ORDRE DES INGÉNIEURS DU QUÉBEC

MAY 2021 SESSION 2021

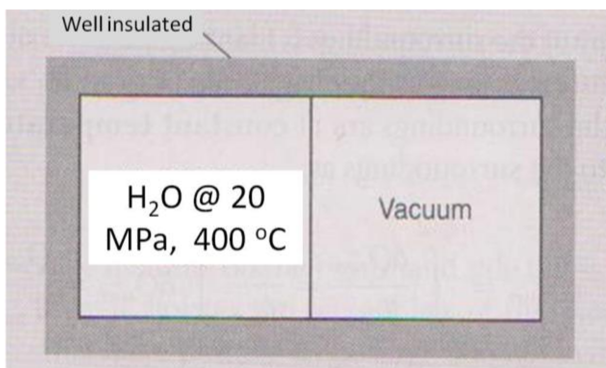
Open-book examination Calculators : only authorized models Duration : 3 hours

Total : 20 pts

16-CH-A1 PROCESS BALANCES AND CHEMICAL THERMODYNAMICS

(4pts) 1. <u>Behavior of steam</u>

10 liters of steam at 400 ºC and 20 MPa are inside of the left compartment of a well insulated reservoir as illustrated. The reservoir includes a second compartment of the same volume under vacuum. At a given time, the wall between both compartments is broken and then the steam fills the complete reservoir.



a) How much work is done by this process?

b) Considering that steam behaves as an ideal gas, determine the final temperature and the entropy variation per mole between the final and initial states.

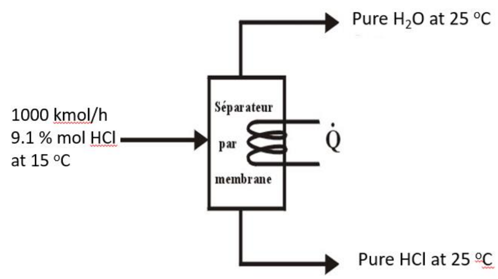
c) Redo these calculations for the real behavior of steam using steam tables. What do you conclude? **An approximate calculation will be accepted**.

(4 pts) 2. <u>Concentration of chlorhydric acid</u>

We wish to concentrate chlorhydric acid at 9.1mol% to obtain pure acid. The dilute acid (1000 kmol/h) is fed at 15 ºC to an inverse osmotic process (séparateur par membrane) and the pure components are removed at 25 ºC (see sketch).

a) Compute the flow rates for the pure H_2O and HCl.

b) Obtain the heat rate to be added or removed to the process (kW). Consider that the work required to do the separation is negligible compared to the heat of mixing.



Data :

i) Heat of mixing at 25 ºC of dilute acid stream = -69.5 kJ/mol of HCl

ii) $\bar{C}_{P_{Sol}} = 71$ kJ/kmol.ºC

(4 pts) 3. <u>Liquefaction of carbon dioxyde</u>

In a liquefaction process of carbon dioxide, CO_2 at 80 °C and 10 MPa is first going through a Joule-Thomson (adiabatic) expansion to 1 MPa, then heat is removed at that pressure until all the CO_2 is condensed. Using the attached diagram (Fig. 1),

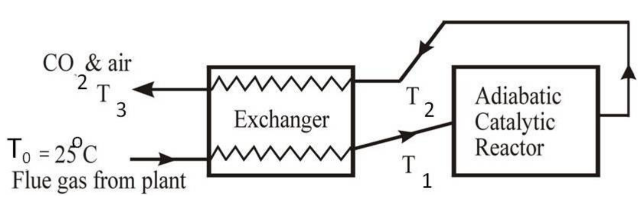
a) What is the CO_2 temperature after the Joule-Thomson expansion?

b) How much heat (kJ/kg$_{CO2}$) needs to be removed for the total condensation of the CO_2?

c) What is the variation of the entropy for the CO_2, and the total variation if the heat is removed by a coolant at -50 ºC? Is this process reversible? Justify briefly.

(4pts) 4. <u>Cleaning of flue gas</u>

Although from a thermodynamic point of view the oxidation of carbon monoxide in carbon dioxide is quite favorable, the kinetics at low temperature and low concentration in CO is not favorable. To reduce the emission of CO in the atmosphere of the effluent of a plant, it is proposed to use a catalytic reactor to convert the CO as illustrated.



The plant effluent is at 25 ºC and 1 atm and contains 3% (mol) of CO and 97% of air. This stream is heated up to temperature T_1, which is equal to 300 ºC, and T_2 is the temperature of the gases at the exit of the adiabatic reactor.

a) Assuming that all the CO is converted into CO_2 at equilibrium at the exit of the adiabatic reactor, determine the temperatures of the streams entering and leaving the reactor.
b) Check if the conversion at the exit is 100% based on the equilibrium constant obtained from Fig. 2.

N.B. We assume that there is no reaction in the heat exchanger and that the heat capacities are constant and equal to:

$$\overline{C}^{o}_{P_{O_2}} = \overline{C}^{o}_{P_{N_2}} = 29.3 \text{ kJ/kmol.K}$$

$$\overline{C}^{o}_{P_{CO}} = 33.4 \text{ kJ/kmol.K}$$

$$\overline{C}^{o}_{P_{CO_2}} = 56.4 \text{ kJ/kmol.K}$$

Standard heat of formation at 25 ºC

$$\Delta\overline{h}^{o}_{f_{CO_2}} = -393.5 \text{ kJ/mol}$$

$$\Delta\overline{h}^{o}_{f_{CO}} = -110.5 \text{ kJ/mol}$$

(4pts) 5. <u>Vaporization of argon</u>

2 kg/s of liquid argon at 135 K are vaporized at constant pressure. Then, the vapor is compressed under steady-state conditions to a final pressure of 25 MPa and temperature of 240 K. The variations of the kinetic and potential energies and the heat losses to the surroundings can be neglected.

Using the generalized diagram supplied (Fig. 3), determine:

a) The pressure at which the vaporization is done.
b) The power required for the compression (kW).

<u>Properties of argon</u>:

T_c = 150.8 K
P_c = 4.87 MPa
Z_c = 0.291
R = 0.208 kJ/kg.K
C_{P0}= 0.52 kJ/kg.K

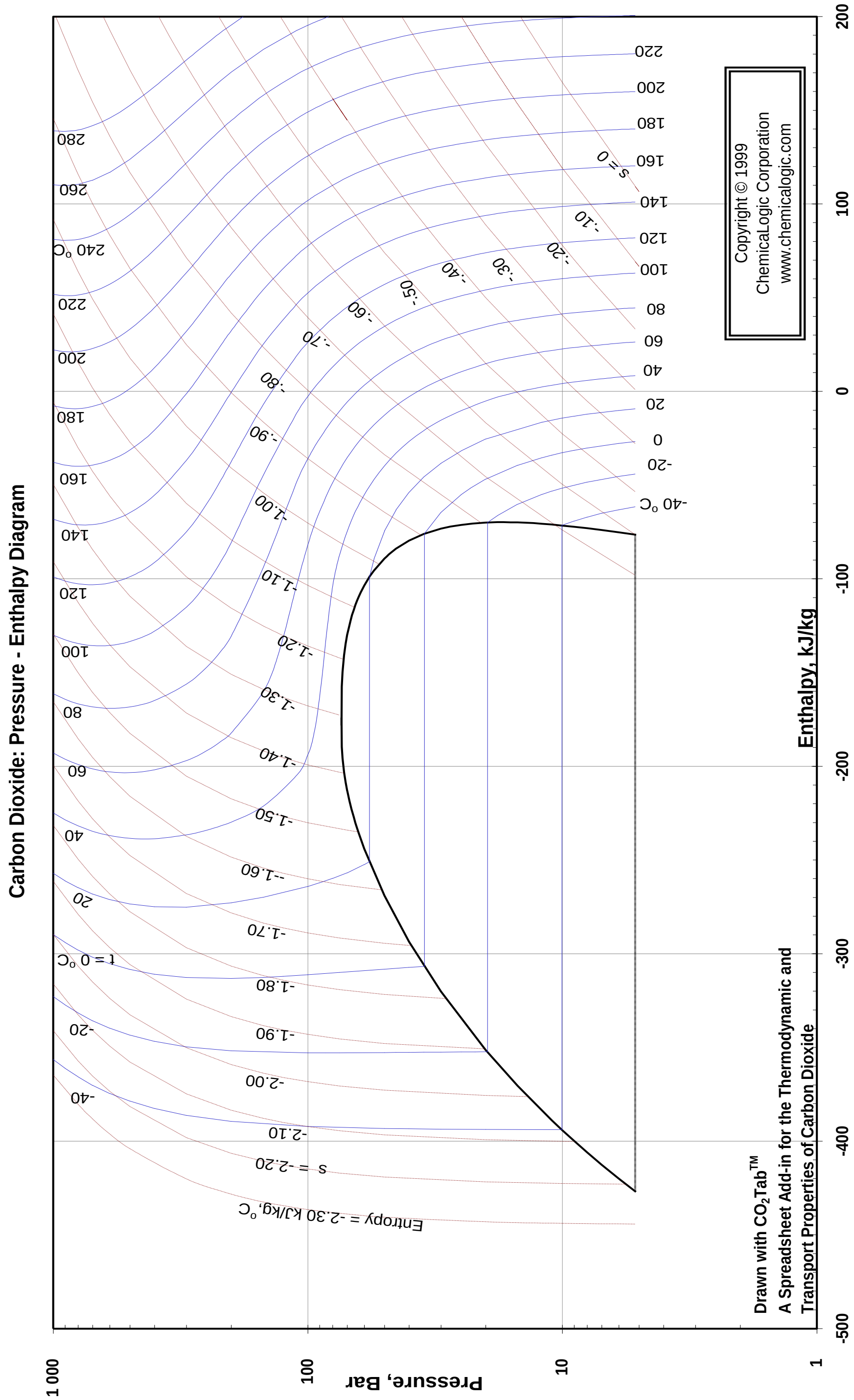


Fig. 1 Mollier diagram for CO_2 (N.B. 1 bar = 10^5 Pa)

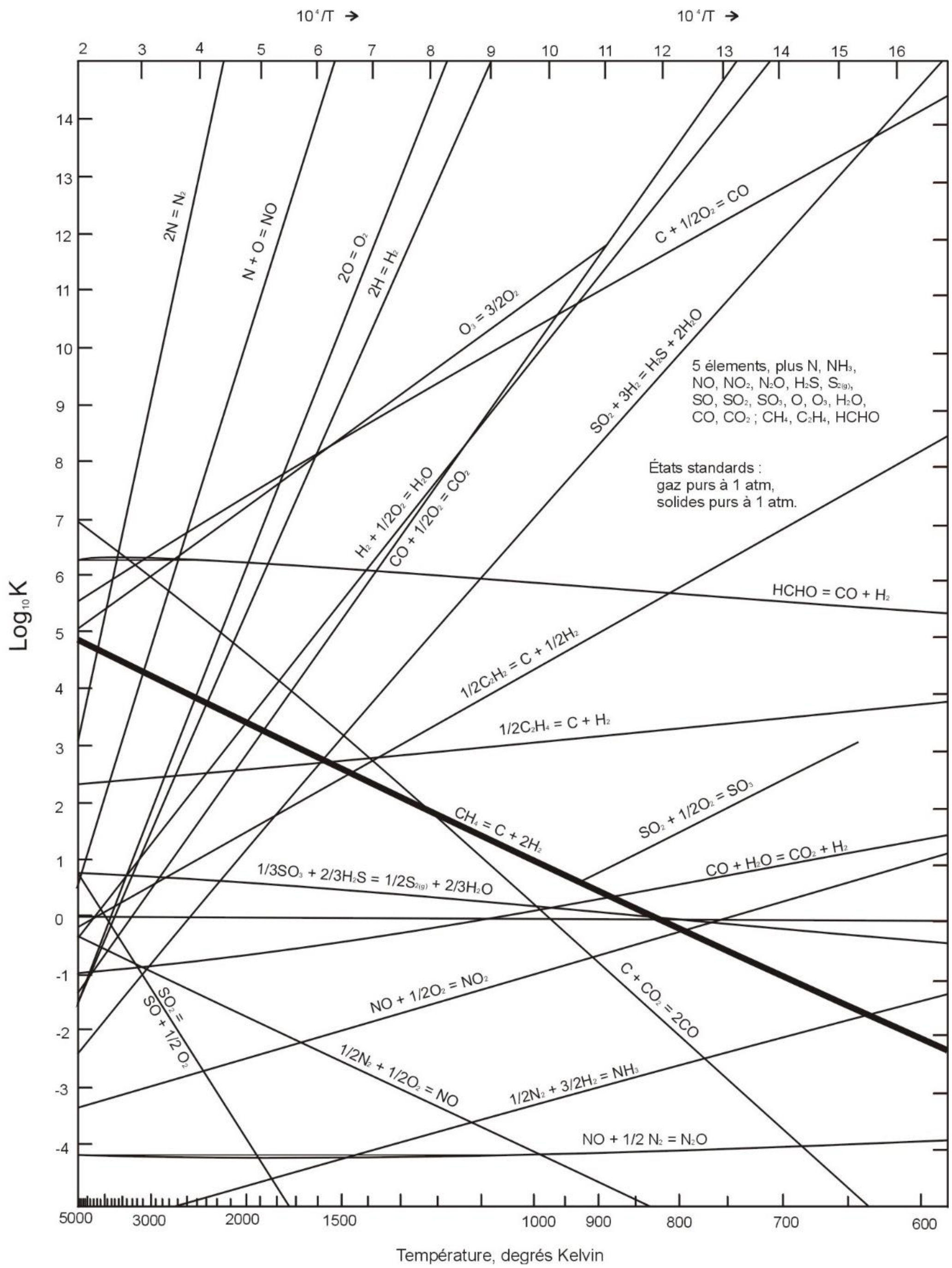


Fig. 2 Equilibrium constants for combustion and reduction reactions.

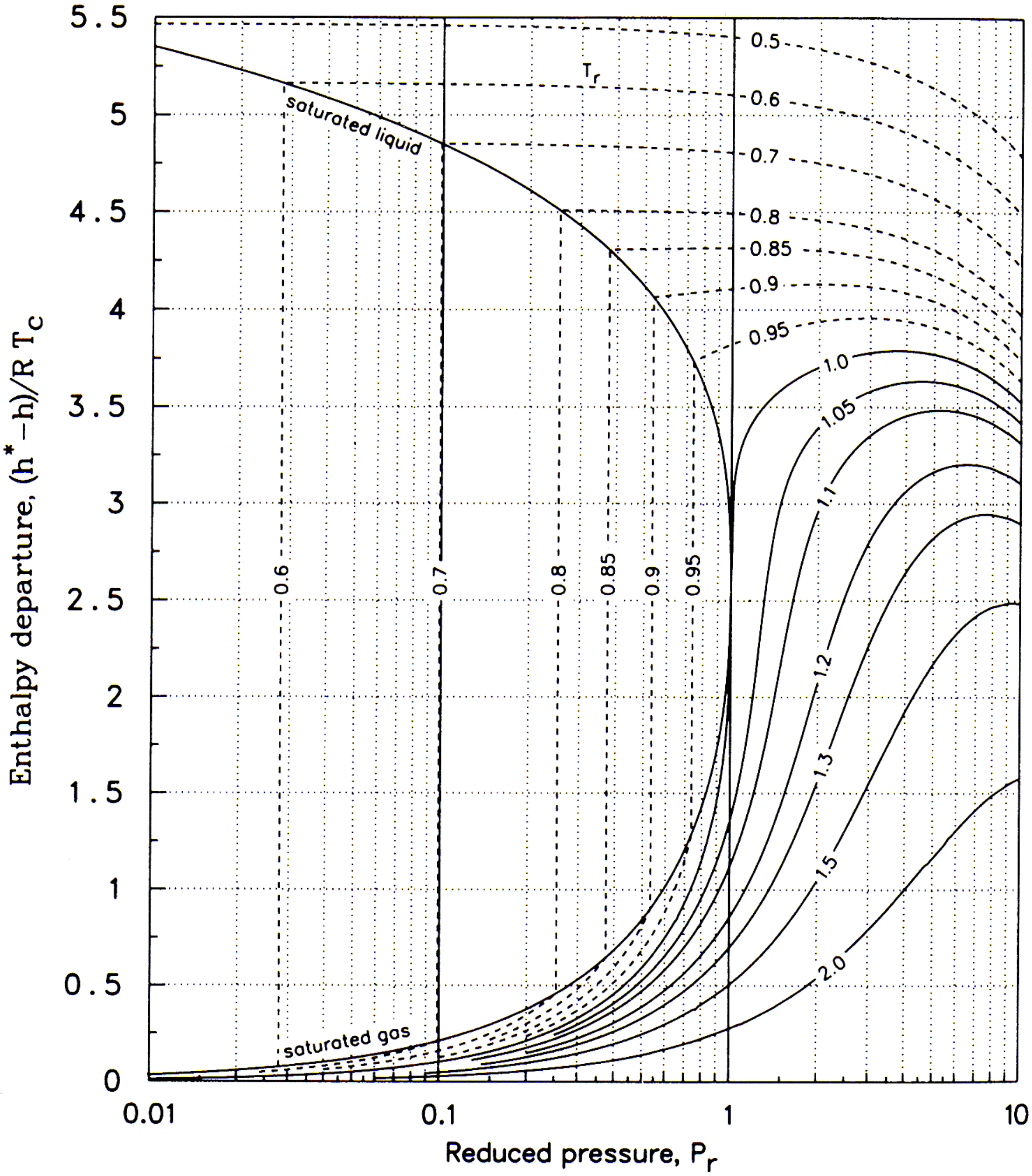


Fig. 3 Generalized enthalpy departure diagram (Z_c=0.29)