ORDRE DES INGÉNIEURS DU QUÉBEC

NOVEMBER 2019 SESSION

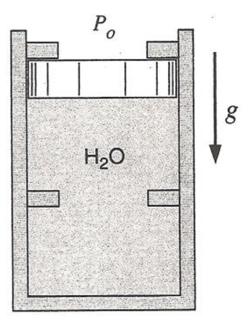
All documentation permitted Only non-programmable calculators are permitted Time allowed : 3 hours

Total : 20 pts

16-CH-A1 PROCESS BALANCES AND CHEMICAL THERMODYNAMICS

(4pts) 1. <u>Change of state</u>

Vapor water, initially at 1 MPa and 500 ^oC, is confined within a cylinder-piston system as illustrated in the figure. The mass of the piston and atmospheric pressure are such that the piston floats freely when the inside pressure is 500 kPa. The system has two stoppers and the volume corresponding to the upper stopper is V_{max} = 3 L, and that of the lower one is V_{min} = 1 L. The system is then cooled down by transferring heat to the surrounding until the piston floats on the lower stopper.



a) Determine the final state of the water.

b) On a *PVT* diagram illustrate the process.

c) Calculate the work done by the system (kJ).

d) Qualitatively, what are the variations of entropy for the system,

for the surroundings and the total variation? Briefly justify your answers.

(4 pts) 2. Drying of caustic soda

Humid crystals of caustic soda need to be dried with a rotating drier operating under steady state at atmospheric pressure. The crystals contain 40 mass % water and are fed at 21 °C. At the exit, they must contain less than 15 mass % water. Hot air is fed in counter-current with respect to the crystals at a rate of 10 m^3/kg humid crystals and the conditions for the air are the following:

$$\text{entrance: } T_1 = 104^\circ\text{C};\ T_{H1} = 32^\circ\text{C}$$
$$\text{exit: } T_2 = 37.7^\circ\text{C};\ T_{H2} = 31^\circ\text{C}$$

where T_{H1} and T_{H2} are the humid temperatures at the entrance and exit.

Using Figure 1,

a) calculate the quantity of water contained in the air at the exit.

b) Calculate the water content of the crystals at the exit. Is the drier satisfactory? **You may assume that the air at the entrance is dried and behaves as an ideal gas.**

(4 pts) 3. Compression of carbon dioxyde

Using the attached diagram (Fig. 2),

a) calculate the required power to compress 1 kg/s of saturated vapor of CO_2 at 0 °C up to 10 MPa. Assume that the compression is adiabatic, the variations of the potential and kinetic energies are negligible and that the yield is 70 %.

b) What is the final temperature?

c) If CO_2 was an ideal gas (R = 0.1889 kJ/kg.K and C_p^o = 0.842 kJ/kg.K, a constant), what would be the required power, assuming the same yield, same initial T and P and same final P?

(4pts) 4. Azeotrope

At 50 °C, the binary solution of 1,4-dioxane (1) and water (2) exhibits an azeotrope at x_1 = 0.554 and P = 22.3 kPa. At that temperature, the vapor pressures are : $P_1^{sat} = 15.6$ kPa and $P_2^{sat} = 12.4$ kPa .

a) Determine the activity coefficients for both components at the azeotrope. Indicate clearly the required hypotheses.

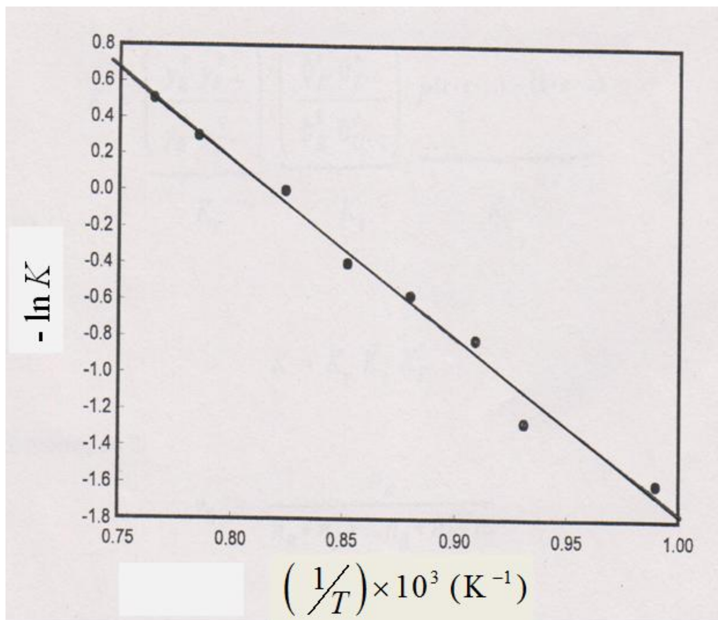
b) Determine the parameters of the de van Laar (two constant) equation.

(4pts) 5. <u>Oxidation of tungstene</u>

The reaction water vapor on solid tungstene allows the release of hydrogen according to the following equilibrium:

$$W(s) + 2H_2O(g) \rightleftarrows WO_2(s) + 2H_2(g)$$

The equilibrium constant K for the reaction at atmospheric pressure is given in the following figure in terms of - ln K vs. $1/T$ (where ln is the natural logarithm).



Equilibrium constant for the oxidation of tungstene

a) For $T = 900$ °C, determine the ratio of the patial pressures, P_{H_2} / P_{H_2O}, at equilibrium. Indicate clearly the required hypotheses.

b) Using this figure and a thermodynamic relation, obtain the heat of reaction per mole of converted water. Is the reaction endothermic or exothermic?

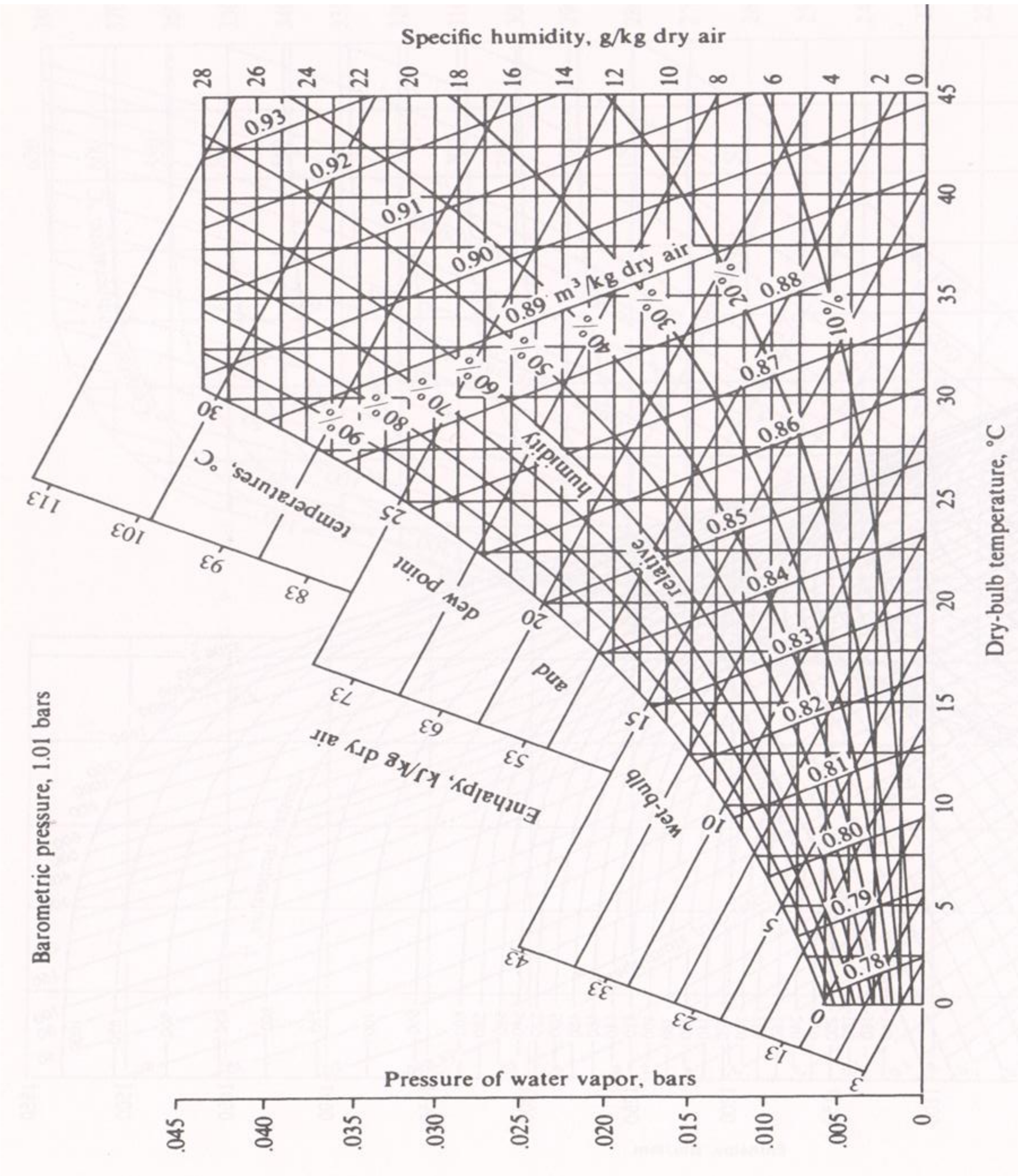


Fig. 1 Psychometric chart

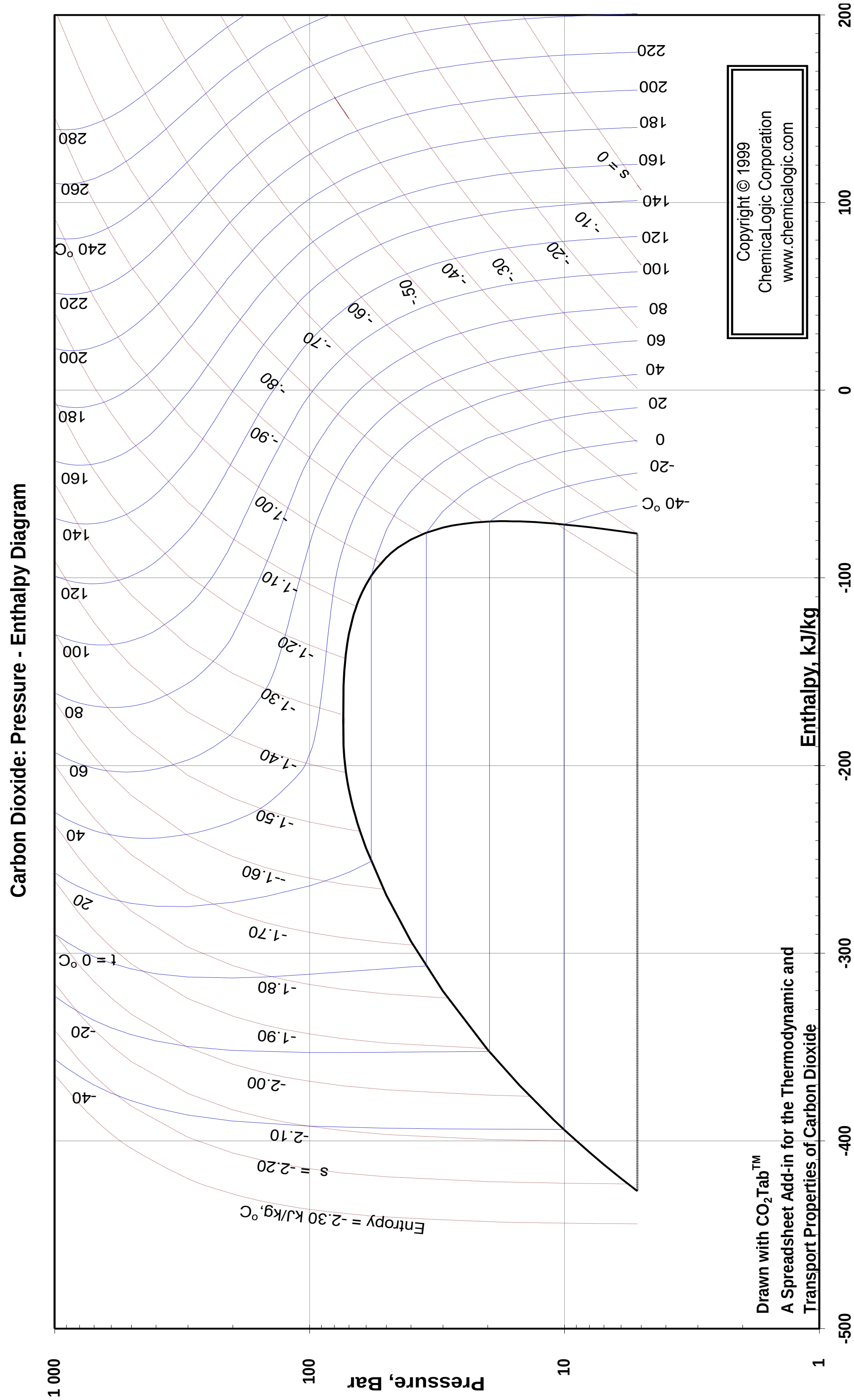


Fig. 2 Mollier diagram for CO_2 (N.B. 1 bar = 10^5 Pa)