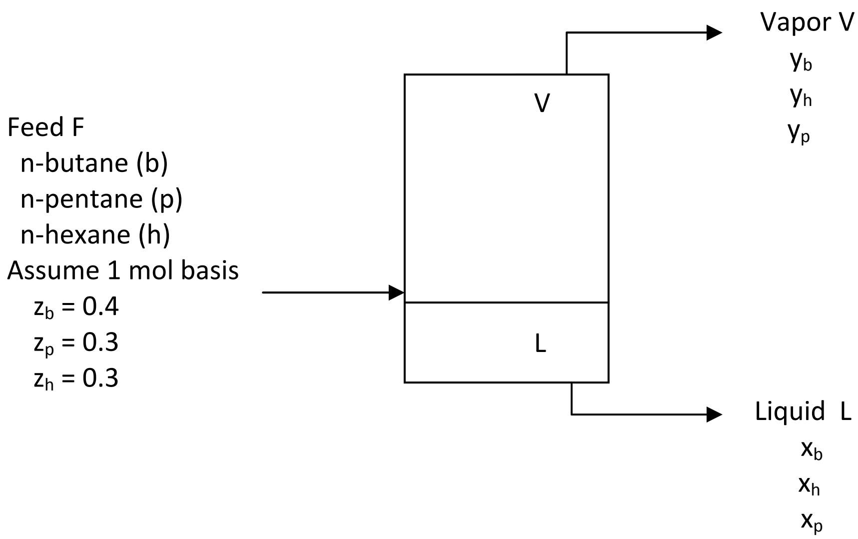
Problem 1 (8.6).

A feed stream containing a mixture of 40% n-butane, 30% n-pentane, and 30% n-hexane flows into a flash unit. The flash temperature is 290 K and the flash pressure is 0.6 bar. What is the ratio of the exit vapor flow rate to the feed flow rate? What are the compositions of the exit streams?



For this analysis, we will assume that the vapor and liquid phases leaving the flash drum are ideal mixtures and use the pure component, Lewis/Randall reference state ($f_i^o = f_i$). The pure component fugacity is

$$f_i^L = \varphi_i^{sat} P_i^{sat} \exp\left(\int_{Pi,sat}^{P} \frac{v_i^l}{RT} dP\right) \qquad (1)$$

At the low pressure, the Poynting correction can be neglected and for an ideal gas, $\varphi = 1$. The above equation simplifies to

$$f_i^L = P_i^{sat} \qquad (2)$$

At equilibrium, the fugacity of component i in the vapor and liquid phases are equal, or

$$\hat{f}_i^v = \hat{f}_i^L \qquad (3)$$

The fugacity in the vapor phase for species i is

$$\hat{f}_i^v = y_i \hat{\varphi}_i^v P \qquad (4)$$

Using the Lewis fugacity rule and the ideal vapor phase fugacity coefficient

$$\hat{\varphi}_i^v = \varphi_i^v \qquad (5)$$

$$\varphi_i = 1 \qquad (6)$$

The vapor phase fugacity for species i becomes

$$\hat{f}_i^v = y_i P \qquad (7)$$

The liquid phase fugacity of species I, using the Lewis/Randall reference state, Eq. 2, and $\gamma_i = 1$

for an ideal solution, becomes

$$\hat{f}_i^L = x_i P_i^{sat} \qquad (8)$$

Substituting Eq.7 and Eq. 8 into Eq. 3, the equilibrium relationship for species i in the vapor and liquid phase is

$$y_i P = x_i P_i^{sat} \qquad (9)$$

There are a total of eight unknown variables (V,L,x_b, x_h , x_p, y_b,y_p,y_h) surrounding the flash separation unit, so we need to write eight independent equations involving these variables. A mass balance on each of the three species can be written:

$$z_i F = y_i V + x_i L \qquad (10)$$

In addition, we can write three equilibrium relations of the form of equation 9 and two equation summing mol fractions of each stream to one:

$$x_b + x_p + x_h = 1 \qquad (11)$$

$$y_b + y_p + y_h = 1 \qquad (12)$$

The saturation pressures P_{sat} for each species at 290 K can be found using Antoine's equation. Substituting the constants from Table A.1.1. and using T = 290 K, the saturation pressure for each pure species is: $P_{sat,h}$ =0.1399 bar, $P_{sat,b}$= 1.878 bar, $P_{sat,p}$=0.5002 bar.

Solving equation 9 for x_i and substituting into Equation 10,

$$z_i = y_i \frac{V}{F} + \frac{y_i P}{P_{sat}} \frac{L}{F} \qquad (13)$$

$$\frac{V}{F} + \frac{L}{F} = 1 \qquad (14)$$

Using Eq. 14 in Eq. 13,

$$z_i = y_i \frac{V}{F} + \frac{y_i P}{P_{sat}} (1 - \frac{V}{F}) \qquad (15)$$

We can assume a basis of one mole being set into the flash drum (F = 1 mol), and solve Eq. 15 for the vapor mol fraction y_i of each species. We can then use Eq. 12 and write

$$\sum_i y_i = 1 = \sum_i \frac{z_i}{\frac{V}{F} + \frac{P}{P_{i,sat}} (1 - \frac{V}{F})} \qquad (16)$$

Equation 16 can be solved for V, and we find that the vapor flowrate is V = 0.4834 mol and that the fraction of feed vaporized is also 0.4834 based on our basis of 1 mol feed. The vapor mol fraction of each species can then be solved for from:

$$y_i = \frac{z_i}{\frac{V}{F} + \frac{P}{P_{sat}} (1 - \frac{V}{F})} \qquad (17)$$

The liquid mol fraction can be calculated by substituting the results of Eq. 15, y_i, into Eq. 9. The composition of the vapor stream is y_b=0.6169, y_h=0.111, and y_p=0.2720. The liquid stream composition is x_b=0.1971, x_h=0.4767, and x_p=0.3262.

Grading:

1. 0.5 pt for each mol fraction (3 pts total)
2. 1 pt for vapor split fraction
3. 1 pt for stating assumption of ideal solution and vapor mixture, or writing $\varphi = \gamma = 1$.
4. 1 pt for correctly calculating Psat for all three species
5. 2 pts for correct equilibrium relationship, Eq. 9
6. 2 pts for mass balance, Eq. 10