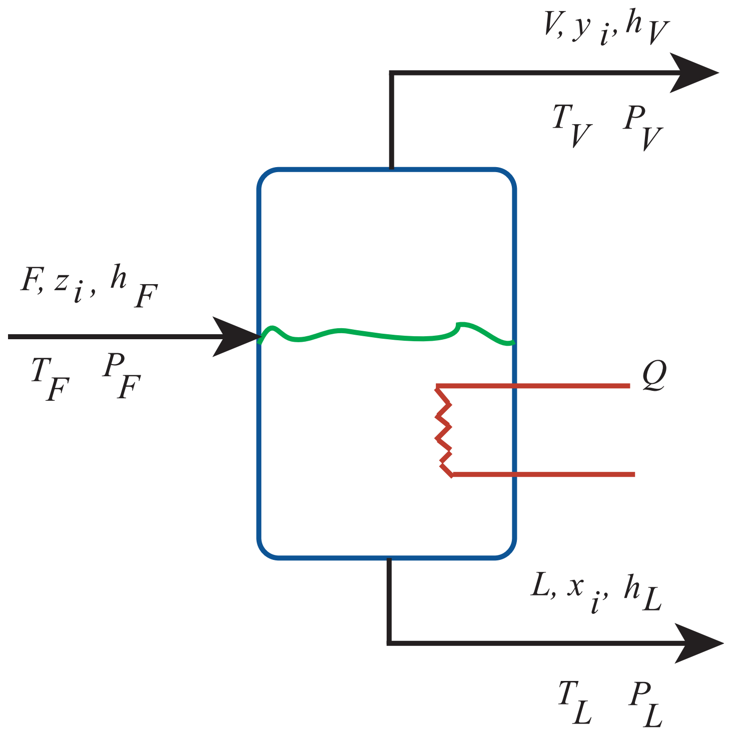
Design of Flash Unit

Flash Unit

- A flash is a single equilibrium-state distillation.
- The feed is partially vaporized to give a vapor richer in the more volatile components than the remaining liquid.
- The vapor and liquid leaving the unit are in equilibrium.
- Unless the relative volatility is large, the degree of separation achievable in a two components in a single unit is poor.
- Flashing is usually an auxiliary operation used to prepare the stream for further processing (vapor recovery system, liquid recovery system).

Flash Unit

Consider a Flash Unit with C components.



Variables: $F, V, L, z_i, y_i, x_i,$
$T_F, T_V, T_L, P_F,$
P_V, P_L, Q

Total: $3C + 10$

Typically, the feed is specified (F, z_i, T_F, P_F).

Thus, $C + 3$ variables are known.

Modeling Multicomponent Flash Unit

Equation	Type	Number
$P_V = P_L$	mechanical equil.	1
$T_V = T_L$	thermal equil.	1
$y_i = K_i x_i$	phase equil.	C
$F z_i = V y_i + L x_i$	mass balance	C
$F = V + L$	total mass balance	1
$h_F F + Q = h_V V + h_L L$	energy balance	1
$\sum_i y_i - \sum_i x_i = 0$	summation	1
		Total = 2C+5

K_i is a function of T_V, P_V, y, x

h_F is a function of T_F, P_F, z and h_L is a function of T_L, P_L, x

$$Degrees\ of\ freedom = \underbrace{(3C+10)}_{(Variables)} - \underbrace{(C+3)}_{(Feed\ Specs.)} - \underbrace{(2C+5)}_{(Equations)} = 2$$

Designing Flash Unit

Since there are two degrees of freedom, two of the variables need to be specified.
The remaining variables can be computed from the mathematical modeled for the flash unit.
The most common set of specifications are as follows:

$T_V,\ P_V$	Isothermal flash
$V/F = 0,\ P_L$	Bubble point temperature
$V/F = 1,\ P_V$	Dew point temperature
$T_L,\ V/F = 0$	Bubble point pressure
$T_V,\ V/F = 1$	Dew point pressure
$Q = 0,\ P_V$	Adiabatic flash
Q, P_V	Nonadiabatic flash
$V/F,\ P_V$	Percent vaporization flash

Solving Flash Unit Equations

- In principle, if two of the variables are specified, one can solve for the remaining $2C + 5$ variables by solving simultaneously the $2C + 5$ equations that were shown previously.
- However, this computation is not straightforward because T and P appear implicitly in the phase equilibrium equations:

$$y_i = K_i x_i$$

and the equation:

$$F z_i = V y_i + L x_i$$

is nonlinear.

Short-cut Method

- Assume that the vapor is an ideal gas and the solution is an ideal solution.
  Raoult's law can be used.
- Redefine equations in terms of split fractions and relative volatility with respect to key component.
  Relative volatility is not very sensitive to temperature and pressure.
- Analyze relationship between pressure, temperature, and composition.
  These relationships are nonlinear.
- Solve model equations sequentially.

Consider a mixture with n components.

- Assume vapor is ideal gas and liquid is ideal solution.

$$y_k = \frac{P_k^0 x_k}{P} \qquad k = 1, 2, ..., n$$

- Define split fractions

$$\xi_k = \frac{v_k}{f_k} \qquad k = 1, 2, ..., n$$
$$1 - \xi_k = 1 - \frac{v_k}{f_k} = \frac{l_k}{f_k}$$

- Define a key component, n
  - The key component is usually the most abundant in the mixture. If all components are nearly equal in moles, choose the one with intermediate volatility.

- Define relative volatility w.r.t. key component.

$$\alpha_{k/n} = \frac{P_k^0}{P_n^0} \qquad k = 1, 2, ..., n-1$$

Recall that

$$y_k = K_k x_k = \frac{P_k^0 x_k}{P}$$

This implies that

$$K_k = \frac{P_k^0}{P}$$

Thus:

$$\alpha_{k/n} = \frac{P_k^0}{P_n^0} = \frac{K_k}{K_n} \qquad k = 1, 2, ..., n-1$$

- Rederive flash equations

$$K_k = \frac{y_k}{x_k} = \frac{v_k/V}{l_k/L} = \frac{\xi_k f_k/V}{(1-\xi_k)f_k/L} = \frac{\xi_k L}{(1-\xi_k)V}$$

Similarly:

$$K_n = \frac{\xi_n L}{(1-\xi_n)V}$$

Thus:

$$\alpha_{k/n} = \frac{K_k}{K_n} = \frac{\xi_k L/(1-\xi_k)V}{\xi_n L/(1-\xi_n)V} = \frac{\xi_k(1-\xi_n)}{\xi_n(1-\xi_k)}$$

Rearranging: $$\boxed{\xi_k = \frac{\alpha_{k/n}\xi_n}{1+(\alpha_{k/n}-1)\xi_n}}$$

P, T and composition at Equilibrium

Suppose there is a saturated liquid stream.
The objective is to find a relation between pressure P and temperature T. We will use the bubble point equation for this calculation. At the bubble point, we have:

$$\sum_{i=1}^{n} y_i = \sum_{i=1}^{n} K_i x_i = 1$$

Dividing the equation by K_n, we have

$$\sum_{i=1}^{n} \frac{K_i}{K_n} x_i = \frac{1}{K_n}$$

Note that the ratio K_i/K_n is the relative volatility α_i. Thus, we can define an average relative volatility as follows:

$$\boxed{\sum_{i=1}^{n} \frac{K_i}{K_n} x_i = \sum_{i=1}^{n} \alpha_i x_i \equiv \bar{\alpha}}$$

Recall that:

$$\alpha_{k/n} = \frac{K_k}{K_n} = \frac{P_k^0}{P_n^0} \qquad K_k = \frac{P_k^0}{P}$$

This implies:

$$\frac{P_k^0}{P} = K_k = \alpha_{k/n} K_n$$

Recall from the previous slide:

$$\frac{1}{K_n} = \bar{\alpha}$$

Substituting, K_n in terms of $\bar{\alpha}$, we have:

$$\boxed{\frac{P_k^0}{P} = \frac{\alpha_{k/n}}{\bar{\alpha}}}$$

which is a simplified bubble point equation.

P, T and composition at Equilibrium

Suppose there is a saturated vapor stream.

The objective is to find a relation between pressure P and temperature T. We will use the dew point equation for this calculation. At the dew point, we have:

$$\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} \frac{y_i}{K_i} = 1$$

Multiplying the equation by K_n, we have

$$\sum_{i=1}^{n} \frac{K_n}{K_i} y_i = K_n$$

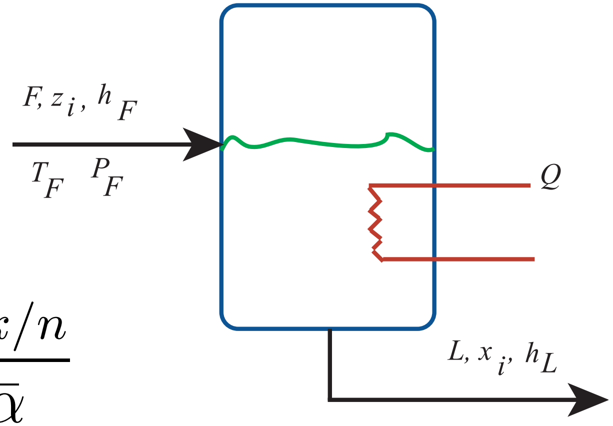
Recall that $K_n = \frac{P_n^0}{P}$ and $\frac{K_i}{K_n} = \alpha_{i/n}$ Thus, we have:

$$\boxed{\sum_{i=1}^{n} \frac{y_i}{\alpha_{i/n}} = \frac{P_n^0}{P}}$$

which is a simplified dew point equation.

T or P Specified at Bubble Point

At the bubble point, all the feed comes out as liquid.



$$\xi_k = 0$$
$$l_k = f_k$$
$$x_k = z_k$$

Bubble Point Equation: $\dfrac{P_k^0}{P} = \dfrac{\alpha_{k/n}}{\bar{\alpha}}$

Choose k to be the most abundant component in the liquid phase. The bubble point equation simplifies to $\dfrac{P_n{}^0}{P} = \dfrac{1}{\bar{\alpha}}$.

If P is fixed, calculate T from	If T is fixed, calculate P from
$P_n^0(T) = \dfrac{P}{\bar{\alpha}}$	$P = \bar{\alpha} P_n^0(T)$

Relation between ξ_n and ϕ

The split fraction of the key component $\xi_n = \dfrac{v_n}{f_n}$ and the vapor fraction $\phi = \dfrac{V}{F}$ are related as follows:

$$
\begin{aligned}
&y_n = K_n x_n \\
&\Rightarrow \frac{v_n}{V} = K_n \frac{l_n}{L} \\
&\Rightarrow \frac{v_n}{l_n} = K_n \frac{V}{L} \\
&\Rightarrow \frac{l_n}{v_n} = \frac{L}{K_n V} \\
&Since\ l_n = f_n - v_n\ and L = F - V,\ we\ have: \\
&\frac{f_n - v_n}{v_n} = \frac{F - V}{K_n V}
\end{aligned}
$$

$$\frac{f_n - v_n}{v_n} = \frac{F - V}{K_n V}$$

$$\Rightarrow \frac{f_n}{v_n} - 1 = \frac{1}{K_n}\frac{F}{V} - \frac{1}{K_n}$$

$$Since\ \xi_n \equiv \frac{v_n}{f_n}\ and\ \phi \equiv \frac{V}{F} :$$

$$\frac{1}{\xi_n} - 1 = \frac{1}{K_n \phi} - \frac{1}{K_n}$$

$$Rearranging :$$

$$\xi_n = \frac{1}{\frac{1}{K_n \phi} - \frac{1}{K_n} + 1}$$

Recap

We derived the following equations:
Split fractions:

$$\xi_k = \frac{\alpha_{k/n}\xi_n}{1 + (\alpha_{k/n} - 1)\xi_n}$$

Simplified bubble-point equation: $\frac{P_k^0}{P} = \frac{\alpha_{k/n}}{\bar{\alpha}}$

Simplified dew-point equation: $\sum_{i=1}^{n} \frac{y_i}{\alpha_{i/n}} = \frac{P_n^0}{P}$

Vapor Fraction and Split Fraction:

$$\xi_n = \frac{1}{\frac{1}{K_n\phi} - \frac{1}{K_n} + 1}$$