

Flash Distillation

All rights reserved. Armando B. Corripio, PhD, PE. 2013

Contents

Flash Distillation.....	1
1 Flash Drum Variables and Specifications	2
2 Flash Drum Balances and Equations	4
2.1 Equilibrium Relations	5
2.2 Enthalpy Balance	7
2.3 Boiling Point Diagram	9
3 Solution of the Flash Equations	14
3.1 Secant Method.	15
Example 1. Design of a Flash Drum	15
Solution.	16
3.1 Bubble Point	19
Example 2. Enthalpy Balance for Liquid Feed	19
3.2 Dew Point	21
Example 3. Enthalpy Balance for Vapor Feed	21
3.3 Design Variable	23
Summary.....	24
Review Questions	25
Problems	25

Flash distillation is used to separate components in a mixture making use of the difference in their volatilities. The operation consists of partially vaporizing or condensing the mixture by either heating or cooling the feed and separating the vapor from the liquid in a tank, called a *flash drum* (see Fig. 1)

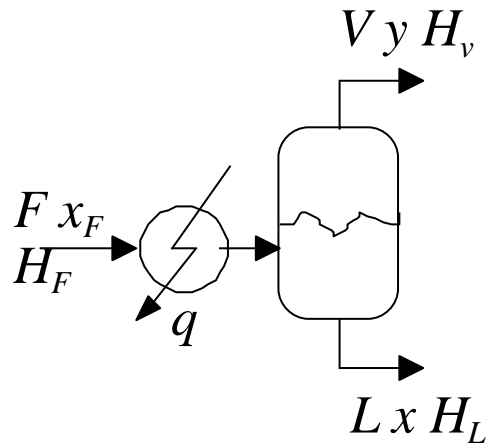


Figure 1. Flash drum

The more volatile or *light* components tend to go to the vapor stream V so that their concentration in the vapor is higher than their feed concentration, that is $y_L > x_{FL}$, while the less volatile or *heavy* components tend to go to the liquid stream and their concentration in the liquid is higher than their concentration in the feed, $x_H > x_{FH}$.

A flash drum is commonly assumed to be an equilibrium stage, that is, the liquid and vapor leaving the drum are assumed to be in equilibrium.

1 Flash Drum Variables and Specifications

As in any design problem, the feed rate, composition and enthalpy are usually specified. These are $C + 1$ variables, where C is the number of components in the feed:

- $C - 1$ component mole fractions x_F (they must add to unity)
- The feed rate F
- The enthalpy H_F , specified as
 - Temperature and pressure,
 - Temperature and saturated liquid or vapor, or
 - Pressure and saturated liquid or vapor.

There are then $2C + 3$ variables associated with the drum

- The vapor and liquid product rates, V and L (2)
- The vapor and liquid mole fractions, y and x ($2C - 2$)
- The vapor and liquid enthalpies, H_V and H_L (2)
- The exchanger heat duty, q .

On the assumption of equilibrium, the vapor and liquid enthalpies are functions of the temperature, pressure and compositions, and can be calculated from them, but this still give us the temperature and the pressure as the design variables.

How many equations can we write on the flash drum? $2C + 1$:

- C independent mass balances (there are C components)
- An enthalpy balance
- C equilibrium relationships, one for each component.

Therefore, two specifications are required to determine the variables of a flash drum. These can be two of the following three:

- ✓ The operating pressure P
- ✓ The operating temperature T
- ✓ The fraction of the feed that is vaporized, V/F .

Notice that the number of required specifications is independent of the number of components.

Because the equilibrium relations are expressed in molar units, the flows and compositions must be in molar flows and mole fractions.

2 Flash Drum Balances and Equations

We can write C independent mass balances on the drum, usually one total mole balance, $C - 1$ component mole balances, and an enthalpy balance. By inspection of Fig. 1, and an enthalpy balance:

$$\text{Total mole balance:} \quad F = V + L \quad (1)$$

$$\text{Component mole balances:} \quad Fx_{Fi} = Vy_i + Lx_i \quad (2)$$

$$\text{Enthalpy balance:} \quad FH_F + q = VH_V + LH_L \quad (3)$$

Where subscript i refers to component i , and only $C - 1$ component mole balances are independent when the total mole balance is used.

The equilibrium relationships result from the minimization of the free energy of each component at equilibrium, but they are usually expressed in terms of the K factors or distributions coefficients:

$$\text{Equilibrium:} \quad y_i = K_i(T, P, x) x_i \quad (4)$$

There are C of these relationships, one for each component. In general, as indicated, the K factor is a function of the temperature, the pressure and the liquid composition.

2.1 Equilibrium Relations

The basic equilibrium relationship is the equality of the chemical potentials of each component in the vapor and the liquid:

$$\mu_{Vi} = \mu_{Li} \quad (5)$$

This results in the equality of the fugacities in the liquid and the vapor as $\mu = RT \ln(f)$, so $f_{Vi} = f_{Li}$. Then

$$v_{Vi} P y_i = \gamma_i v_i^{\circ} P_i^{\circ}(T) x_i \quad (6)$$

Where ν_{Vi} = vapor fugacity coefficient of component i at T and P

ν_i° = fugacity coefficient of component i saturated at T

P = the total absolute pressure of the drum

γ_i = activity coefficient of component i at T , P , and x

$P_i^\circ(T)$ = vapor pressure of component i at T

Equation (6) is the general equation used by process simulators (Aspen Plus, HySys, Process, etc.) to carry out precise flash calculations. Depending on the thermodynamic models used it can represent equilibrium for very non-ideal mixtures and predict azeotrope and more than one liquid phase. The calculations are simpler for

- Mixtures of non-polar compounds such as hydrocarbons for which the activity coefficients, γ , are unity and the K factors are available in the literature for many compounds as functions of temperature and pressure, that is, independent of the liquid compositions and the other components in the mixture.
- Ideal mixtures with similar intermolecular forces for which the activity and fugacity coefficients are unity and the K factors become the ratio of the component vapor pressure to the total absolute pressure. This is known as Raoult's law:

$$K_i(T, P) = \frac{P_i^\circ(T)}{P} \quad (7)$$

The vapor pressure is obtained as a function of pressure from a correlation known as the Antoine equation:

$$P_i^o(T) = e^{A_i - \frac{B_i}{T+C_i}} \quad (8)$$

Where the constants, A_i , B_i and C_i , are available in the literature for many compounds.

2.2 Enthalpy Balance

The enthalpy balance gives the heat duty of the exchanger required for the separation. In general, as mentioned before, the molar enthalpies are functions of the temperature, the pressure and the compositions. Process simulators have correlations to very accurately estimate the enthalpies of very non-ideal solutions, but for most hydrocarbon mixtures very good approximations are obtained neglecting the temperature and pressure dependence, which is small except at very high pressures.

Liquid Feed

When the feed is in the liquid state, the enthalpy balance, Eq. (3), can be simplified by solving for L from Eq. (1) and substituting into Eq. (3):

$$q = V(H_V - H_L) - F(H_F - H_L) = V\lambda_V - FC_{pF}(T_F - T) \quad (9)$$

where λ_V is the latent heat of the vapor and C_{pF} is the molar heat capacity of the feed (assumed liquid). The latent heat is calculated using the vapor mole fractions and the component molar latent heats:

$$\lambda_V = y_1\lambda_1 + y_2\lambda_2 + y_3\lambda_3 + \dots \quad (10)$$

where λ_i is the molar latent heat of component i . The molar heat capacity of the feed is calculated using the feed mole fractions and the molar heat capacities of the components:

$$C_{pF} = x_{F1}C_{p1} + x_{F2}C_{p2} + x_{F3}C_{p3} + \dots \quad (11)$$

Where C_{pi} is the liquid molar heat capacity of component i .

Vapor Feed

If the feed to the flash drum is vapor, the equation must be modified by solving for V from Eq. (1) and substituting into Eq. (3) to get:

$$q = F(H_V - H_F) - L(H_V - H_L) = FC_{pF}(T - T_F) - L\lambda_V \quad (12)$$

In this case the liquid mole fractions x_i must be used to calculate λ_v in Eq. (10) and the component molar heat capacities in Eq. (11) must be those of the vapor feed. In this case the heat duty q will usually be negative, meaning that heat must be removed in the heat exchanger to partially condense the vapor feed.

2.3 Boiling Point Diagram

Figure 2 shows the boiling point *diagram* for a mixture of benzene and toluene at 1 atm. We will use this diagram to introduce some very important concepts on flash distillation.

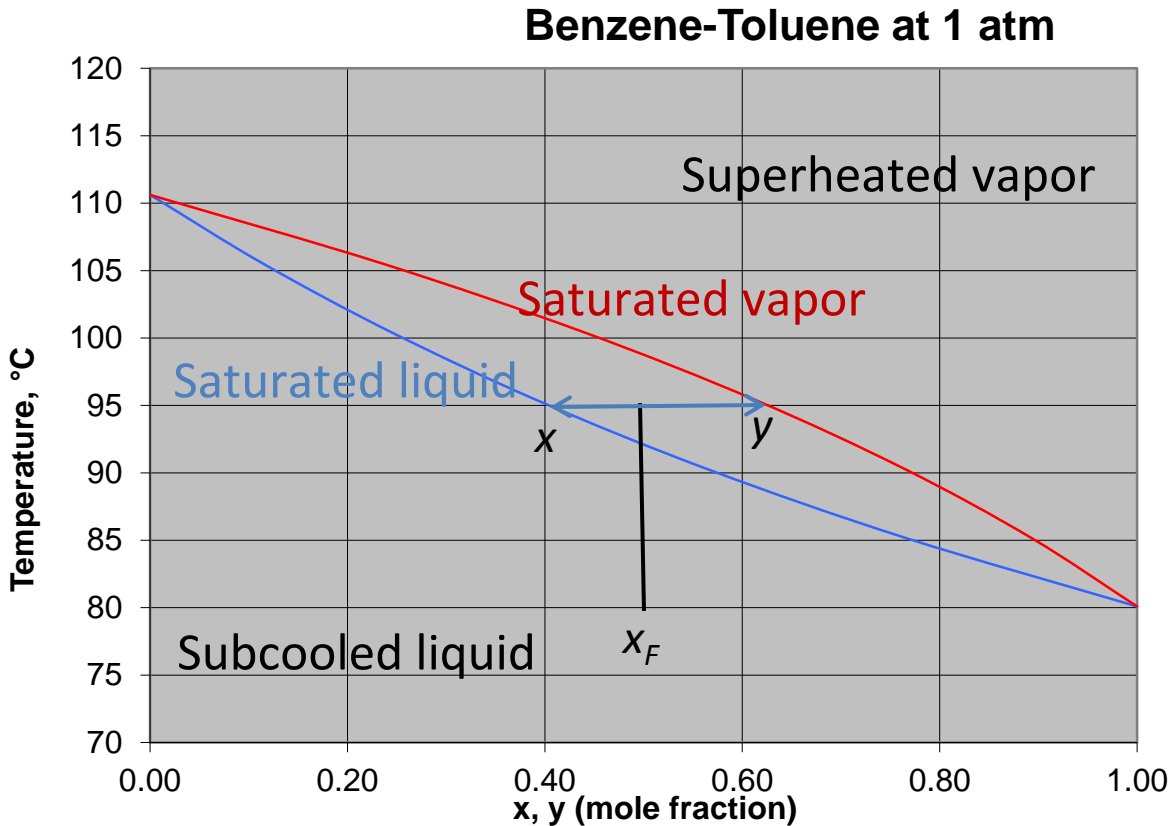


Figure 2. Boiling point diagram for benzene-toluene at 1 atm

The lower line in the figure represents the boiling temperature of the *saturated liquid* as a function of composition. This temperature is known as the *bubble point* of the mixture, because it is the temperature at which the liquid is in equilibrium with a bubble of vapor, too small to change the composition of the liquid.

The upper line is the condensation temperature of the *saturated vapor* as a function of composition. This temperature is also known as the *dew point* of the mixture because the vapor is in equilibrium with a small drop of the liquid, too small to change the composition of the vapor.

Between the two lines the mixture is part liquid and part vapor and the two phases can be separated in a flash drum. The mixture is said to be *partially vaporized*. Below the saturated liquid (bubble point) line the mixture is said to be a *sub-cooled liquid* and above the saturated vapor (dew point) line the mixture is said to be a *superheated vapor*. It is evident that for a flash drum to work it must operate at a temperature between the bubble point and the dew point of the feed.

Let us use Fig. 2 to look at how a flash drum works. Starting with a sub-cooled liquid with 50% benzene and 50% toluene, let us heat it up gradually.

1. As the figure shows, when the temperature reaches about 92.5°C the liquid reaches saturation, that is, the first bubble of vapor forms. So the bubble point of a 50% mixture at 1 atm pressure is 92.5°C .
2. As we continue to heat the mixture to 95°C it partially vaporizes. If we now separate the two phases in a flash drum, the vapor has a benzene mole fraction of 0.63 and the liquid has a benzene mole fraction of 0.40. That is, the benzene is more concentrated in the vapor and less concentrated in the liquid than the original mixture. It follows that the toluene is more concentrated in the liquid and less in the vapor than the original mixture. This is how the flash drum separates the components in a mixture according to their volatility. Which is the light component and which the heavy component in this example?
3. If instead of separating the phases we continue to heat the mixture, when the temperature reaches about 98°C it becomes saturated vapor. Thus the dew point of the 50% mixture at 1

atm pressure is 98°C . If heated to higher temperatures the mixture becomes a superheated vapor.

The boiling point diagram of Fig. 2 shows the bubble point and dew point as functions of the benzene mole fraction at 1 atm pressure. Notice that when the benzene concentration is zero the bubble point and dew point are the same and equal to 110.6°C . This is the normal boiling point of pure toluene. On the right side the bubble point and dew point are equal to the normal boiling point of pure benzene, 80°C . Notice also that near the two ends, when the mixture is close to pure toluene or benzene, the difference between the dew point and the bubble point is much lower than near the middle.

Countercurrent Stage Distillation.

The operation of a countercurrent stage distillation column consists of contacting the vapor and liquid phases in opposite directions in trays. Each tray effects a flash separation between the vapor and the liquid phases with the composition of the light components in the vapor phase increasing as it flows through the trays up the column and the composition of the heavy components in the liquid phase increasing as it cascades from tray to tray down the column. When the vapor contacts the liquid in a tray part of it condenses providing the heat to partially vaporize the liquid.

Non-ideal Solutions.

Not all solutions are ideal as the benzene-toluene solution of Fig. 2. Some solutions form azeotropes and have boiling diagrams similar to that of Fig. 3.

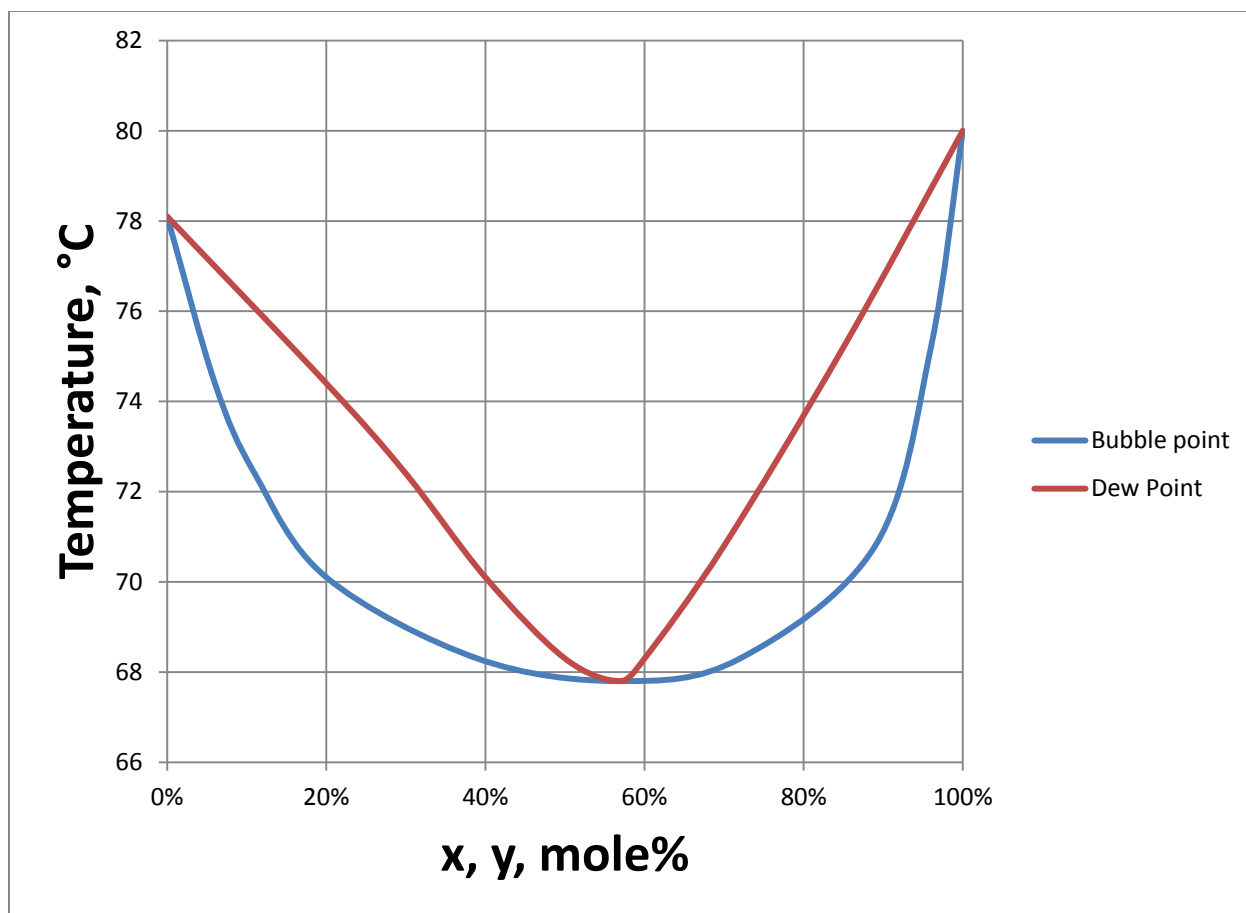


Figure 3. Low-boiling azeotrope: benzene-ethanol at 1 atm

As the figure shows, the azeotrope consists of 57 mole% benzene and 43 mole% ethanol. At this composition the bubble point and dew point are the same and lower than the boiling points of pure ethanol and pure benzene, hence the “low-boiling” designation. Other mixtures form high-boiling azeotropes.

Because of the azeotrope it is not possible to separate a mixture into its pure components by simple distillation. Notice that to the left of the azeotrope the benzene has a higher composition in the vapor than in the liquid while to the right of the azeotrope the benzene composition is higher in the liquid than in the vapor.

3 Solution of the Flash Equations

The flash equations, Eqs. (1) through (4), must usually be solved by iterative (trial and error) methods. The solution is aided by substituting Eq. (4) into Eq. (2):

$$F x_{Fi} = V K_i x_i + L x_i$$

Solve for x_i :

$$x_i = \frac{F x_{Fi}}{V K_i + L} \quad (13)$$

Assume that the specifications are the feed flow, composition and enthalpy, the pressure and the fraction of the feed vaporized. The solution procedure is then as follows:

1. Calculate the liquid rate, $L = F - V$
2. Assume a temperature and calculate K_i for each component
3. Calculate x_i using Eq. (13) for each component
4. Repeat steps 2 and 3 until $\sum x_i = 1.0$

When the K factor calculation can be programmed, the iteration can be carried out in a hand-held calculator having the "Solve" function, or in computer programs such as Excel ("Goal seek" function), or MathCad ("Given-Find" function). However, if the K factors must be looked up in a graph or a table, those methods cannot be used. In such cases the *Secant Method* is the most efficient way to arrive at a solution.

3.1 Secant Method.

Define the iteration error as $e = \sum x_i - 1$. Then:

1. Assume two initial temperature values, T_1 and T_2
2. Calculate K_i and x_i for each component for each temperature and determine e_1 for T_1 and e_2 for T_2
3. Estimate the next temperature as follows

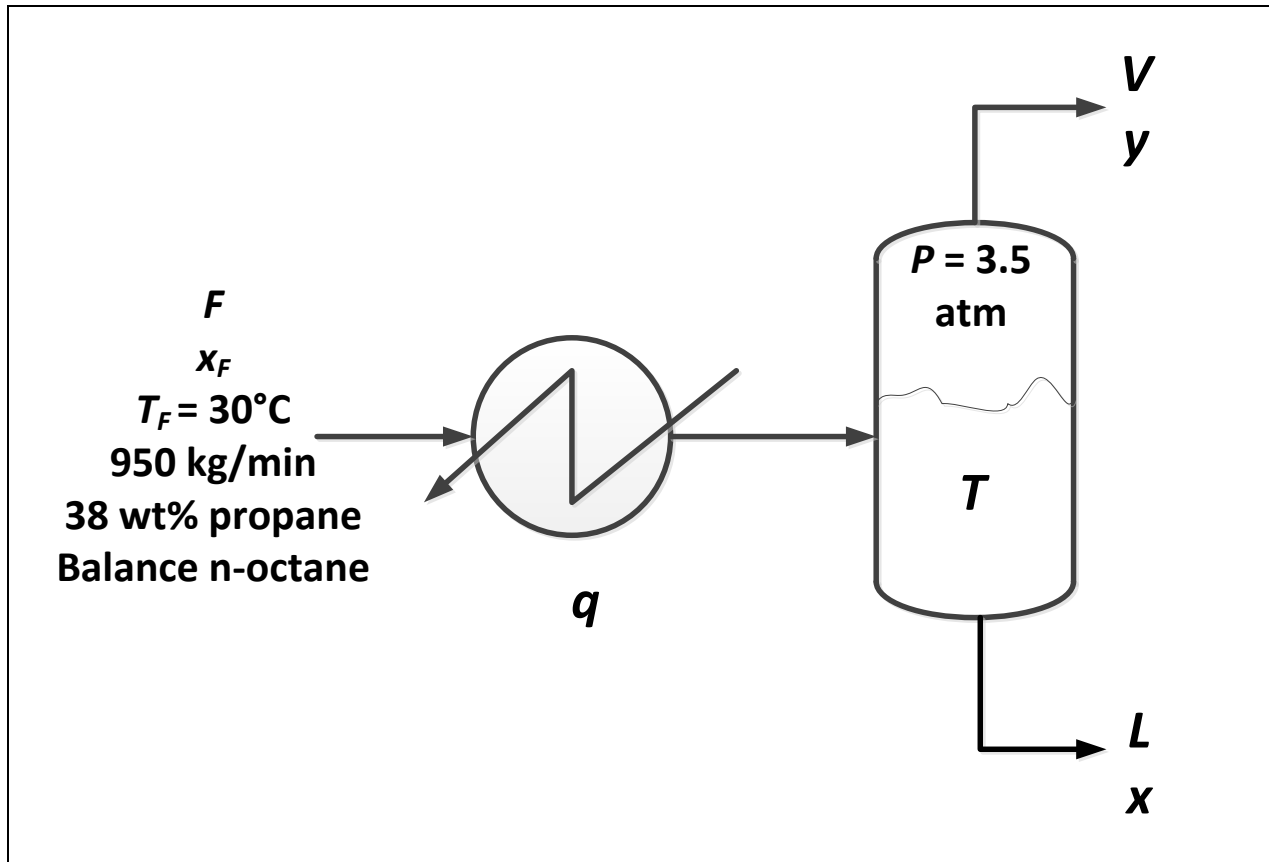
$$T_{k+1} = T_k - e_k \frac{T_k - T_{k-1}}{e_k - e_{k-1}}$$

4. Stop the iteration when the next value of the temperature varies by less than 0.1° from the previous value.

The secant method is very efficient and converges within four or five iterations. It definitely beats trying values of the temperature at random. You should add this method to your arsenal of computation methods.

Example 1. Design of a Flash Drum

A liquid mixture containing 38 weight% of propane and the balance n-octane is to be separated in a flash drum operating at 3.5 atm. The feed rate is 950 kg/min and enters at 30°C . Using a reasonable vaporization fraction determine the temperature and product flows and compositions, the exchanger heat duty, and the recovery of each component.



Solution. Because the equilibrium relationship is given in molar units we must first convert the weight fractions and mass flow to molar basis. The molecular weights are 44 for propane and 114 for octane.

Mole fractions:
$$x = \frac{\frac{0.38}{44}}{\frac{0.38}{44} + \frac{1-0.38}{114}} = 0.614$$

Average molecular weight:
$$MW = 0.614(44) + (1 - 0.614)114 = 71.0$$

Molar rate of feed:
$$F = \left(\frac{950 \text{ kg}}{\text{min}}\right) \left(\frac{60 \text{ min}}{\text{hr}}\right) \left(\frac{\text{kmole}}{71.0 \text{ kg}}\right) = 802 \frac{\text{kmole}}{\text{hr}}$$

Design variable: As the two components have very different volatilities it is expected that most of the propane goes to the

vapor and most of the n-butane goes to the liquid. So set the vaporization fraction to 61% on a molar basis:

$$V = (0.61)(802) = 489 \text{ kmole/hr}$$

$$L = 802 - 489 = 313 \text{ kmole/hr}$$

From Reid, Sherwood & Prausnitz, 3rd ed., 1977, Appendix, the Antoine constants are, with the vapor pressure in mm Hg:

$$\text{Propane: } A = 15.726 \quad B = 1872.46K \quad C = -25.16K$$

$$\text{n-octane: } A = 15.9426 \quad B = 3120.29K \quad C = -63.63$$

$$\text{The pressure is: } (3.5 \text{ atm})(760 \text{ mm Hg}) = 2660 \text{ mm Hg}$$

Start the iteration with

$$T_1 = 40^\circ\text{C} + 273 = 313K: \quad K_p = e^{15.726 - \frac{1872.46}{313 - 25.16}} \frac{1}{2660} = 3.81$$

$$K_o = e^{15.9426 - \frac{3120.29}{313 - 63.63}} \frac{1}{2660} = 0.0117$$

$$x_p = \frac{802(0.614)}{489(3.81) + 313} = 0.226 \quad x_o = \frac{802(1 - 0.614)}{489(0.0117) + 313} = 0.973$$

$$e_1 = 0.226 + 0.973 - 1 = 0.199$$

$$T_2 = 60^\circ\text{C} + 273 = 333K \quad K_p = 5.82 \quad K_o = 0.0296$$

$$x_p = 0.156 \quad x_o = 0.947 \quad e_2 = 0.103$$

$$\text{Secant: } T_3 = 60 - 0.103 \frac{60 - 40}{0.103 - 0.199} = 81.4^\circ\text{C}$$

The rest of the iterations are summarized in the following table:

T, °C	Kp	Ko	x	1 - x	e
40.0	3.81	0.0117	0.226	0.973	0.199
60.0	5.82	0.0296	0.156	0.947	0.103
81.4	8.63	0.0693	0.109	0.894	0.002
81.9	8.71	0.0706	0.108	0.892	-1.44E-04

Temperature: 81.9°C

Liquid product: $L = 313$ kmole/hr $x = 0.108$

Vapor product: $V = 489$ kmole/hr $y = Kx = 8.71(0.108) = 0.937$

Propane recovery: $\frac{Vy}{Fx_F} = \frac{489(0.937)}{802(0.614)} = 0.932$

n-octane recovery: $\frac{L(1-x)}{F(1-x_F)} = \frac{313(1-0.108)}{802(1-0.614)} = 0.900$

Enthalpy balance: From Reid, Sherwood & Prausnitz, 3rd ed., 1977, Appendix, the latent heats are:

Propane: $\lambda_p = 4,487$ kcal/kmole; n-octane: $\lambda_o = 8,825$ kcal/kmole

Vapors: $\lambda_V = y\lambda_p + (1-y)\lambda_o = \left[0.937 \frac{4487 \text{ kcal}}{\text{kmole}} + (1-0.937) \frac{8825 \text{ kcal}}{\text{kmole}}\right] \frac{4.187 \text{ kJ}}{\text{kcal}} = 19770 \frac{\text{kJ}}{\text{kmole}}$

From Perry's, 8th ed., Table 2-153, the molar heat capacities:

Propane: 146 kJ/kmole-°C; n-octane: 261 kJ/kmole-°C

Feed: $C_{pF} = x_F C_{pp} + (1-x_F)C_{po} = 0.614(146) + (1-0.614)(261) = 190 \frac{\text{kJ}}{\text{kmole } ^\circ\text{C}}$

Heat duty:

$$q = V\lambda_V - FC_{pF}(T_F - T) = 489(19770) - 802(190)(30 - 81.9) = 17.6 \times 10^6 \frac{\text{kJ}}{\text{hr}}$$

This example shows that when the relative volatility of the components is high (in this case $8.71/0.0706 = 12.3$) the product compositions can be relatively pure and the recoveries high. This would not be the case if the relative volatility were nearer 1.0 which case a countercurrent stage distillation column would be required to obtain pre products and high recoveries.

3.1 Bubble Point

The bubble point of a mixture is the liquid saturation temperature. It is obtained by solving the flash equations for $V = 0$, thus $L = F$ and $x_i = x_{Fi}$. The solution procedure is as follows:

1. Assume a temperature and calculate K_i for each component
2. Calculate $y_i = K_i x_i$ for each component
3. Repeat steps 1 and 2 until $\sum y_i = 1.0$

Again there are several ways to solve the iteration and the Secant method is one of them.

Example 2. Enthalpy Balance for Liquid Feed

Calculate the heat duty for Example 1 if the feed is saturated liquid at 4.2 atm (3190 mm Hg). Start the iteration:

$$T_1 = 30^\circ\text{C} + 273 = 303\text{K}: \quad K_p = e^{15.726 - \frac{1872.46}{303 - 25.16}} \frac{1}{3190} = 2.51$$

$$K_o = e^{15.9426 - \frac{3120.29}{303 - 63.63}} \frac{1}{3190} = 0.00578$$

$$x = x_F = 0.614$$

$$y_p = K_p x = (2.51)(0.614) = 1.543$$

$$y_o = K_o(1 - x) = (0.00578)(1 - 0.614) = 0.002$$

$$e_1 = 1.543 + 0.002 - 1 = 0.545$$

$$T_2 = 20^\circ\text{C} + 273 = 333\text{K}$$

$$K_p = 1.96$$

$$K_o = 0.00328$$

$$y_p = 1.200$$

$$y_o = 0.001$$

$$e_2 = 0.201$$

$$\text{Secant: } T_3 = 20 - 0.201 \frac{20 - 30}{0.201 - 0.545} = 14.1^\circ\text{C}$$

The rest of the iterations are summarized in the following table:

30.0	2.51	0.00578	1.543	0.002	0.545
20.0	1.96	0.00328	1.200	0.001	0.201
14.1	1.67	0.00230	1.027	0.001	0.028
13.2	1.63	0.00217	1.001	0.001	0.002
13.2	1.63	0.00216	0.999	0.001	1.7315E-05

So, the feed is at its bubble point, 13.2°C . The rest of the results of Example 1 are the same except for the exchanger heat duty:

$$q = V\lambda_V - FC_{pF}(T_F - T) = 489(19770) - 802(190)(13.2 - 81.9) = 20.2 \times 10^6 \frac{\text{kJ}}{\text{hr}}$$

Notice the conditions in the flash drum are not changed. The feed is at a higher pressure than the drum to allow for pressure drop in the heat exchanger.

3.2 Dew Point

The dew point of a mixture is the vapor saturation temperature. It is obtained by solving the flash equations for $L = 0$, thus $V = F$ and $y_i = x_{Fi}$. The solution procedure is as follows:

1. Assume a temperature and calculate K_i for each component
2. Calculate $x_i = y_i/K_i$ for each component
3. Repeat steps 1 and 2 until $\sum x_i = 1.0$

Again there are several ways to solve the iteration and the Secant method is one of them.

Example 3. Enthalpy Balance for Vapor Feed

Calculate the heat duty for Example 1 if the feed is saturated vapor at 4.2 atm (3190 mm Hg). Start the iteration:

$$T_1 = 130^\circ\text{C} + 273 = 403\text{K}: K_p = e^{15.726 - \frac{1872.46}{403 - 25.16}} \frac{1}{3190} = 14.94$$

$$K_o = e^{15.9426 - \frac{3120.29}{403 - 63.63}} \frac{1}{3190} = 0.268$$

$$y = x_F = 0.614 \quad x_p = \frac{y}{K_p} = \frac{0.614}{14.94} = 0.041$$

$$x_o = \frac{1 - y}{K_o} = \frac{1 - 0.614}{0.268} = 1.440$$

$$e_1 = 0.041 + 1.440 - 1 = 0.481$$

$$T_2 = 140^\circ\text{C} + 273 = 413\text{K} \quad K_p = 16.97 \quad K_o = 0.349$$

$$x_p = 0.036 \quad x_o = 1.107 \quad e_2 = 0.143$$

Secant: $T_3 = 140 - 0.143 \frac{140-130}{0.143-0.481} = 144.2^\circ\text{C}$

The rest of the iterations are summarized in the following table:

T, °C	Kp	Ko	xp	xo	e
130.0	14.94	0.268	0.041	1.440	0.481
140.0	16.97	0.349	0.036	1.107	0.143
144.2	17.88	0.388	0.034	0.995	0.029
145.3	18.12	0.399	0.034	0.968	0.002
145.4	18.14	0.400	0.034	0.966	4.06E-05

So the feed is at its dew point, 145.4°C . Because the feed is vapor, we must use Eq. (12), calculate the latent heat using the liquid mole fractions, and use the vapor molar heat capacities to calculate the feed heat capacity.

$$\lambda_V = x\lambda_p + (1-x)\lambda_o = \left[0.108 \frac{4487\text{kcal}}{\text{kmole}} + (1-0.108) \frac{8825\text{kcal}}{\text{kmole}}\right] \frac{4.1587\text{kJ}}{\text{kcal}} = 32750 \frac{\text{kJ}}{\text{kmole}}$$

From Perry's, 8th ed., Table 2-156, the molar heat capacities at the average temperature of $(81.9 + 145.4)/2 = 113.7^\circ\text{C}$ (386.8 K):

$$\text{Propane: } C_{pp} = 51.92 + 192.45 \left[\frac{\frac{1626.5}{386.8}}{\sinh\left(\frac{1626.5}{386.8}\right)} \right]^2 + 116.8 \left[\frac{\frac{723.6}{386.8}}{\cosh\left(\frac{723.6}{386.8}\right)} \right]^2 = 92.0 \frac{\text{kJ}}{\text{kmole-}^\circ\text{C}}$$

$$\text{n-octane: } C_{po} = 135.54 + 443.1 \left[\frac{\frac{1635.6}{386.8}}{\sinh\left(\frac{1635.6}{386.8}\right)} \right]^2 + 305.4 \left[\frac{\frac{746.4}{386.8}}{\cosh\left(\frac{746.4}{386.8}\right)} \right]^2 = 234.2 \frac{\text{kJ}}{\text{kmole-}^\circ\text{C}}$$

$$\text{Feed: } C_{pF} = x_F C_{pp} + (1-x_F) C_{po} = 0.614(92.0) + (1-0.614)(234.2) = 146.9 \frac{\text{kJ}}{\text{kmole-}^\circ\text{C}}$$

Heat duty:

$$q = FC_{pF}(T - T_F) - L\lambda_V = 802(146.9)(81.9 - 145.4) - 313(32750) = -17.7 \times 10^6 \frac{\text{kJ}}{\text{hr}}$$

The minus sign means that the exchanger must remove this heat to cool the feed and condense the liquid product.

3.3 Design Variable

As any design problem, the design of a flash drum is usually indeterminate requiring the engineer to select some design variable. Any of the three possible specifications can be a design variable, but recall that only two specifications are required.

- **Fraction Vaporized.** As Example 1 shows, when the relative volatility of the components is high the vapor fraction on a molar basis should be near the mole fraction of the light component in the feed. This is also a good way to specify in other cases.
- **Temperature.** When specifying the flash temperature and the feed is vapor, the temperature should be above ambient temperature so that refrigeration is avoided in the heat exchanger, because refrigeration is much more expensive than cooling water or air at ambient temperature. If the feed to the flash drum is liquid, the temperature should not be so high that it requires higher steam pressure than necessary in the heat exchanger because the cost of steam goes up with its pressure.
- **Pressure.** The consideration for pressure follows the same guidelines as for the temperature, because the flash temperature depends on the pressure. Unfortunately the temperature required at a given pressure is not known until the problem is solved.

These guidelines apply equally when solving the flash distillation problem manually or with a process simulator. When using the process simulator the usual specifications are the temperature and the pressure. The correct procedure is to look at the composition of the vapor and liquid products and keep in mind the following:

- Increasing the pressure or decreasing the temperature increases the composition of the light components in the liquid. This reduces the recovery of light components in the vapor.
- Decreasing the pressure or increasing the temperature increases the concentration of the heavy components in the vapor. This reduces the recovery of the heavy components in the liquid.

Summary

These notes have presented the design of separation by flash distillation. A flash drum is a single stage operation that separates the components in the feed based on the difference in their volatilities. The mass and enthalpy balances allow us to compute the temperature or pressure of the flash and the product flows and compositions.

The Secant method is recommended to solve the iterative flash calculations when other solution tools are not available.

Review Questions

1. Briefly describe the operation of flash distillation.
2. Which property of the components makes it possible to separate them by flash distillation?
3. Enumerate the feed stream specifications on a flash drum?
4. Enumerate the equations and variables associated with the flash drum and its exchanger.
5. How many specifications are required to define a flash distillation problem?
6. What is the K factor in the equilibrium relationship?
7. When does Raoult's law apply?
8. What is a sub-cooled liquid mixture? A saturated liquid mixture? A partially vaporized mixture? A saturated vapor mixture? A superheated liquid mixture?
9. For what purpose is the Secant method used?
10. What is the bubble point of a mixture? What is the dew point?
11. What is an azeotrope?
12. How is the vaporized fraction of the feed in a flash drum selected?
13. What is the feed temperature selected when the feed to the flash drum is a saturated vapor?

Problems

1. **Design of Butane-Pentane Flash Distillation Unit.** A flash drum is to separate 1,300 kg/min of a mixture of 48 weight% n-butane and the balance n-pentane at 600 kPa. The feed enters as a saturated liquid mixture at 660 kPa. Draw a schematic of the flash drum showing all the problem data and determine the temperature at which it separates using a reasonable vaporization fraction. Determine also the heat required to operate the flash separator, the flows and compositions of the vapor and liquid product streams, and the recovery of n-butane in the vapor and of n-pentane in the liquid. Heat of mixing is negligible. Data: The distribution coefficients $K = y/x$ can be determined by the following correlation:

$$\ln(PK) = A - B/T$$

where P is the pressure in kPa and T the temperature in K.
For n-butane: $A = 13.285$ $B = 2280 \text{ K}$

$$\lambda = 5350 \text{ cal/mole} \quad c_{pL} = 32 \text{ cal/mole-}^\circ\text{C}$$

For n-pentane: $A = 13.849$ $B = 2792 \text{ K}$

$$\lambda = 6160 \text{ cal/mole} \quad c_{pL} = 38 \text{ cal/mole-}^\circ\text{C}$$

2. **Flash distillation of n-butane-n-octane mixture.** A saturated liquid mixture at 180 kPa containing 30 weight% n-butane, and the balance n-octane is partially vaporized in a heat exchanger and fed to a flash drum running at 120 kPa. The feed rate is 38,000 kg/hr. Draw a schematic of the flash drum showing all the problem data and determine the flash temperature, the liquid and vapor product rates and compositions, the recovery of n-butane in the vapor and of

n-octane in the liquid, and the heat duty of the exchanger using a reasonable vaporization rate. Data from Reid, Prausnitz, and Sherwood, 3rd edition, Appendix:

	Antoine constants			λ	c_p
	A	B,K	C,K	Cal/mole	joule/mole-°C
n-butane	15.6782	2154.90	-34.42	5352	154
n-octane	15.9426	3120.29	-63.63	8225	261

In the Antoine equation the vapor pressure is in mm Hg.

3. **Flash Separation of a Butane-Octane Vapor Mixture.** Design the separator of Problem 2 with the feed entering as a saturated vapor. The exchanger partially condenses the vapor and the design variable is the fraction of the feed that is condensed, that is, L/F . A correlation and corresponding data for the heat capacity of the vapor feed are available in Perry's, 8th edition, Table 2-156.
4. **Design of a Benzene-Toluene Flash Separator.** A flash drum is to separate 35,700 barrels/day of a saturated liquid mixture containing 51 weight% benzene and the balance toluene at 1.9 atm pressure. The specific gravity of the mixture is 0.87, and the flash drum operates at 1.2 atm. One barrel = 0.159 m³ (42 gallons). Draw a schematic of the flash drum showing the problem data on the schematic and, using a reasonable vaporization rate, determine the flash temperature, the heat required to operate the flash separator in kJ/hr, the flows and compositions of the vapor

and liquid outlet streams, and the recoveries of benzene and toluene.

Data: From Perry's, 8th ed., Tables 2-150 and 2-153.

Benzene: $\lambda = 31,000 \text{ kJ/kmole}$ $C_{pL} = 165.3 \text{ kJ/kmole-}^\circ\text{C}$

Toluene: $\lambda = 35,300 \text{ kJ/kmole}$ $C_{pL} = 190.4 \text{ kJ/kmole-}^\circ\text{C}$

Antoine constants for vapor pressure in mm Hg, from Reid, Prausnitz, and Sherwood, 3rd edition, Appendix:

Benzene: $A = 15.9008$ $B = 2788.51 \text{ K}$ $C = -52.36 \text{ K}$

Toluene: $A = 16.0137$ $B = 3096.52 \text{ K}$ $C = -53.67 \text{ K}$

5. **Flash distillation of n-butane-n-hexane mixture.** A

saturated liquid mixture at 400 kPa containing 57 weight% n-butane and the balance n-hexane is partially vaporized in a heat exchanger and fed to a flash drum running at 330 kPa. The feed flow is 5,200 kg/min. Draw a schematic of the flash drum showing all the problem data and, using a reasonable vaporization rate, determine the flash temperature, the compositions and flows of the vapor and liquid products, the heat duty of the exchanger, and the recoveries of the two components. State all assumptions.

Data from Reid, Prausnitz, and Sherwood, 3rd edition, Appendix (For the liquid heat capacity see Perry's Ch. E. Handbook, 8th ed., Tables 2-153):

Antoine constants:

λ , kcal/kmole	A	B, K	C, K
------------------------	---	------	------

n-butane	5,352	15.6782	2154.90	-34.42
n-hexane	6,896	15.8366	2697.55	-48.78

In The Antoine equation the vapor pressure is in mm Hg.

6. **Design of a benzene-ethylbenzene flash drum.** A flash drum is to separate 3,700 kg/min of a mixture of 52.5 weight% benzene and the balance ethylbenzene entering at 2.6 atm pressure. The drum operates at 2.0 atm. Draw a schematic of the flash drum showing all the problem data and, using a reasonable vaporization rate, determine the flows and compositions of the product streams, the flash temperature, the exchanger heat duty, and the recoveries of the two components.

Data:

Benzene: $\lambda = 7352 \text{ kcal/kmole}$ $C_{pL} = 32 \text{ kcal/kmole-}^\circ\text{C}$

Ethylbenzene: $\lambda = 8500 \text{ kcal/kmole}$ $C_{pL} = 38 \text{ kcal/kmole-}^\circ\text{C}$

Antoine constants for vapor pressure in mm Hg, from Reid, Prausnitz, and Sherwood, 3rd edition, Appendix:

Benzene: $A = 15.9008$ $B = 2788.51 \text{ K}$ $C = -52.36 \text{ K}$

Ethylbenzene: $A = 16.0195$ $B = 3279.47 \text{ K}$ $C = -59.95 \text{ K}$