2.9 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_{perm},

$$u_{perm} = K_{drum}\sqrt{\frac{\rho_L - \rho_v}{\rho_v}}$$

(2-64)

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

K_{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

$$K_{drum} = (\text{Const.})\exp[A + B\ln F_{lv} + C(\ln F_{lv})^2 + D(\ln F_{lv})^3 + E(\ln F_{lv})^4]$$

(2-65)

where $F_{lv} = \frac{W_L}{W_v}\sqrt{\frac{\rho_v}{\rho_L}}$ and const = 1.0 ft/s,

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

A = –1.877478097

B = –0.8145804597

C = –0.1870744085

D = –0.0145228667

E = –0.0010148518

The resulting value for K_{drum} typically ranges from 0.1 to 0.35.

Step 2. Using the known vapor rate, V, convert u_{perm} into a horizontal area. The vapor flow rate, V, in lbmol/h is

$$V\left(\frac{\text{lbmol}}{\text{h}}\right) = \frac{u_{perm}\left(\frac{\text{ft}}{\text{s}}\right)\left(\frac{3600\ \text{s}}{\text{h}}\right) A_c\ (\text{ft}^2)\ \rho_v \left(\frac{\text{lbm}}{\text{ft}^3}\right)}{MW_{vapor}\left(\frac{\text{lbm}}{\text{lbmol}}\right)}$$

Solving for the cross-sectional area,

$$A_c = \frac{V(MW_v)}{u_{perm}(3600)\rho_v}$$

(2-66)

For a vertical drum, diameter D is

$$D = \sqrt{\frac{4A_c}{\pi}}$$

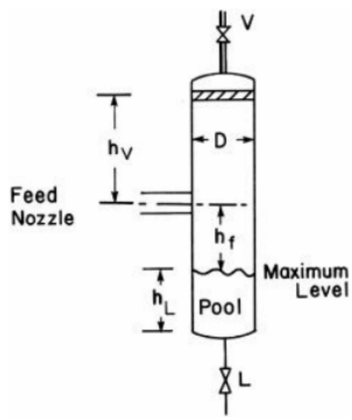
(2-67)

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_{total}/D ranges from 3.0 to 5.0. The appropriate value of h_{total}/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_f, 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_{surge}.

$$h_L = \frac{V_{surge}}{\pi D^2/4}$$

(2-68)

The geometry can now be checked, since

$$\frac{h_{total}}{D} = \frac{h_v + h_f + h_L}{D}$$

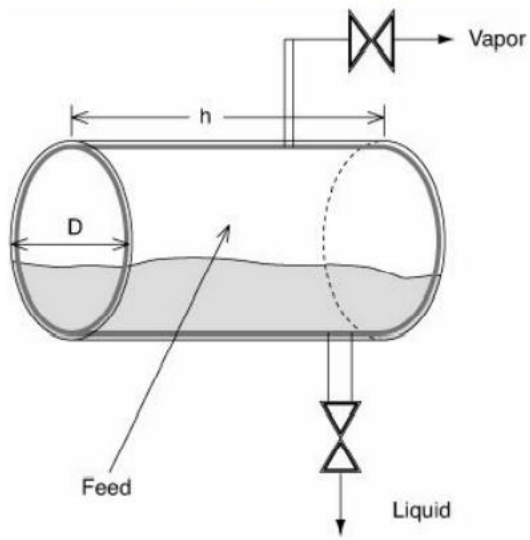
should be between 3 and 5. These procedures are illustrated in Example 2-4. If $h_{total}/D < 3$, a larger liquid surge volume should be allowed. If $h_{total}/D > 5$, a horizontal flash drum should be used.

Horizontal flash drums (Figure 2-15) are used for large flow rates because additional disengagement area is formed by making the column longer and horizontal columns are cheaper than vertical ones.

$$A_T = \frac{V\ MW_v}{u_{perm}\ 3600\ \rho_v}$$

(2-69a)

Figure 2-15. Horizontal flash drum



If we arbitrarily choose h/D = constant C and solve for diameter D, we obtain

$$D = \sqrt{\frac{V\ MW_v}{u_{perm}\ 3600\ \rho_v C}}$$

(2-69b)

If the ideal gas law is valid, the molar density $\hat{\rho}_V$ and the mass density ρv are,

$$\hat{\rho}_V = \frac{n}{V} = \frac{p}{RT} \text{ and } \rho_V = \hat{\rho}_V (MW_V)$$

(2-69c)

Equation (2-69b) becomes

$$D = \sqrt{\frac{VRT}{3600\ Cpu_{perm}}} \text{ for ideal gas}$$

(2-69d)

The value of u is found from Eq. (2-64) with (Blackwell, 1984)

$$K_{horizontal} = 1.25\ K_{vertical}$$

(2-69e)

where $K_{vertical}$ is determined from Eq. (2-65).

The typical range for h/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 lbmol/h that is 40 mol% n-hexane and 60 mol% n-octane at 101.3 kPa (1 atm). We wish to produce a vapor that is 60 mol% n-hexane. Solution of the flash equations with equilibrium data gives $x_H = 0.19$, $T_{drum} = 378K$, 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. (2-64) to (2-68). For this we need to estimate the following physical properties: ρ_L, ρ_v, MW_v. 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 ρ_L by assuming additive volumes. Calculate ρ_v from the ideal gas law. Then calculate u_{perm} from Eq. (2-64) and diameter from Eq. (2-68).

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):

$$\overline{V}_L = x_H \overline{V}_H + x_o \overline{V}_o = x_H \frac{MW_H}{\rho_H} + \frac{x_o MW_o}{\rho_o}$$

From the *Handbook of Chemistry and Physics*, ρ_H = 0.659 g/mL and ρ_O = 0.703 g/mL at 20°C. Thus,

$$\overline{V}_L = (0.19)\frac{86.17}{0.659} + (0.81)\frac{114.22}{0.703} = 156.45 \text{ mL/mol}$$

Then

$$\rho_L = \frac{\overline{MW}_L}{\overline{V}_L} = \frac{108.89}{156.45} = 0.6960 \text{ g/mL}$$

2. Vapor Density

Density in moles per liter for ideal gas is $\hat{\rho}_v = n/V = p/RT$, which in g/L is $\rho_v = p\,\overline{MW}_v/RT$.

The average molecular weight of the vapor is

$$\overline{MW}_v = y_H MW_H + y_O MW_O$$

where $y_H = 0.60$ and $y_O = 0.40$, and thus $\overline{MW}_v = 97.39 \text{ lb/lbmol}$. This gives

$$\rho_v = \frac{(1.0\text{atm})(97.39\text{g/mol})}{(82.0575\ \frac{\text{mL atm}}{\text{mol K}})(378\text{K})} = 3.14 \times 10^{-3} \text{ g/mL}$$

3. K_{drum} Calculation.

Calculation of flow parameter F_{lv}:

$$V = (V/F)(F) = (0.51)(1500) = 765 \text{ lbmol/h}$$
$$W_v = (V)(\overline{MW}_v) = (765)(97.39) = 74{,}503 \text{ lb/h}$$
$$L = F - V = 735 \text{ lbmol/h}$$
$$W_L = (L)(\overline{MW}_L) = (735)(108.89) = 80{,}034 \text{ lb/h}$$
$$F_{1v} = \frac{W_L}{W_v}\sqrt{\frac{\rho_v}{\rho_L}} = \frac{80034}{74503}\sqrt{\frac{3.14 \times 10^{-3}}{0.6960}} = 0.0722$$

K_{drum} from Eq. (2-65) gives $K_{drum} = 0.4433$, which seems a bit high but agrees with Watkins's (1967) chart.

4.

$$u_{perm} = K_{drum}\sqrt{\frac{\rho_L - \rho_v}{\rho_v}}$$
$$= 0.4433\sqrt{\frac{0.6960 - 0.00314}{0.00314}} = 6.5849 \text{ ft/s}$$

5.

$$A_c = \frac{V(\overline{MW}_v)}{u_{perm}(3600)\rho_v}$$
$$= \frac{(765)(97.39)(454 \text{ g/lb})}{(6.5849)(3600)(0.00314 \text{ g/mL})(28316.85 \text{ mL/ft}^3)}$$
$$= 16.047 \text{ ft}^2$$
$$D = \sqrt{\frac{4A_c}{\pi}} = 4.01 \text{ ft}$$

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

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

E. Check. This drum size is reasonable. Minimums for h_v and h_f are easily met. Note that units do work out in all calculations; however, one must be careful with units, particularly calculating A_c and D.

F. Generalization. If the ideal gas law is not valid, a compressibility factor could be inserted in the equation for ρ_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.