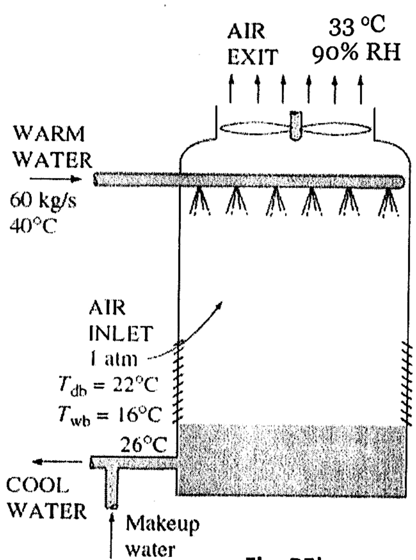

Fig. P5b

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

6.

(a) Explain why it is important to match the heat source temperature and the heat utilization temperature for any thermal application. **5**

(b) An insulated piston–cylinder device contains 2 L of saturated liquid water at a constant pressure of 150 kPa. An electric resistance heater inside the cylinder is turned on, and electrical work is done on the water in the amount of 2200 kJ. Determine (i) the minimum work with which this process could be accomplished and (ii) the exergy destroyed during the actual process. **See Fig. P6b.** **20**

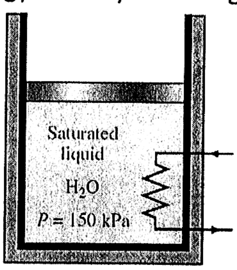

Fig P6b

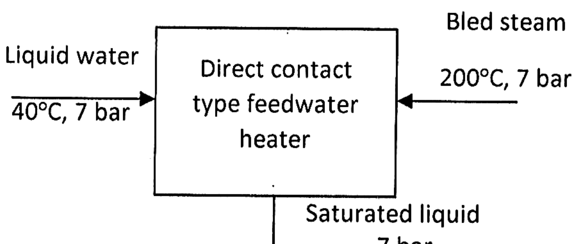

Fig P7b

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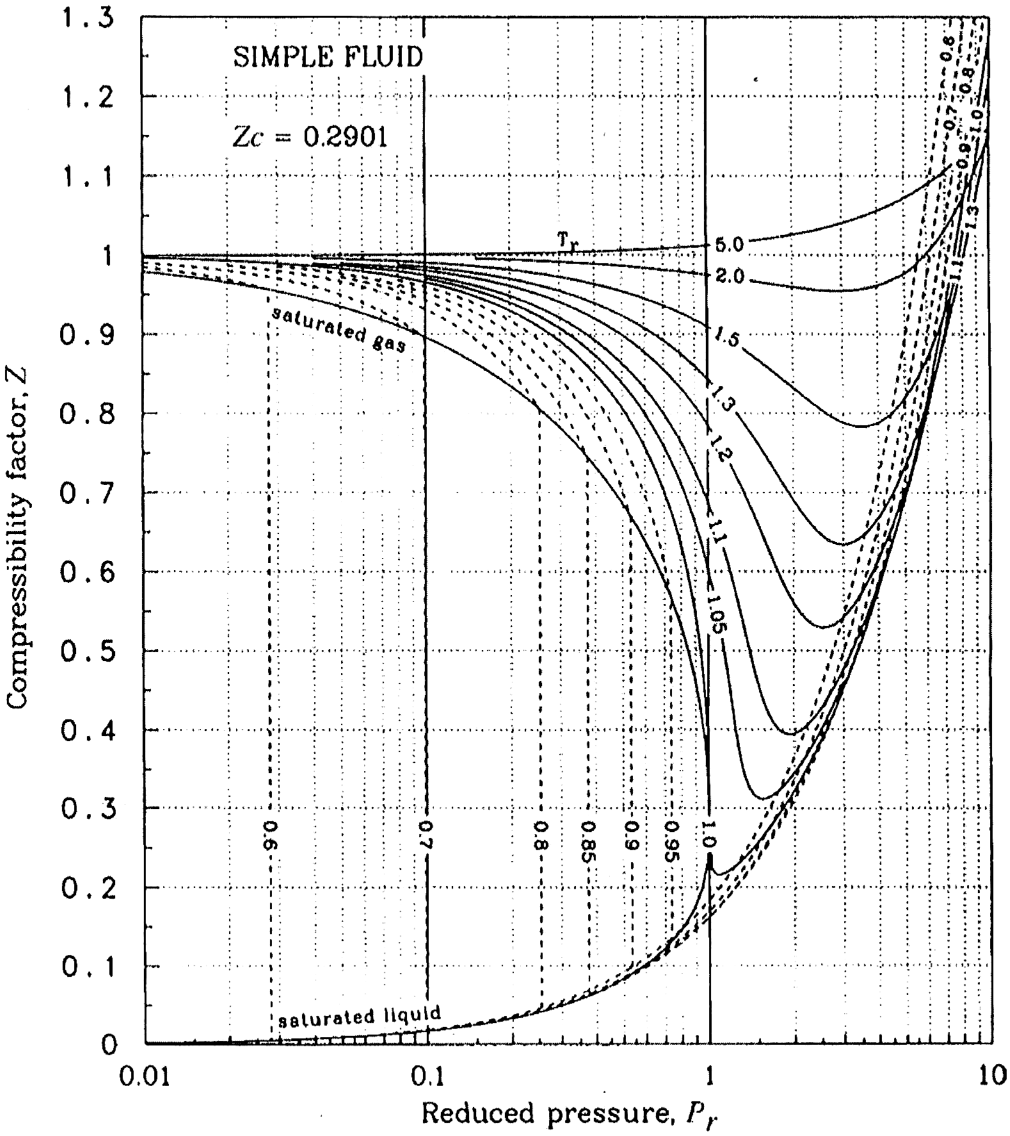
7.

(a) Write the availability balance equation for an open system and identify what each term means. **5**

(b) A direct contact type feedwater heater in a regenerative vapor power plant operates at steady state with liquid entering at inlet 1 with T_1 = 40°C and p_1 = 7.0 bar. Bled steam from turbine is taken at T_2=200°C and p_2=7.0 bar enters at inlet 2 to heat the feedwater. Saturated liquid water exits with a pressure of p_3 = 7.0 bar. Ignoring heat transfer with the surroundings and all kinetic and potential energy effects, (a) determine the ratio of mass flow rates $\dot{m}_1/\dot{m}_2$, (b) the rate of exergy destruction, in kJ per kg of liquid exiting, and (c) the Second Law efficiency. **See Fig. P7b.** **20**



Generalized Compressibility Chart

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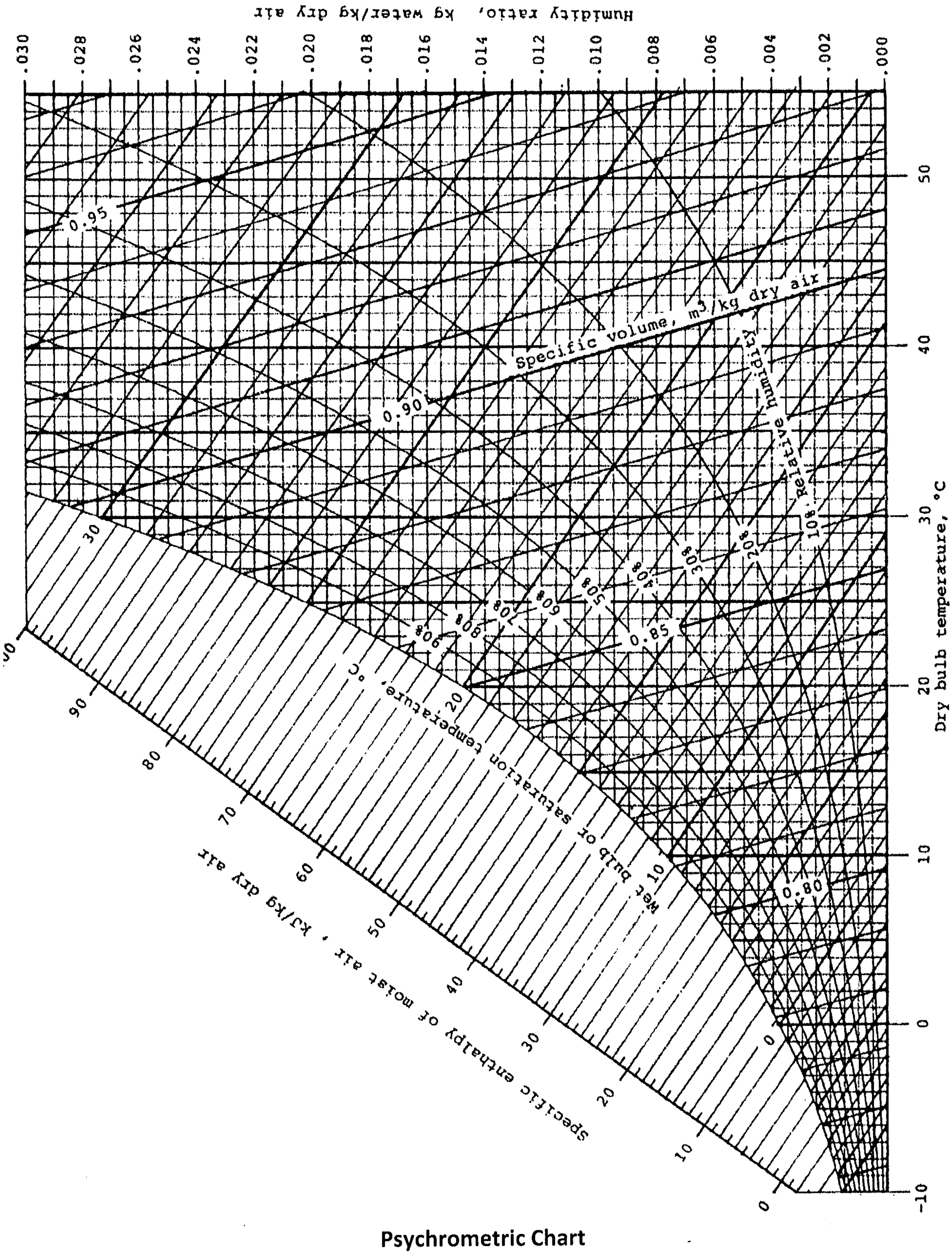

Psychrometric Chart