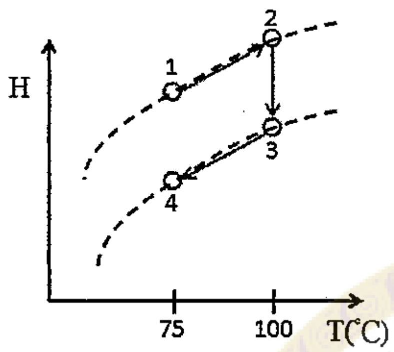
1. 1 kg of steam at a pressure of one atmosphere is supercooled to 75 °C by being brought into contact with a large reservoir at that temperature. While the steam does not condense immediately when it reaches 75 °C, it does after a couple of hours.



(a) Following a reversible path (from point 1 to point 4) as shown in the left figure, calculate the total amount of heat exchanged between the water and the environment starting from the point that the steam was supercooled to 75 °C. (10%)

(b) What is the entropy change of the water during the same period? (8%)

(c) By how much does the entropy of the universe increase? (7%)

(Latent heat of vaporization is 2257 kJ/kg, average heat capacity of water is 4.2 KJ/kg·K and the heat capacity of steam is approximately 2.0 KJ/kg·K, boiling point of water is 100 °C).

2. A gas mixture at one atmosphere total pressure has the following composition:

Component	H_2	O_2	H_2O
Mole fraction	0.05	0.03	0.92

At 700 °C, for the reaction to form the products H_2O:

$$2H_2 + O_2 \rightarrow 2H_2O, \qquad \Delta G^0 = -393\ \text{KJ} \qquad \text{(I)}$$

Given the internal energy change $dU = TdS - PdV + \sum_{i=1}^{n} \mu_i dn_i$, where

μ_i and n_i are the chemical potential and the molar number of species i, respectively.

(a) Use Legendre transformation to derive the Gibbs free energy change dG from dU. (6%) (Hint: the control variables for Gibbs free energy are T and P, let $G = U - TS + PV$, use product rules $d(XY) = YdX + XdY$ to change variables.)

(b) Providing the definition $\mu_k = G_k^0 + RT\ln a_k$, where a_k indicates the activity of species k. Derive the expression of dG for reaction (I) in terms of ΔG^0 and the activities of gas species. (6%)

(c) At equilibrium the system free energy change $dG = 0$, the equilibrium constant K can be derived from $0 = \Delta G^0 + RT\ln(K)$. Providing the gas constant $R = 8.314$ J/mol·K, what is the equilibrium constant of reaction (I) for the given conditions? Briefly explain the meaning of the results you acquired for reaction

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(I) (6%)

(d) The activity of a gas species k, a_k, is defined as its partial pressure normalized by 1 atm. Following the second law of thermodynamics, determine whether reaction (I) will spontaneous occur for the given composition and conditions. (7%)

3. A vapor-compression dehumidifier maintains a cool surface at 5 °C to collect dew.

(a) Assuming the air flow rate over the cool surface is 5 kg/hr, please calculate the moisture removal rate (kg/hr) for a space of 20°C dry-bulb temperature, and 80% relative humidity. (10%)

(b) Is the humidifier of this kind suitable for a space with low dry-bulb temperature? Why? (5%)

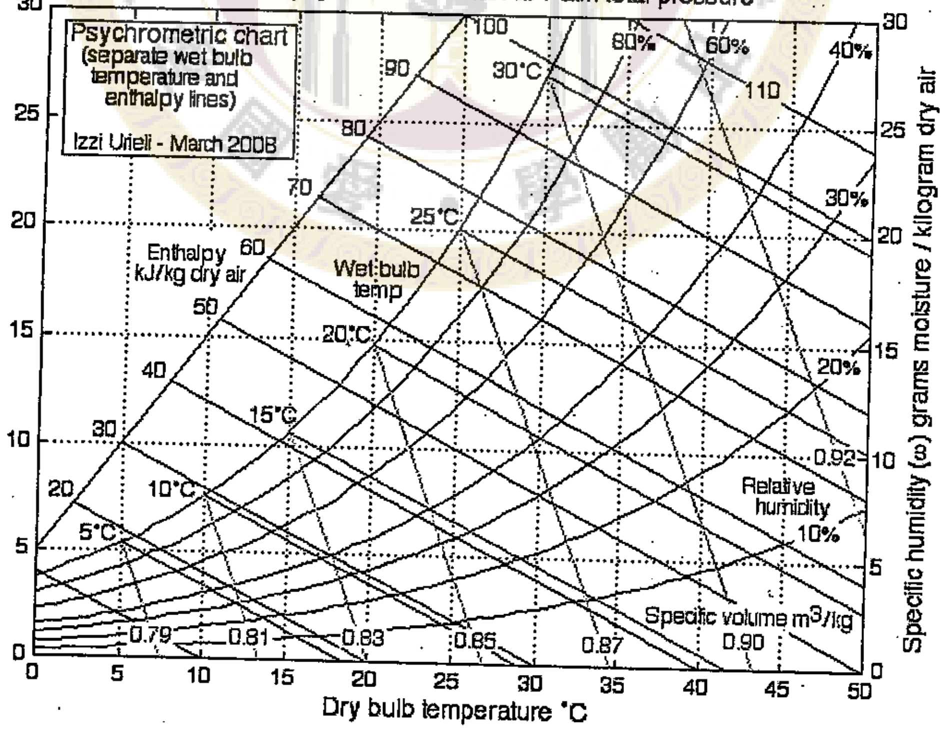
(c) For the situation in (b), calculate the refrigerant flow rate (kg/hr) of the humidifier using R-134a refrigerant with a high pressure of 1 MPa. Assume the refrigeration cycle is ideal. (10%)

4.

(a) If an **ideal** heat pump using R-134a retrieves heat from a heat source of 20 °C and produces hot water of 80 °C, please estimate its COP_{HP}. Draw all processes of the cycle on the P-h diagram. (10%)

(b) Re-estimate the COP_{HP} if the refrigerant changes to R-744. The condensation temperature may vary from 60 to 100 °C to achieve an average of 80 °C. Draw all processes of the cycle on the P-h diagram. (15%)

Simplified psychrometric chart at 1 atm total pressure



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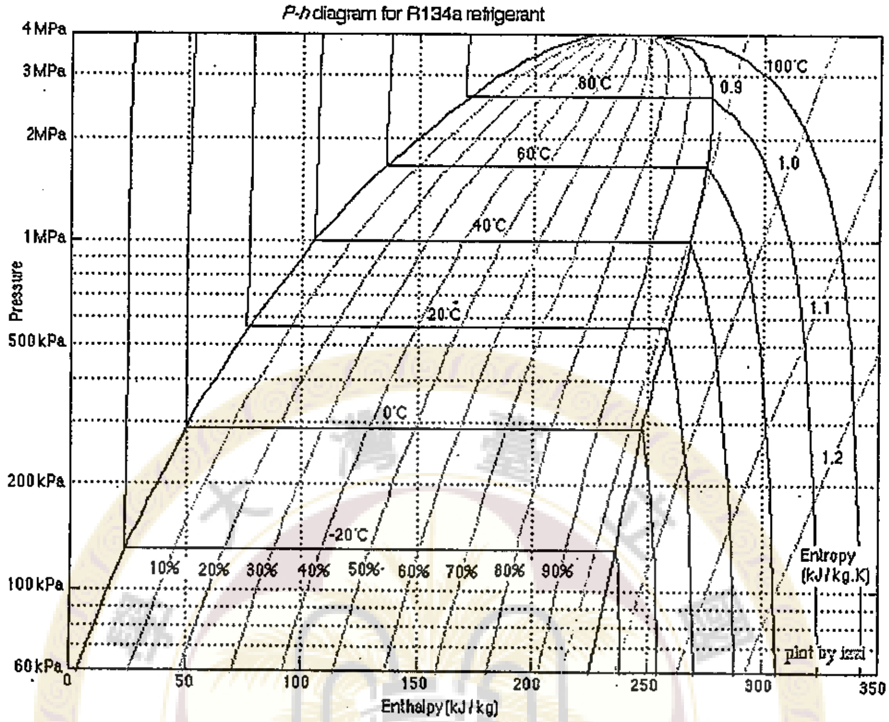
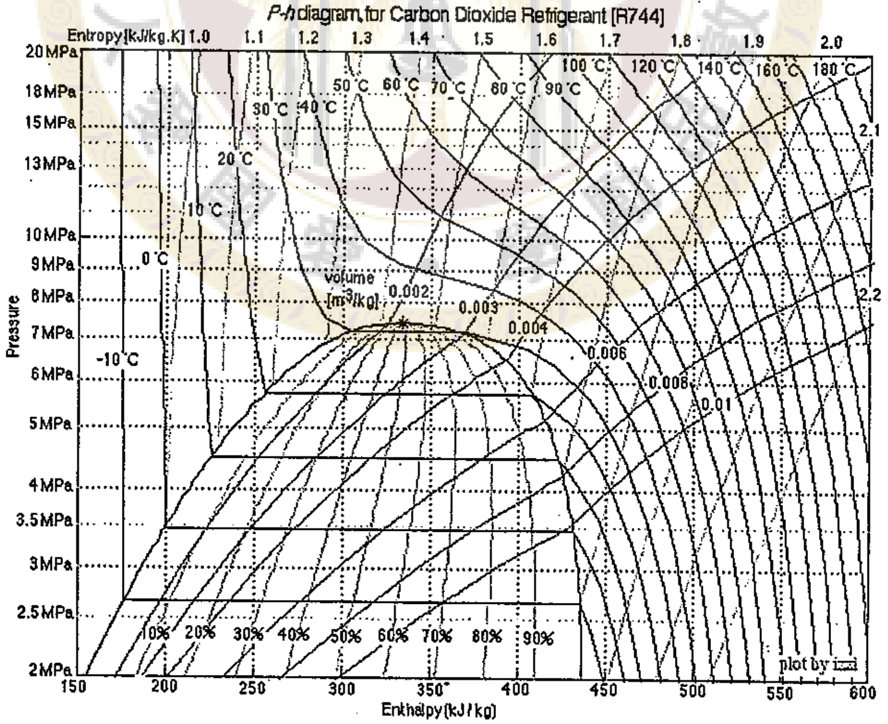
P-h diagram for R134a refrigerant



P-h diagram for Carbon Dioxide Refrigerant [R744]



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