Quiz III, Problem 5: Flash Separations

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For the binary case, we are provided with the total system pressure and the mole fractions of the two exit streams. Since the total pressure is 0.2 bar, we can safely assume ideal gas behavior. Additionally, we are told to assume that the liquid phase behaves ideally. Thus, for each species, we have $y_i P = x_i P_i^{sat}$, or

$$\begin{aligned} K_i &\equiv \frac{y_i}{x_i} \\ &= \frac{P_i^{sat}}{P} \end{aligned}$$

From this equation, we can calculate the vapor pressure of components A and B:

$$\begin{aligned} P_A^{sat} &= \frac{y_A P}{x_A} \\ &= 0.28 \text{ [bar]} \\ P_B^{sat} &= \frac{y_B P}{x_B} \\ &= 0.12 \text{ [bar]} \end{aligned}$$

[+2 points]

Additionally, we are given the vapor pressure for component C: $P_C^{sat} = 0.08$ bar. With this information, and the fact that the total pressure for the tertiary system is 0.1 bar, we can calculate the K-values for the new system:

$$
\begin{aligned}
K_i &= \frac{P_i^{sat}}{P} \\
K_A &= 2.8 \\
K_B &= 1.2 \\
K_C &= 0.8
\end{aligned}
$$

[+3 points]

There are two ways that you can calculate the mole fractions: (i) using the total pressure, or (ii) using a mass balance. First, we present the pressure method. For a solution obeying Raoult's law, the total pressure is given by:

$$
\begin{aligned}
P &= \sum x_i P_i^{sat} \\
&= x_A\left(P_A^{sat} + P_B^{sat} - 2P_C^{sat}\right) + P_C^{sat} \\
&\text{or} \\
x_A &= \frac{P - P_C^{sat}}{P_A^{sat} + P_B^{sat} - 2P_C^{sat}} \\
&= 0.083
\end{aligned}
$$

Alternatively, the mass balance method yields the following three equations:

$$
\begin{aligned}
z_A &= x_A \frac{L}{F} + y_A \frac{V}{F} \\
z_B &= x_B \frac{L}{F} + y_B \frac{V}{F} \\
z_C &= x_C \frac{L}{F} + y_C \frac{V}{F}
\end{aligned}
$$

For the ternary system, we are told that the molar flow rate of the vapor stream is 10% of the feed stream flow rate, or $V/F = 0.1$. Additionally, we are told that $x_B = x_A$. Lastly, we know that $y_i = x_i K_i$. Thus, if we substitute these results into the mass balances and sum the three equations, we get:

$$\begin{aligned} 1 &= x_A \frac{9}{10} + x_A K_A \frac{1}{10} \\ &+ x_A \frac{9}{10} + x_A K_B \frac{1}{10} \\ &+ (1-2x_A)\frac{9}{10} + (1-2x_A)\, K_C \frac{1}{10} \end{aligned}$$

[+2 points]

Plugging in the numbers, this equation reduce to:

$$\begin{aligned} 1 &= 0.24 x_A + 0.98 \\ &\text{or} \\ x_A &= \frac{1}{12} \end{aligned}$$

[+12 points].

Now that we have x_A, we can calculate the other liquid mole fractions, since $x_B = x_A$ and $x_C = 1 - x_A - x_B$, it follows that:

$$\begin{aligned} x_A &= 0.083 \\ x_B &= 0.083 \\ x_C &= 0.834 \end{aligned}$$

[+4 points]

Similarly, from $y_i = x_i K_i$, we get:

$$\begin{aligned} y_A &= 0.233 \\ y_B &= 0.100 \\ y_C &= 0.667 \end{aligned}$$

[+6 points]

And from the original mole balance, we get: $z_i = x_i \times 9/10 + y_i \times 1/10$, or:

$$\begin{aligned} z_A &= 0.098 \\ z_B &= 0.085 \\ z_C &= 0.817 \end{aligned}$$

[+6 points]