CENG 122 Separation Process
Sample Problem Set A
Office Hour: Tuesday and Thursdays, 5:00PM – 6:00PM

PROBLEM 1:
According to the equilibrium data of a binary mixture of hydrogen and methane shown in the figure below, the relative volatility of hydrogen to methane is relatively high and increases with decreasing temperature. One way of separating hydrogen-methane mixture is partial condensation at low temperature. Such operation must be carried out at a temperature below the dew point of the mixture and at high pressure. In a partial condensation unit operation, a gas mixture containing 60 mol% hydrogen and 40 mol % methane at 1000 psia is cooled to form equilibrium vapor and liquid products.

(a) Show that relative volatility of hydrogen to methane α_{HM} is relatively high and increases with decreasing temperature at 1000 psia by calculating values of α_{HM} at two distinct temperatures.

(b) What are the percent deviations of the actual α_{HM} value and the K values from that assuming an ideal mixture of hydrogen and methane at 1000 psia and -200 ^oF? Based on the calculated deviations, make a comment on the non-ideality of hydrogen and methane.

(c) Calculate the dew point temperature (T_{dew}) of the feed gas mixture.

(d) If the gas mixture at 1000 psia is cooled to a temperature of -200 ^oF, what fraction of feed will be condensed?

(e) If the gas mixture at 1000 psia is cooled to a temperature of -200 ^oF, what are the percent purity and percent recovery of hydrogen in the vapor product?

Useful equations:

$$P_H^s(psia) = 190.8\, Exp[5.603 - \frac{418.2}{T(F) + 474.2}]$$
$$P_M^s(psia) = 673.1\, Exp[5.141 - \frac{1742.6}{T(F) + 452.9}]$$

See next page for experimental data.

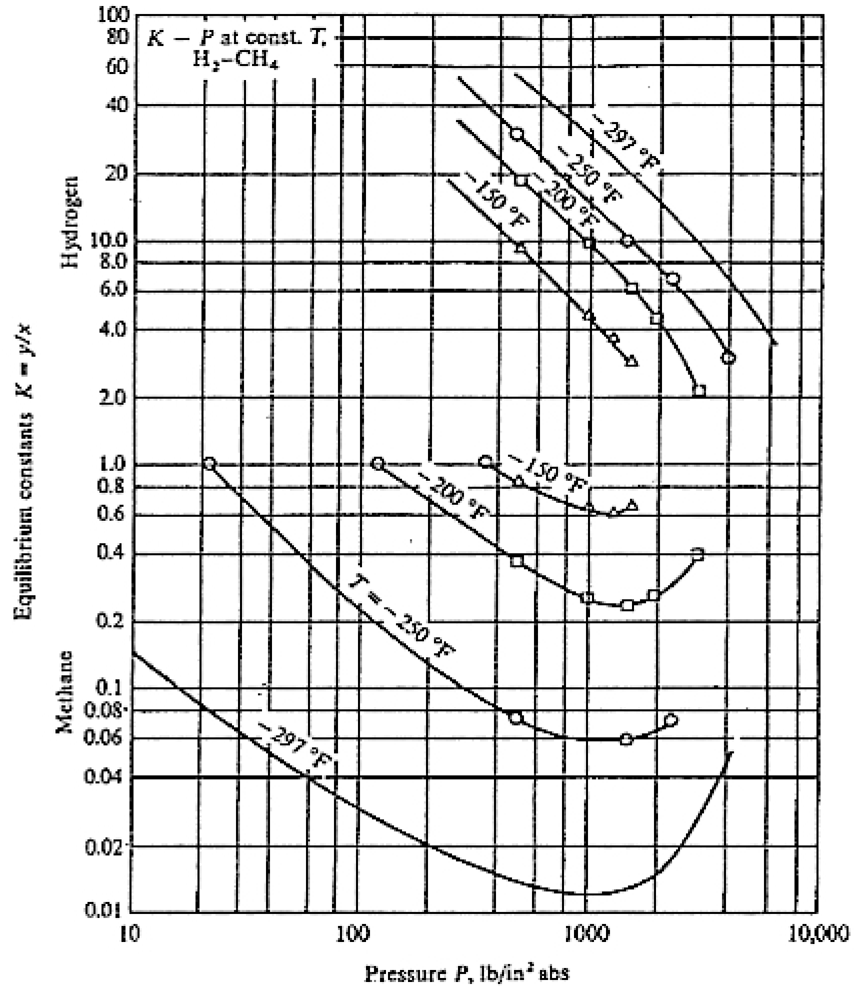


Figure 2-23 Equilibrium ratios for the system hydrogen-methane. *(From Benham and Katz, 1957, p. 33; used by permission.)*

PROBLEM 2:

A 100 lbmol/hr mixture of 25 mol% ammonia and 75 mol% water at 1 atm and 100 ^oF is to be separated in a flash drum into vapor and liquid products.

(a) Assuming it is an ideal solution; calculate the relative volatility of the feed.
(b) What fraction of feed is vaporized?
(c) What are the percent purity and percent recovery of ammonia in the vapor product?

Useful Data:

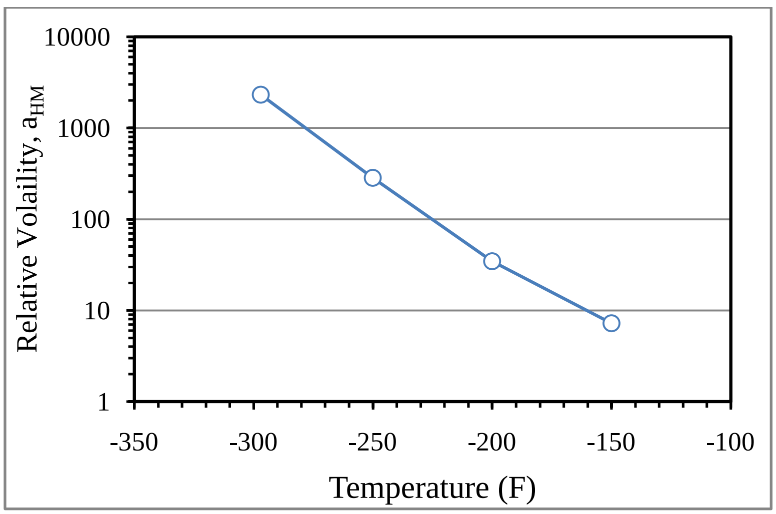
$$P_A^s(psia) = 1653.7\, Exp[6.152 - \frac{4253.8}{T(F) + 418.9}]$$

$$P_W^s(psia) = 3206.7\, Exp[6.533 - \frac{7173.8}{T(F) + 389.5}]$$

Solutions

1.a.

T (^oF)	K_M	K_H	α_{HM}
-297	0.013	30.0	2307.7
-250	0.060	17.0	283.3
-200	0.290	10.0	34.5
-150	0.650	4.7	7.2



1.b.

$$K = \frac{P^s}{P} \quad \text{for ideal}$$

at -200°F using Antoine equ:

$P_H^s = 1.126 \times 10^4$ psia $K_H = 11.26$

$P_M^s = 1.170 \times 10^2$ psia $K_m = 0.117$

$$\alpha_{HM\,(ideal)} = \frac{K_H}{K_m} = 96.2$$

$$\%\,dev = 100\left(\frac{|\alpha_{HM\,real} - \alpha_{HM\,ideal}|}{\alpha_{HM\,real}}\right) = \left(\frac{|96.2 - 34.5|}{34.5}\right)\cdot 100$$

$$= 178.9\%$$

$$K_H\ \%\,dev = \left(\frac{|10 - 11.26|}{10}\right)\cdot 100 = 12.6\%$$

$$K_m\ \%\,dev = \left(\frac{|0.29 - 0.117|}{0.29}\right)\cdot 100 = 59.6\%$$

non-ideality from Both species

1.C.

Dew Point : $\sum \frac{z_i}{K_i} = 1$

$z_H = 0.6$, $z_m = 0.4$

at -200°F , $\frac{0.6}{10} + \frac{0.4}{0.29} = 1.43 \neq 1$

at -150°F , $\frac{0.6}{4.7} + \frac{0.4}{0.65} = 0.74 \neq 1$

at $T \simeq -175$°F , $K_m \simeq 0.4$ $K_H \simeq 7$

$$\frac{0.6}{7} + \frac{0.4}{0.4} = 1.09 \simeq 1$$

Dew point is near -175°F

D.Y.

1.d.

$$\psi = \frac{V}{F} = \frac{z_1\left[\frac{K_1 - K_2}{1 - K_2}\right] - 1}{K_1 - 1} = \frac{z_1}{1 - K_2} - \frac{z_2}{K_1 - 1}$$ (see table 4.4)

$$= \frac{0.6}{1 - 0.29} - \frac{0.4}{10 - 1}$$

$$= 0.8006 \simeq 0.8$$

$$\frac{L}{F} = 1 - \psi = 0.2$$

1.e.

$$x_H = \frac{0.6}{1 + 0.8(10-1)} = \frac{z_H}{1 + \psi(K_H - 1)}$$

$$= 0.07312 \simeq 0.073$$

$$y_H = K_H \cdot x_H = 10(0.073) = 0.73$$

$$y_M = 1 - y_H = 1 - 0.73 = 0.27$$

$$\% \text{ purity} = 100 \times y_H = 73\%$$

$$\% \text{ recovery} = \frac{y_H \cdot V}{z_H \cdot F} = 100\left(\frac{0.73}{0.6} \cdot 0.8\right) = 97\%$$

D.Y.

2.a. assuming ideal solution

$$P_A^s = 213.8 \text{ psia} \qquad K_A = P_A^s / P = 14.55$$

$$P_W^s = 0.952 \text{ Psia} \qquad K_W = P_W^s / P = 0.065$$

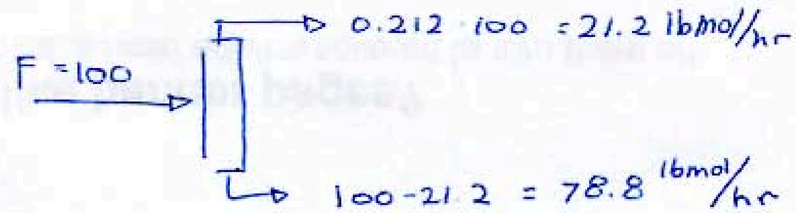
$$\alpha = \frac{K_A}{K_W} = \frac{14.55}{0.065} = 224.6$$

2.b.

Solve $\sum \frac{z_i(1-k_i)}{1+\psi(k_i-1)} = 0$

$$\psi = \frac{V}{F} = \left(\frac{z_A}{1-k_W}\right) - \left(\frac{1-z_W}{k_A-1}\right) = \left(\frac{0.25}{1-0.065}\right) - \left(\frac{0.75}{14.55-1}\right) = 0.212$$

2.c.



$$X_A = \frac{z_A}{1+\psi(K_A-1)} = \frac{0.25}{1+(0.212)(14.55-1)} = 0.065$$

$$Y_A = K_A \cdot X_A = (14.55)(0.065) = \sout{0.996}\ 0.946$$

% purity = 94.6 %

$$\% \text{ Recovery} = \frac{(0.946)(21.2)}{0.25 \cdot 100} = 0.802 = 80.2\%$$

D.Y.