are found from the F value. After 27.9 °C. Obviously, the V/F os­
versed V/F os­
are found from the F value. After 27.9 °C. Obvi­
versed V/F os­
Table 2-6. Note the reversed V/F os­
versed V/F os­
F. Generalization. The use of the computer greatly reduces calculation time on this double trial-and-error problem. Use of a process simulator that includes VLE and enthalpy correlations will be fastest.

2.8 SIZE CALCULATION

Once the vapor and liquid compositions and flow rates have been determined, the flash drum can be sized. This is an empirical procedure. We will discuss the specific procedure first for vertical flash drums (Figure 2-1) and then adjust the procedure for horizontal flash drums.

Step 1. Calculate the permissible vapor velocity, $u_{\text{perm}}$:

$$u_{\text{perm}} = K_{\text{drum}} \sqrt{\frac{F_L - P_v}{P_v}}$$  \hspace{1cm} (2-59)

$u_{\text{perm}}$ is the maximum permissible vapor velocity in feet per second at the maximum cross-sectional area. $P_L$ and $P_v$ are the liquid and vapor densities. $K_{\text{drum}}$ is in ft/s.

$K_{\text{drum}}$ is an empirical constant that depends on the type of drum. For vertical drums the value has been correlated graphically by Watkins (1967) for 85% of flood with no demister. Approximately 5% liquid will be entrained with the vapor. Use of the same design with a demister will reduce entrainment to less than 1%. The demister traps small liquid droplets on fine wires and prevents them from exiting. The droplets then coalesce into larger droplets, which fall off the wire and through the rising vapor into the liquid pool at the bottom of the flash chamber. Blackwell (1984) fit Watkins' correlation to the equation

$$K_{\text{drum}} = \exp(A + B \ln F_L + C(\ln F_L)^2 + D(\ln F_L)^3 + E(\ln F_L)^4)$$  \hspace{1cm} (2-60)

where $F_L = \frac{W_L}{W_V \sqrt{\rho_L}}$

with $W_L$ and $W_V$ being the liquid and vapor flow rates in weight units per hour (e.g., lb/hr). The constants are (Blackwell, 1984):

$$A = -1.877478097 \quad C = -0.1870744085 \quad E = -0.0010148518$$

$$B = -0.8145804597 \quad D = -0.0145228667$$

The resulting value for $K_{\text{drum}}$ typically ranges from 0.4 to 0.35.

2.8 Size Calculation

45
Step 2. Using the known vapor rate, \( V \), convert \( u_{\text{perm}} \) into a horizontal area. The vapor flow rate, \( V \), in lb moles/hr is

\[
V \left( \text{lb moles/hr} \right) = \frac{u_{\text{perm}} (3600 \text{ s}) A_v \left( \frac{\text{ft}^3}{\text{lb mole}} \right)}{\text{MW}_{\text{vap}} \left( \frac{\text{lb mole}}{\text{lb mole}} \right)}
\]

Solving for the cross-sectional area,

\[
A_v = \frac{V (\text{MW})}{u_{\text{perm}} (3600) \rho_v}
\]

For a vertical drum, diameter \( D \) is

\[
D = \sqrt{\frac{4A_v}{\pi}}
\]

Usually, the diameter is increased to the next largest 6-in. increment.

Step 3. Set the length/diameter ratio either by rule of thumb or by the required liquid surge volume. For vertical flash drums, the rule of thumb is that \( h_{\text{col}}/D \) ranges from 3.0 to 5.0. The appropriate value of \( h_{\text{col}}/D \) within this range can be found by minimizing the total vessel weight (which minimizes cost).

Flash drums are often used as liquid surge tanks in addition to separating liquid and vapor. The design procedure for this case is discussed by Watkins (1967) for petrochemical applications.

The height of the drum above the centerline of the feed nozzle, \( h_v \), should be 36 in. plus one-half the diameter of the feed line (see Figure 2-14). The minimum of this distance is 48 in.

**Figure 2-14. Measurements for vertical flash drum**
The height of the center of the feed line above the maximum level of the liquid pool, \( h_1 \), should be 12 in. plus one-half the diameter of the feed line. The minimum distance for this free space is 18 in.

The depth of the liquid pool, \( h_L \), can be determined from the desired surge volume, \( V_{\text{surge}} \):

\[
h_L = \frac{V_{\text{surge}}}{\pi D^2/4}
\]  
(2-63)

The geometry can now be checked, since

\[
\frac{h_{\text{total}}}{D} = \frac{h_1 + h_L}{D}
\]
should be between 3 and 5. These procedures are illustrated in Example 2-4. If \( h_{\text{total}}/D < 3 \), a larger liquid surge volume should be allowed. If \( h_{\text{total}}/D > 5 \), a horizontal flash drum should be used. Calculator programs for sizing both vertical and horizontal drums are available (Blackwell, 1984).

For horizontal drums Blackwell (1984) recommends using

\[
K_{\text{horizontal}} = 1.25 K_{\text{vertical}}
\]  
(2-64a)

Calculate \( A_r \) from Eq. (2-61) and empirically determine the total cross sectional area \( A_r \) as,

\[
A_r = A_f/0.2
\]  
(2-64b)

and then the diameter of the horizontal drum is,

\[
D_{\text{horizontal}} = \sqrt[4]{4 A_r / \pi}
\]  
(2-64c)

The typical range for \( h_{\text{total}}/D \) is from 3 to 5. Horizontal drums are particularly useful when large liquid surge capacities are needed. More detailed design procedures and methods for horizontal drums are presented by Evans (1980), Blackwell (1984), and Watkins (1967). Note that in industries other than petrochemicals that sizing may vary.

**EXAMPLE 2-4. Calculation of drum size**

A vertical flash drum is to flash a liquid feed of 1500 lb moles/hr that is 40 mole % n-hexane and 60 mole % n-octane at 101.3 kPa (1 atm). We wish to produce a vapor that is 60 mole % n-hexane. Solution of the flash equations with equilibrium data gives \( x_H = 0.19 \), \( T_{\text{drum}} = 378K \), and \( V/F = 0.51 \). What size flash drum is required?

**Solution**

A. Define. We wish to find diameter and length of flash drum.

B. Explore. We want to use the empirical method developed in Eqs. (2-59) to (2-63). For this we need to estimate the following physical properties: \( P_L, P_v, \) \( MW' \). To do this we need to know something about the behavior of the gas and of the liquid.
C. Plan. Assume ideal gas and ideal mixtures for liquid. Calculate average \( \rho_L \) by assuming additive volumes. Calculate \( \rho_v \) from the ideal gas law. Then calculate \( u_p \) from Eq. (2.59) and diameter from Eq. (2.63).

D. Do It.

1. Liquid Density
   The average liquid molecular weight is
   \[
   \overline{MW}_L = x_H MW_H + x_O MW_O
   \]
   where subscript H is n-hexane and O is n-octane. Calculate or look up the molecular weights. \( MW_H = 86.17 \) and \( MW_O = 114.22 \). Then \( \overline{MW}_L = (0.19)(86.17) + (0.81)(114.22) = 108.89 \). The specific volume is the sum of mole fractions multiplied by the pure component specific volumes (ideal mixture):
   \[
   \overline{V}_L = x_H \overline{V}_H + x_O \overline{V}_O = \frac{x_H MW_H}{\rho_H} + \frac{x_O MW_O}{\rho_O}
   \]
   From the Handbook of Chemistry and Physics, \( \rho_H = 0.659 \) g/mL and \( \rho_O = 0.703 \) g/mL at 20 °C. Thus,
   \[
   \overline{V}_L = (0.19) 0.659 + (0.81) 0.703 = 156.45 \text{ mL/g-mole}
   \]
   Then
   \[
   \rho_L = \frac{\overline{MW}_L}{\overline{V}_L} = \frac{108.89}{156.45} = 0.696 \text{ g/mL}
   \]

2. Vapor Density
   Density in moles per liter for ideal gas is \( \rho_v = n/V = pRT \), which in grams per liter is \( \rho_v = p MW_v/RT \).
   The average molecular weight of the vapor is
   \[
   MW_v = y_H MW_H + y_O MW_O
   \]
   where \( y_H = 0.60 \) and \( y_O = 0.40 \), and thus \( \overline{MW}_v = 97.39 \) lb/lb-mole. This gives
   \[
   \rho_v = \frac{(1.00 \text{ atm})(97.39 \text{ g/mole})}{(82.0575 \text{ mL atm })(378 \text{ K})} = 3.14 \times 10^{-2} \text{ g/mL}
   \]

3. \( K_{v,\text{com}} \) Calculation.
   Calculation of flow parameter \( F_v \):
   \[
   V = (\overline{V}_f/F_t) = (0.5)(1900) = 765 \text{ lb moles/hr}
   \]
   \[
   W_L = (V)(\overline{MW}_L) = (765)(97.39) = 74,503 \text{ lb/hr}
   \]
   \[
   L = F - V = 735 \text{ lb moles/hr}
   \]

4. 2.9. Using Existing

   Individual pieces then available each in used equipment be used instead of new equipment; new equipment;
\[ W_L = (L)(MW_L) = (735)(108.89) = 80,034 \text{ lb/hr} \]

\[ F_L = \frac{W_L}{\rho_L} = \frac{80034}{74503} = 0.0722 \]

\[ K_{\text{avg}} \text{ from Eq. (2-60) gives } K_{\text{avg}} = 0.4433, \text{ which seems a bit high but agrees with Watkin's (1967) chart.} \]

\[ u_{\text{perm}} = K_{\text{drum}} \frac{P_L - P_v}{P_v} = 0.4433 \frac{0.6960 - 0.00314}{0.00314} = 6.5849 \text{ ft/s} \]

\[ A_s = \frac{V(MW_L)}{u_{\text{perm}}(3600)\rho_v} = \frac{(765)(97.39)(454 \text{ g/lb})}{(6.5849)(3600)(0.00314 \text{ g/mL})(28316.85 \text{ mL/ft}^3)} = 16.047 \text{ ft}^2 \]

\[ D = \sqrt{\frac{4A_s}{\pi}} = 4.01 \text{ ft} \]

Use a 4.0 ft diameter drum or 4.5 ft to be safe.

6. If use \( h_{\text{total}}/D = 4, h_{\text{total}} = 4(4.5 \text{ ft}) = 18.0 \text{ ft.} \)

E. Check. This drum size is reasonable. Minimums for \( h_1 \) and \( h_2 \) are easily eay.

Note that units do work out in all calculations; however, one must be careful with units, particularly calculating \( A_s \) and \( D \).

F. Generalization. If the ideal gas law is not valid, a compressibility factor could be inserted in the equation for \( p_v \). Note that most of the work involved calculation of the physical properties. This is often true in designing equipment. In practice we pick a standard size drum (4.0 or 4.5 ft diameter) instead of custom building the drum.

2.9. Using Existing Flash Drums

Individual pieces of equipment will often outlive the entire plant. This used equipment is then available either in the plant's salvage section or from used equipment dealers. As long as used equipment is clean and structurally sound (it pays to have an expert check it), it can be used instead of designing and building new equipment. Used equipment and off-the-shelf new equipment will often be cheaper and will have faster delivery than custom-designed new equipment; however, it may have been designed for a different separation. The chal-
The existing flash drum has its dimensions $h_{\text{total}}$ and $D$ specified. Solving Eqs. (2-61) and (2-62) for a vertical drum for $V$, we have

$$V_{\text{max}} = \frac{\pi(D^2) u_{\text{perm}}^3 (3000) \rho}{4MW_v} \quad (2-65)$$

This vapor velocity is the maximum for this existing drum, since it will give a linear vapor velocity equal to $u_{\text{perm}}$.

The maximum vapor capacity of the drum limits the product of $(V/F)$ multiplied by $F$, since we must have

$$(V/F) F < V_{\text{max}} \quad (2-66)$$

If Eq. (2-66) is satisfied, then use of the drum is straightforward. If Eq. (2-66) is violated, something has to give. Some of the possible adjustments are:

a. Add chevrons or a demister to increase $V_{\text{max}}$ or to reduce entrainment (Weinsky, 1994).
b. Reduce feed rate to the drum.
c. Reduce $V/F$. Less vapor product with more of the more volatile components will be produced.
d. Use existing drums in parallel. This reduces feed rate to each drum.
e. Use existing drums in series (see Problems 2.D2 and 2.D5).
f. Try increasing the pressure (note that this changes everything—see Problem 2.C1).
g. Buy a different flash drum or build a new one.
h. Use some combination of these alternatives.
i. The engineer can use ingenuity to solve the problem in the cheapest and quickest way.

2.10 SUMMARY—OBJECTIVES

This chapter has discussed VLE and the calculation procedures for binary and multicomponent flash distillation. At this point you should be able to satisfy the following objectives:

1. Explain and sketch the basic flash distillation process
2. Find desired VLE data in the literature or on the Web
3. Plot and use $y$-$x$, temperature-composition, enthalpy-composition diagrams; explain the relationship between these three types of diagrams
4. Derive and plot the operating equation for a binary flash distillation on a $y$-$x$ diagram; solve both sequential and simultaneous binary flash distillation problems
5. Define and use $K$ values, Raoult's law, and relative volatility
6. Derive the Raoult-Rice equation for multicomponent flash distillation, and use it with Newtonian convergence to determine $V/F$
7. Solve sequential multicomponent flash distillation problems
8. Determine the length and diameter of a flash drum
9. Use existing flash drums for a new separation problem
Permissible Vapor Velocity

\[ U_{\text{perm}} = \frac{K_e h_m}{v} \left( \frac{P_e - P_v}{P_v} \right) \]

(\(=\) \(\frac{\text{ft}}{s}\))

Relates them to Volumetric gas flow rate to \( U_{\text{perm}} \)

\[ V \left( \frac{1 \text{ mole}}{\text{hr}} \right) = \frac{U_{\text{perm}} \text{ ft/s} \times \text{Ac} \times \frac{\text{ft}^2}{\text{sec}} \times \frac{P_v \text{ psi}}{P_e \text{ psi}}}{\text{MW vapor} \left( \frac{\text{lbm}}{100 \text{ degree F}} \right)} \]

\[ P_e = \frac{1000 \text{ psi}}{\text{m}^2} \]
\[ P_v = \frac{12 \text{ psi}}{\text{m}^2} \]

\[ \text{Solve } \frac{6000 - 1.2}{1.2} = 28.8501878 \]
\[ \text{Solve } \frac{600 - 1.2}{1.2} = 22.3382079 \]

Keram 0.1 - 0.35  Pts

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