H. SILLA, "Chemical Process Engineering – Design and Economics", 2003

close to the side of the vessel as recommended by Patterson [16]. A vortex will occur at a higher liquid level when a tank is draining with no inflow of liquid than when a tank has both equal inflow and outflow. Finally, to minimize the formation of a vortex at low liquid levels, a vortex breaker is installed at a vessel outlet. Vortex breakers may be flat plates, crosses, radial vanes or gratings. Although Patterson [16] gives dimensions for a flat-plate design he recommends radial vanes, as shown in Figure 6.4, or a grating. Another design, recommended by Frank [75], is four vanes at right angles with a flat circular plate welded at the top.

ACCUMULATORS

Accumulators are not separators. In one application, an accumulator placed after a total condenser provides reflux to a fractionator and prevents column fluctuations in flow rate from affecting downstream equipment. In this application the accumulator is called a reflux drum. A reflux drum is shown in Figure 6.3. Liquid from a condenser accumulates in the drum before being split into reflux and product streams. At the top of the drum is a vent to exhaust noncondensable gases that may enter the distillation column. The liquid flows out of the drum into a pump. To prevent gases from entering the pump, the drum is designed with a vortex breaker at the exit line.

The total volume of an accumulator is calculated using a residence time, also called surge time, which is obtained from experience, according to the type and degree of the process control required. After examining 18 accumulators in service, Younger [11] recommended a residence time of 5 to 10 min. Once a residence time is selected, size the accumulator for half-full operation to accommodate either an increase or decrease in liquid level. Thus, the accumulator volume is calculated from Equation 6.5.1 in Table 6.5, where equations for sizing an accumulator are listed. The volumetric liquid flow rate, V_L, is obtained from a mass balance on the system. After calculating the total accumulator volume, calculate the accumulator diameter and length by solving Equations 6.5.3 and 6.5.4. Equation 6.5.4 is a rule-of-thumb for L/D. According to Younger [11], for an L/D ratio of 2.5 to 6 the cost varies by only 2%. After surveying several accumulators in use, Younger [11] found that fifteen were horizontally placed and three were vertically placed.

Table 6.6 outlines a calculation procedure for sizing an accumulator. According to Gerunda [4], the calculated diameter for a vessel is rounded off in six-inch increments, starting with a 30 in (0.762 m) diameter vessel. Six-inch increments are required to match standard-diameter heads for the ends of a vessel (Aerstin, 6.5). The maximum vessel diameter is limited to about 13.5 ft (4.11 m), because of shipping limitations by rail or truck. If a larger diameter than 13.5 ft (4.11 m) is required, then the process engineer must consider either specifying two or more vessels in parallel or fabricating a larger diameter vessel at the construction site. If a vessel is less than 30 in (0.762 m) in diameter, use standard pipe. After calculating the vessel length, round it off in three-inch increments.

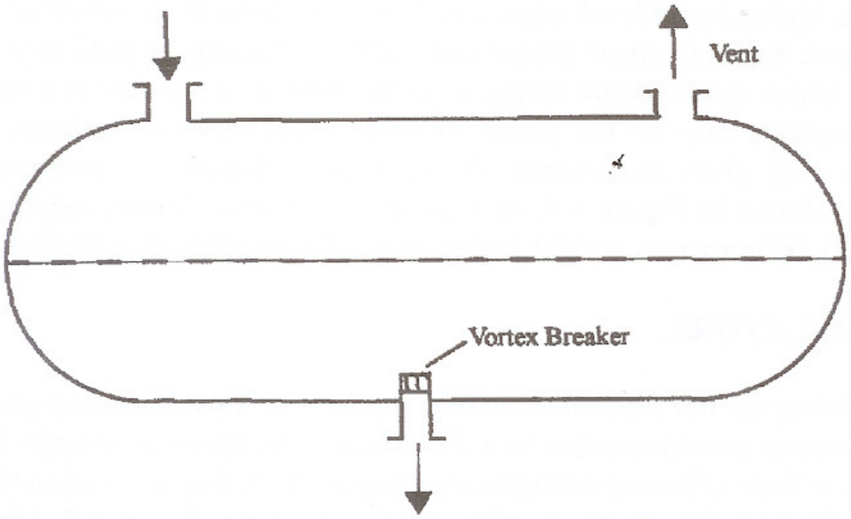

Figure 6.3 An accumulator.

Table 6.5 Summary of Equations for Sizing Accumulators

Subscripts: L = liquid –– HV = vessel head

$$V = 2\, V_L'\, t_S \qquad (6.5.1)$$

$$t_S = 5 \text{ to } 10 \text{ min} \qquad (6.5.2)$$

$$V = \frac{\pi \cdot D^2 L}{4} + 2\, f_{HV}\, D^3 \qquad (6.5.3)$$

$$L/D = 2.5 \text{ to } 6 \qquad (6.5.4)$$

$f_{HV} = 0.1309$ –– for a 2:1 ellipsoidal head, or (6.5.5)
$f_{HV} = 0.0778$ –– for a torispherical head

Unknowns
t_S, D, L, P, V, f_{HV}

Table 6.6 Calculation Procedure for Sizing Accumulators

1. Select a residence or surge time, t_S, from Equation 6.5.2.

2. Calculate the accumulator volume, V, from Equation 6.5.1

3. Select a vessel head. If the internal pressure is 150 psig (10.3 barg) or less, select a torispherical head. If the internal pressure is above 150 psig (10.3 barg), select a 2:1 ellipsoidal head.

4. Select the geometrical factor for the volume of the head, f_{HV}, from Equation 6.5.5.

5. Substitute Equation 6.5.4 into Equation 6.5.3 and solve for the vessel diameter, D.

6. Round off D in 6 in (.152 m) increments, starting with 30 in (0.762 m). If the diameter is less than 30 in (0.762 m), use standard pipe.

7. Calculate the length, L, of the accumulator using Equation 6.5.4.

8. Round off L in 3 in (7.62 cm) increments, for example, 5.0, 5.25, 5.5, 5.75 ft, etc.

Example 6.1 Sizing a Reflux Drum

A fractionator separates dimethylformamide from water and acetic acid. The distillate contains a trace amount of acetic acid. Assuming that the fractionator uses a total condenser, estimate the diameter, length, and wall thickness of the reflux drum. Because the mixture contains acetic acid, use stainless steel (SS 316) for the drum.

Data

Distillate flow rate	16,000 lb/h (7,260 kg/h}
Acetic acid	20 ppm
Temperature	212 °F (100 °C)
Pressure	14.7 psia (11.013 bar)
Density	62.38 lb/ft^3 (9993 kg/m^3}

Follow the calculation procedure outlined in Table 6.6. First, calculate the reflux-drum volume from Equations 6.5.1 and 6.5.2 in Table 6.5. From Equation 6.5.2, take the average of the surge times.

$$V = 2\ \frac{16000\ \text{lb}}{1\ \text{h}}\ \frac{7.5\ \text{min}}{1}\ \frac{1\ \ \text{ft}^3}{62.38\ \text{lb}}\ \frac{1\ \ \text{h}}{60\ \text{min}} = 64.12\ \text{ft}^3\ \ (1.816\ \text{m}^3)$$

From Equation 6.5.4, select an average L/D ratio.

$$L/D = 4.25$$

Substitute this ratio into Equation 6.5.3, and solve for D^3 to obtain

$$D^3 = \frac{V}{1.063\ \pi + 2\ f_{HV}}$$

Calculate the design pressure from Equation 6.3.1. Because the pressure is atmospheric, the gage pressure $P_o = 0$, and therefore the design pressure is 25 psig (1.72 barg) According to step 3 in Table 6.6, select a torispherical head because the design pressure is less than 150 psig (10.3 barg). Thus, from Equation 6.5.5, $f_{HV} = 0.0778$. From the above equation for D^3, we obtain.

$$D^3 = \frac{64.12}{1.063\ (3.142) + 2\ (0.0778)} = 18.34\ \text{ft}^3\ (0.5194\ \text{m}^3)$$

$$D = 2.637\ \text{ft}\ (\ 31.64\ \text{in},\ 0.803\ \text{m})$$

Because the drum diameter is greater than 30 in (0.762 m) but less than 36 in (0.914 m), round off D to the highest 6 in increment, which is 36 in (0.914 m). From Equation 6.5.4, L = 4.25 (3.0) = 12.75 ft (3.89 m). This length requires no rounding.

Now, calculate the head thickness following the procedure outlined in Table 6.4. From Table 6.1, with no X-ray inspection, the weld efficiency for the weld joining the head to the shell is 0.80. Because of the acetic acid present in the distillate, we select SS 316, which has an allowable stress of 15,200 psi ($1.04\text{x}10^5$ kPa). For the moment, neglect the corrosion allowance. From Equations 6.3.1 and 6.3.3 for a torispherical head, the head thickness

$$t_H = \frac{1.104\ \ (25)\ (36)}{2\ (0.80)\ (15200) - 0.2\ (25)} = 0.04086\ \text{in}\ (1.04\ \text{mm})$$

Next, calculate the shell thickness from Equations 6.3.2 and 6.3.4. From Table 6.1, with no x-ray inspection of the longtudinal weld, $\varepsilon = 0.7$. Again, if we neglect the corrosion allowance,

$$t_S = \frac{25\,(36)}{2\,(0.7)\,(15200) - 1.2\,(25)} = 0.04235 \text{ in } (1.08 \text{ mm})$$

Thus, the shell wall thickness is essentially the same as the head thickness. According to Table 6.2, the minimum wall thickness is 3/32 in (2.38 mm) for high-alloy steels. The application of this rule-of-thumb more than doubles the wall thickness, which should be an adequate corrosion allowance. The selection of a corrosion allowance in the final design must be based on past experience or from laboratory and pilot plant tests.

PHASE SEPARATORS

Gas-Liquid Separators

As stated by Holmes and Chen [12], the reasons for using gas-liquid or vapor-liquid separators are to recover valuable products, improve product purity, reduce emissions, and protect downstream equipment. Gas-liquid separators are used after flashing a hot liquid across a valve. In this case the separator is called a flash drum.

A vertical gas-liquid separator is shown in Figure 6.4. The gas-liquid mixture is separated by gravity and impaction. The mixture enters the separator about midway where a splash plate deflects the stream downward. Most of the liquid flows downward, and the vapor, containing liquid drops, flow upward. As the vapor rises, large drops settle to the bottom of the separator by gravity. According to Watkins [14], 95 % separation of liquid from vapor is normal. If greater than 95 % liquid separation is required, then use a wire-mesh mist eliminator, installed near the vapor outlet. Very small drops are separated by impaction using a wire-mesh pad located at the top of the separator. The mesh usually consists of 0.011 in (0.279 mm) diameter wires interlocked by a knitting machine to form a pad from 4 to 6 in (0.102 to 0.152 m) thick [12]. Entrained liquid drops in the vapor impact on the wires and coalesce until the drops become heavy enough to break away from the wire and fall to the bottom of the separator. Because of the large free volume of the pad – 97 to 99 % – the pressure drop across the pad is usually less than 1.0 in of water [13]. The separation efficiency of a pad is about 99.9% or greater.

The major objective in sizing a gas-liquid separator is to lower the gas velocity sufficiently to reduce the number of liquid droplets from being entrained in the gas. Thus, the separator diameter must be determined. The separator is also designed as an accumulator for the liquid portion of the stream. Thus, the liquid