It is often necessary to separate two immiscible liquids, the light and heavy phases, and a vapor.

A typical example in petroleum refining is the separation of water, and a hydro-carbon liquid and vapor.

As with two-phase designs, three-phase units can be either vertical or horizontal, although they typically are horizontal.

The vertical orientation is only used if there is a large amount of vapor to be separated from a small amount of the light and heavy liquid (<10-20% by weight).

Unfortunately, there are no simple rules for separator selection.

The design of three-phase separators is similar to their two-phase counter-parts, except that the liquid section differs.

For the vertical type, a baffle commonly keeps the liquid separation section calm to promote the separation.

There are different variations of horizontal three-phase vapor-liquid separators.

The liquid separation section is usually a variation of a device to provide interface level control, which may include a boot or a weir.
A boot typically is specified when the volume of heavy liquid is not substantial (< 15-20% of total liquid by weight), while a weir is used when the volume is substantial.

These horizontal separators are illustrated in Figure 2.

The bucket-and-weir type design is used when interface level control may be difficult, such as with heavy oils or when large amounts of an emulsion or a paraffin are present.
Interface control with weir
**Basic Designs of Horizontal Three-Phase Separators**

**Interface control with boot**

- Feed inlet
- Vapor outlet
- Min. 12 in.
- Min. 12 in.
- Light liquid holdup/surge
- Interface
- Heavy liquid
- Heavy liquid outlet

**Basic Designs of Horizontal Three-Phase Separators**

**Bucket and weir**

- Feed inlet
- Vapor outlet
- Light liquid
- Heavy liquid
- Light liquid outlet
- Heavy liquid outlet

Note: \( N = \frac{1}{2} d_N + 6 \text{ in.} \)

\( d_N = \text{Nozzle dia.} \)
The flow of rising light droplets in the heavy liquid phase or settling heavy droplets in the light liquid phase is considered laminar and is governed by Stokes’ law:

$$U_T = \frac{1488 \mu D_p^2 (\rho_H - \rho_L)}{18 \mu}$$  \hspace{1cm} (1)

where 1488 converts viscosity of the continuous phase from lb/(ft)(s) to cP.

Simplifying Eq. 1 and converting the units of the terminal settling velocity to in./min from ft/s results in:

$$U_T = \frac{2.06151 \times 10^{-5} D_p^2 (\rho_H - \rho_L)}{\mu}$$  \hspace{1cm} (2)

$D_p$ is in microns (1 micron = 3.28084 x 10^{-6} feet)
$U_T$ in./min.
Eq. 2 may be rewritten as:

\[ U_r = \frac{k_S (\rho_H - \rho_L)}{\mu} \]  

where \( k_S = 2.06151 \times 10^{-5} D_p^2 \)

Values of \( k_S \) are given for some systems in Table 1.

---

**Table 1**  
**Typical values of \( k_S \) for liquid-liquid separations.**

<table>
<thead>
<tr>
<th>Light Phase</th>
<th>Heavy Phase</th>
<th>Minimum droplet dia., ( \mu m )</th>
<th>( k_S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbons</td>
<td>Water or caustic</td>
<td>127</td>
<td>0.333</td>
</tr>
<tr>
<td>( S_G ) at 60°F &lt; 0.85</td>
<td>Water or caustic</td>
<td>89</td>
<td>0.163</td>
</tr>
<tr>
<td>Water</td>
<td>Furfural</td>
<td>89</td>
<td>0.163</td>
</tr>
<tr>
<td>Methylene ketone</td>
<td>Water</td>
<td>89</td>
<td>0.163</td>
</tr>
<tr>
<td>sec-Butyl alcohol</td>
<td>Water</td>
<td>89</td>
<td>0.163</td>
</tr>
<tr>
<td>Methyl isobutyl ketone</td>
<td>Water</td>
<td>89</td>
<td>0.163</td>
</tr>
<tr>
<td>Nonyl alcohol</td>
<td>Water</td>
<td>89</td>
<td>0.163</td>
</tr>
</tbody>
</table>
From Eqs. 1-3, it can be seen that the settling velocity of a droplet is inversely proportional to the viscosity of the continuous phase. Hence, it is more difficult (requires more time) to settle the droplets out of the continuous phase with the greater viscosity, since $U_T$ is lower.

Practically speaking, $U_T$ is typically limited in calculations to 10 in./min maximum.

For vertical separators, the diameter required for vapor disengagement is calculated as previous.

In sizing a separator, the heights of the light and heavy liquids are assumed, and the settling velocities and settling times are then calculated.

The residence times of the light and heavy liquids are determined next.

For the liquids to separate, the residence time of the light liquid must be greater than the time required for the heavy droplets to settle out of the light liquid phase.

The residence time of the heavy liquid must be greater than the time required for the light liquid droplets to rise out of the heavy liquid phase.

If these conditions are not satisfied, then liquid separation is controlling and the vessel diameter must be increased.
Holdup time for liquids must be added to residence time.

The height of the vertical three-phase separator is calculated in the same manner as for the two-phase case.

For horizontal separators with a given diameter, the heights of the light and heavy liquids are assumed so that the cross-sectional area can be calculated.

With the vapor disengagement area set by guidelines, the lengths required by holdup requirements and vapor/liquid separation are calculated.

Then, with the assumed heights of the light and heavy liquids and calculated values of settling velocities, the settling times are calculated.

The actual residence times for the light and heavy liquids are subsequently calculated and compared with the required settling time, as in the vertical case.

If the residence times are not greater than the required settling times, then either the diameter should be increased or, for a given diameter, the length should be increased (liquid separation is controlling).

In the subsequent design procedures, the latter approach is used, along with the procedures discussed in our previous paper for vapor/liquid separation.
Design Procedure
THREE-PHASE SEPARATORS

VERTICAL SEPARATORS
For a three-phase vertical separator, the total height can be broken into different sections, as shown in Figure 1.

The separator height is then calculated by adding the heights of these sections.

If a mist eliminator pad is used, additional height is added.

The calculations of diameter and height are detailed as follow:

1- Calculate the vertical terminal velocity:

$$U_T = K \left( \frac{\rho_H - \rho_L}{\mu} \right)^{0.5}$$  \hspace{1cm} (4)

set $V_V = 0.75 \, V_t$ for a conservative design.

2- Calculate the vapor volumetric flow rate:

$$Q_V = \frac{W_V}{3600 \rho_V}$$  \hspace{1cm} (5)
3- Calculate the vessel internal diameter, \( D_v \):

\[
D_{VD} = \left( \frac{4Q_v}{\pi U_v} \right)^{0.5} \quad (6)
\]

If there is a mist eliminator, add 3-6 in. to \( D_{VD} \) to accommodate a support ring and round up to the next 6-in. increment to obtain \( D \); if there is no mist eliminator, \( D = D_{VD} \).

4- Calculate the setting velocity of the heavy liquid out of the light liquid using Stokes’ law (the maximum is 10 in./min):

\[
U_{HL} = \frac{k_s (\rho_H - \rho_L)}{\mu_L} \quad (7)
\]

where \( k_s \) is obtained from Table 1 or is calculated (see Eq. 3).

5- Similarly, calculate the rising velocity of the light liquid out of the heavy liquid phase using Stokes' law:

\[
U_{LH} = \frac{k_s (\rho_H - \rho_L)}{\mu_H} \quad (8)
\]

6- Calculate the light and heavy liquid volumetric flow rates, \( Q_{LL} \) and \( Q_{HL} \):

\[
Q_{LL} = \frac{W_{LL}}{60\rho_L} \quad (9)
\]

\[
Q_{HL} = \frac{W_{HL}}{60\rho_H} \quad (10)
\]
**DESIGN PROCEDURE**

7- Assume $H_L = 1$ ft (minimum) and calculate the settling time for the heavy liquid droplets to settle through this distance (12 is a conversion factor for ft to in.):

$$t_{\text{HL}} = \frac{12H_L}{U_{\text{HL}}} \quad (11)$$

8- Assume $H_H = 1$ ft (minimum) and calculate the settling time for the light liquid droplets to rise through this distance:

$$t_{\text{LH}} = \frac{12H_H}{U_{\text{LH}}} \quad (12)$$

**DESIGN PROCEDURE**

9- If there is a baffle Plate, calculate the area:

a. Calculate $(\rho_L - \rho_V)$.

b. Assume $H_R$ (use 9 in. as a minimum) and calculate $H_L + H_R$.

c. Use Figure 3 to obtain $G$. 
d. Calculate $A_D$:

$$A_D = \left(\frac{7.48\text{gal}}{\text{ft}^3}\right)\left(\frac{60\text{ min}}{\text{h}}\right)\left(\frac{Q_{LL} - Q_{HL}}{G}\right) \quad (13)$$

e. Assume $W_D = 4$ in.


---

**Figure 3.** $G$ is found from the downcomer allowable flow.
g. Use Table 3 to determine \( A_D / A \).

h. Calculate \( A = (\pi/4)D^2 \).

i. Calculate \( A_D \).

j. Select the larger value of \( A_D \).

k. Calculate the area of the baffle plate settling area for the light liquid; \( A_L = A - A_D \)

\[ y = a + bx + cx^2 + gx^3 + hx^4 + ix^5 \]

\[ 1.0 + bx + dx^2 + fx^3 + hx^4 \]

<table>
<thead>
<tr>
<th>HID to ( AA_L )</th>
<th>( y = AA_L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a = 4.755920 \times 10^7 )</td>
<td>( x = HID )</td>
</tr>
<tr>
<td>( c = 0.174875 )</td>
<td>( d = -6.355805 )</td>
</tr>
<tr>
<td>( e = 5.666873 )</td>
<td>( f = 4.018448 )</td>
</tr>
<tr>
<td>( g = -4.916411 )</td>
<td>( h = -1.801705 )</td>
</tr>
<tr>
<td>( i = -0.405348 )</td>
<td>( J = 0.00133756 )</td>
</tr>
<tr>
<td>( b = 26.787101 )</td>
<td>( c = 3.329231 )</td>
</tr>
<tr>
<td>( d = -22.923932 )</td>
<td>( e = 24.335318 )</td>
</tr>
<tr>
<td>( f = -14.844824 )</td>
<td>( g = -36.999176 )</td>
</tr>
<tr>
<td>( h = 10.529572 )</td>
<td>( i = 9.892851 )</td>
</tr>
</tbody>
</table>

\[ A/A_L \text{ to } HID^\rho \]

10- Calculate the residence time of each phase based on the volumes occupied by the light and heavy phases

\[ \theta_{LL} = \frac{H_L A_L}{Q_{LL}} \] (14a)

\[ \theta_{HL} = \frac{H_H A_H}{Q_{HL}} \] (14b)

If \( \theta_{LL} < t_{HL} \) or \( \theta_{LL} < t_{LH} \) increase the diameter and repeat the procedure from Step 7 (liquid separation is controlling).

Note that \( A_h = A \).
11- Calculate the height of the light liquid above the outlet (holdup height) based on required holdup time:

\[ H_R = \frac{Q_{LL} T_H}{A_L} \]  \hspace{1cm} (15)

Check this value with the value assumed in Step 9b to ensure that the assumed value is reasonable.

If surge is not specified, calculate the surge height based on surge time:

\[ H_S = \frac{(Q_{LL} + Q_{HL}) T_S}{A} \]  \hspace{1cm} (16)

The minimum is 6 in.

12- Calculate the vessel height using the guidelines:

\[ H_A = 6 \text{ in. minimum.} \]

\[ H_{BN} = \frac{1}{2} d_N + \text{greater of (2 ft or } H_S + 0.5 \text{ ft)} \]

\[ H_D = 0.5D \text{ or a minimum of:} \]

36 in. + \( \frac{1}{2} d_N \) (without mist eliminator), or

24 in. + \( \frac{1}{2} d_N \) (with mist eliminator):

\[ H_T = H_R + H_L + H_T + H_A + H_{BN} + H_D \]  \hspace{1cm} (17)

If a mist eliminator pad is used, additional height is added as shown in Figure 1.
**HORIZONTAL SEPARATORS**

**design procedure:**

**no boot or weir**

---

**HORIZONTAL DESIGN PROCEDURE: NO BOOT OR WEIR**

1. Calculate the vapor volumetric flow rate, \( Q_v \), using Eq. 5.

   \[
   Q_v = \frac{W_v}{3600\rho_v}
   \]  
   
   (5)

2. Calculate the light and heavy liquid volumetric flow rates, \( Q_{LL} \) and \( Q_{HL} \), using Eqs. 9 and 10.

   \[
   Q_{LL} = \frac{W_{LL}}{60\rho_L}
   \]  
   
   (9)

   \[
   Q_{HL} = \frac{W_{HL}}{60\rho_H}
   \]  
   
   (10)
**HORIZONTAL DESIGN PROCEDURE: NO BOOT OR WEIR**

3- Calculate the vertical terminal velocity, $U_T$, using Eq. 4. (select a $K$ value from Table 2) and set $U_V = 0.75 U_T$.

$$U_T = K \left( \frac{\rho_H - \rho_L}{\mu} \right)^{0.5}$$  \hspace{1cm} (4)

4- Select holdup and surge times from Table 6 and calculate the holdup and surge volumes, $V_H$ and $V_S$, (unless surge is otherwise specified, such as a slug volume):

$$V_H = T_H Q_L$$  \hspace{1cm} (18)

$$V_S = T_S Q_L$$  \hspace{1cm} (19)

**HORIZONTAL DESIGN PROCEDURE: HEAVY LIQUID BOOT**

5- Obtain an L/D from Table 7 and initially calculate the diameter according to:

$$D = \left( \frac{4(V_H + V_S)}{\pi (0.5)(L/D)} \right)^{1/3}$$  \hspace{1cm} (20)

Calculate the total cross-sectional area

$$A_T = \frac{\pi}{4} D^2$$  \hspace{1cm} (21)

**Table 7: L/D ratio guidelines**

<table>
<thead>
<tr>
<th>Vessel operating pressure, psig</th>
<th>L/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 &lt; P \leq 250$</td>
<td>1.5–3.0</td>
</tr>
<tr>
<td>$250 &lt; P &lt; 500$</td>
<td>3.0–4.0</td>
</tr>
<tr>
<td>$500 &lt; P$</td>
<td>4.0–6.0</td>
</tr>
</tbody>
</table>
**Horizontal Design Procedure: Heavy Liquid Boot**

6- Set the vapor space height, $H_V$, to the larger of 0.2D or 2 ft; 1 ft if there is no mist eliminator. Using $H_V/D$ in Table 3, obtain $A_V/A_T$, and calculate $A_V$.

7- Set the heights of the heavy and light liquids, $H_{HL}$ and $H_{LL}$.

8- Find $(A_{HL} + A_{LL})/A_T$ using $(H_{HL} + H_{LL})/D$ in Table 3, and calculate $A_{HL} + A_{LL}$.

9- Calculate the minimum length to accommodate the liquid holdup/surge:

$$L = \frac{V_H + V_S}{A_T - A_V - (A_{HL} - A_{LL})}$$  \hspace{1cm} (22)

---

**Horizontal Design Procedure: Heavy Liquid Boot**

10- Calculate the liquid dropout time,

$$\phi = H_V/U_V$$  \hspace{1cm} (23)

11- Calculate the actual vapor velocity:

$$U_{VA} = Q_V/A_V$$  \hspace{1cm} (24)

12- Calculate the minimum length required for vapor-liquid disengagement, $L_{MIN}$:

$$L_{MIN} = U_{VA} \phi$$  \hspace{1cm} (25)
13- If $L < L_{MIN}$, then set $L = L_{MIN}$ (Vapor/liquid separation controls). This simply results in some extra holdup. This simply results in some extra holdup and residence time.

If $L << L_{MIN}$, then increase $H_V$ and recalculate $A_V$, and repeat from the step 9.

If $L > L_{MIN}$, the design is acceptable for vapor/liquid separation.

If $L >> L_{MIN}$ (Liquid holdup controls), $L$ can only be reduced and $L_{MIN}$ increased if $H_V$ is reduced.

$H_V$ may only be reduced if it is greater than the minimum specified in the step 6.

---

(With reduced $H_V$ recalculate $A_V$, and repeat the procedure from step 9).

**Note:** For this and other calculations, "much greater than" (>>) and "much less than" (<<) mean a variance of greater than 20%.

14- Calculate the settling velocities of the heavy liquid out of the light liquid phase and the light liquid out of the heavy liquid phase, $U_{HL}$ and $U_{LH}$, using Eqs. 7 and 8 (find $k_S$, from Table 1).

$$U_{HL} = \frac{k_S (\rho_H - \rho_L)}{\mu_L}$$  \hspace{1cm} (7)

$$U_{LH} = \frac{k_S (\rho_H - \rho_L)}{\mu_H}$$  \hspace{1cm} (8)
15- Calculate the settling times of the heavy liquid out of the light phase and the light liquid out of the heavy phase

\[
t_{\text{HL}} = 12\left(D - H_v - H_{\text{HL}}\right)/U_{\text{HL}}
\]

(26)

\[
t_{\text{LH}} = 12H_{\text{HL}}/U_{\text{LH}}
\]

(27)

16- Calculate the residence times of the light and heavy liquids:

\[
\theta_{\text{HL}} = A_{\text{HL}}L / Q_{\text{HL}}
\]

(28)

\[
\theta_{\text{LL}} = \frac{(A_T - A_v - A_{\text{HL}})L}{Q_{\text{LL}}}
\]

(29)

17- If \( \theta_{\text{HL}} < t_{\text{LH}} \) or \( \theta_{\text{LL}} < t_{\text{HL}} \) then increase the vessel length (liquid separation controls):

\[
L = \max \left( \frac{t_{\text{LH}}Q_{\text{HL}}}{A_{\text{HL}}}, \frac{t_{\text{HL}}Q_{\text{LL}}}{(A_T - A_v - A_{\text{HL}})} \right)
\]

(30)

18- Calculate L/D.

- If L/D << 1.5, decrease D (unless it is already at its minimum)
- If L/D >> 6.0 then increase D; repeat from Step 5.

19- Calculate the thickness of the shell and heads according to Table 8.
Table 8: Wall thickness, surface area, and approximate vessel weight

<table>
<thead>
<tr>
<th>Component</th>
<th>Wall Thickness, in.</th>
<th>Surface Area, ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>( \frac{PD}{2SE - 1.2P + t_c} )</td>
<td>( \pi DL )</td>
</tr>
<tr>
<td>2:1 Elliptical Heads</td>
<td>( \frac{PD}{2SE - 0.2P + t_c} )</td>
<td>1.09 ( D² )</td>
</tr>
<tr>
<td>Hemispherical Heads</td>
<td>( \frac{PD}{4SE - 0.4P + t_c} )</td>
<td>1.571 ( D² )</td>
</tr>
<tr>
<td>Dished Heads</td>
<td>( \frac{0.885PD}{SE - 0.1P + t_c} )</td>
<td>0.842 ( D² )</td>
</tr>
</tbody>
</table>

Approximate Vessel Weight:

\[ W = \left( \frac{490 \text{ lb}}{1 \text{ in.}} \right) \left( \frac{t}{12} \right) \left( A_{\text{Shell}} + 2A_{\text{Head}} \right) \]

Notes: The design pressure, \( P \), is typically either the operating pressure with 15 to 30 psi added to it or the operating pressure + 10%, whichever is greater. For the allowable stress, \( S \), see Reference (3). The joint efficiency, \( E \), ranges from 0.6 to 1, use 0.85 for spot-examined joints, and 1 for 100% X-rayed joints. The corrosion allowance, \( t_c \), typically ranges from \( \frac{1}{32} \) in. to \( \frac{1}{8} \) in. The vessel thickness, \( t \), is the larger of \( t_e \) and \( t_c \) up to the nearest \( \frac{1}{32} \) in.

**HORIZONTAL DESIGN PROCEDURE: NO BOOT OR WEIR**

20- Calculate surface area of the shell and heads according to Table 8.

21- Calculate the approximate vessel weight according to Table 8.

22- Increase or decrease the vessel diameter by 6-in. increments and repeat the calculations until the L/D ratio ranges from 1.5-6.0.

23- Using the optimum vessel size (minimum weight), calculate the normal and high liquid levels:

\[ H_{\text{NLL}} = D - H_V \]  \( (31) \)

\[ A_{\text{NLL}} = (A_{\text{HL}} + A_{\text{LL}}) + \frac{V_{\text{H}}}{L} \]  \( (32) \)

Obtain \( H_{\text{NLL}} \) using Table 3 with the value of \( A_{\text{NLL}}/A_t \).
HORIZONTAL SEPARATORS

**design procedure:**

**HEAVY LIQUID BOOT**

---

**HORIZONTAL DESIGN PROCEDURE: HEAVY LIQUID BOOT**

1- Calculate the vapor volumetric flow rate, \( Q_v \), using Eq. 5.

\[
Q_v = \frac{W_v}{3600 \rho_v}
\]  

(5)

2- Calculate the light and heavy liquid volumetric flow rates, \( Q_{LL} \) and \( Q_{HL} \), using Eqs. 9 and 10.

\[
Q_{LL} = \frac{W_{LL}}{60 \rho_L}
\]  

(9)

\[
Q_{HL} = \frac{W_{HL}}{60 \rho_H}
\]  

(10)
11/26/2013

**HORIZONTAL DESIGN PROCEDURE: NO BOOT OR WEIR**

3- Calculate the vertical terminal velocity, $U_T$, using Eq. 4. (select a $K$ value from Table 2) and set $U_v = 0.75 U_T$.

$$U_T = K \left( \frac{\rho_H - \rho_L}{\mu} \right)^{0.5} \quad (4)$$

4- Select holdup and surge times from Table 6 and calculate the holdup and surge volumes, $V_H$ and $V_S$, (unless surge is otherwise specified, such as a slug volume):

$$V_H = T_H Q_L \quad (18)$$

$$V_S = T_S Q_L \quad (19)$$

**HORIZONTAL DESIGN PROCEDURE: HEAVY LIQUID BOOT**

5- Obtain an L/D from Table 7 and initially calculate the diameter according to:

$$D = \left( \frac{4(V_H + V_S)}{\pi (0.5)(L / D)} \right)^{1/3} \quad (20)$$

Calculate the total cross-sectional area, $A_T$, using eq. 21.

$$A_T = \frac{\pi}{4} D^2 \quad (21)$$

**Table 7: L/D ratio guidelines**

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6- Set the vapor space height, $H_v$, to the larger of 0.2D or 2 ft; 1 ft if there is no mist eliminator. Using $H_v/D$ in Table 3, obtain $A_v/A_r$, and calculate $A_v$.

7- Set the light liquid heights in the vessel and boot, $H_{LLV}$ and $H_{LLB}$

8- Calculate the cross-sectional area of the light liquid above the bottom of the vessel, $A_{LLV}$, using $H_{LLV}/D$ in Table 3.

9- Calculate the minimum length to accommodate the liquid holdup/surge:

$$L = \frac{V_{II} + V_S}{A_r - A_v - A_{LLV}} \quad (22)$$

10- Calculate the liquid dropout time, $\phi$, using eq. 23.

$$\phi = H_v/U_v \quad (23)$$

11- Calculate the actual vapor velocity, $U_{VA}$, using eq. 24.

$$U_{VA} = Q_v/A_v \quad (24)$$

12- Calculate the minimum length required for vapor-liquid disengagement, $L_{MIN}$, using eq. 25.

$$L_{MIN} = U_{VA} \phi \quad (25)$$
# Horizontal Design Procedure: Heavy Liquid Boot

## 13- If \( L < L_{MIN} \), then set \( L = L_{MIN} \) (Vapor/liquid separation controls).

This simply results in some extra holdup. This simply results in some extra holdup and residence time.

If \( L \ll L_{MIN} \), then increase \( H_v \) and recalculate \( A_v \), and repeat from the step 9.

If \( L > L_{MIN} \), the design is acceptable for vapor/liquid separation.

If \( L \gg L_{MIN} \), liquid holdup controls. \( L \) can only be reduced and \( L_{MIN} \) increased if \( H_v \) is reduced.

\( H_v \) may only be reduced if it is greater than the minimum specified in the step 6.

With reduced \( H_v \), recalculate \( A_v \), and repeat the procedure from step 9.

---

## 14- Calculate the settling velocities of the heavy liquid out of the light liquid phase, \( U_{HL} \), using eq. 7 (obtain \( k_s \) from Table 1).

\[
U_{HL} = \frac{k_s (\rho_H - \rho_L)}{\mu_L}
\]  \( (7) \)

15- Calculate the settling time of the heavy liquid out of the light liquid phase:

\[
t_{HL} = \frac{12(H_{LLB} + D - H_v)}{U_{HL}}
\]  \( (35) \)
16- Calculate the residence times of the light and heavy liquids

\[ \theta_{LL} = \frac{(A_T - A_V)L}{Q_{LL}} \]  

(36)

Note: This volume of light liquid ignores the light liquid volume in the boot.

17- If \( \theta_{LL} < t_{HL} \), then increase the vessel length (liquid separation controls):

\[ L = \frac{t_{HL} Q_{LL}}{(A_T - A_V)} \]  

(37)

18- Calculate L/D.

If \( L/D << 1.5 \), decrease D (unless it is already at its minimum) 
if \( L/D >> 6.0 \) then increase D; repeat from Step 5.

19- Calculate the thickness of the shell and heads according to Table 8.

20- Calculate surface area of the shell and heads according to Table 8.

21- Calculate the surface area of the shell and heads according to Table 8.

22- Increase or decrease the vessel diameter by 6-in. increments 
and repeat the calculations until the L/D ratio ranges from 1.5-6.0.
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<tr>
<td>Shell</td>
<td>( \frac{PD}{2SE - 1.2P + t_c} )</td>
<td>( \pi DL )</td>
</tr>
<tr>
<td>2:1 Elliptical Heads</td>
<td>( \frac{PD}{2SE - 0.2P + t_c} )</td>
<td>1.08 ( D^2 )</td>
</tr>
<tr>
<td>Hemispherical Heads</td>
<td>( \frac{PD}{4SE - 0.4P + t_c} )</td>
<td>1.571 ( D^2 )</td>
</tr>
<tr>
<td>Dished Heads</td>
<td>( \frac{0.885PD}{SE - 0.1P + t_c} )</td>
<td>0.842 ( D^2 )</td>
</tr>
</tbody>
</table>

Approximate Vessel Weight

\[
W = \left( \frac{490 \text{ lb}}{R^2} \right) \left( \frac{1}{12} \right) (A_{\text{max}} + 2A_{\text{min}})
\]

Notes: The design pressure, \( P \), is typically either the operating pressure with 15 to 30 psi added to it or the operating pressure + 10%, whichever is greater. For the allowable stress, \( S \), see Reference (3). The joint efficiency, \( E \), ranges from 0.6 to 1; use 0.85 for spot-examined joints, and 1 for 100% X-rayed joints. The corrosion allowance, \( t_c \), typically ranges from \( \frac{1}{32} \) to \( \frac{1}{16} \) in. The vessel thickness, \( t \), is the larger of \( t_d \) and \( t_n \) up to the nearest \( \frac{1}{64} \) in.

**Horizontal Design Procedure: Heavy Liquid Boot**

23- with the optimum vessel size (minimum weight), calculate the normal and high liquid levels:

\[
H_{\text{HLL}} = D - H_V
\]

\[
A_{\text{NLL}} = A_{\text{LLV}} + \frac{V_H}{L}
\]

Determine \( H_{\text{NLL}} \) using Table 3 with the value of \( A_{\text{NLL}}/A_V \).

24- Design the heavy liquid boot:

Set the height of the heavy liquid, \( H_{\text{HL}} \), calculate the rising velocity of the light liquid out of the heavy liquid phase, \( U_{\text{LH}} \), using Eq. 8 (find \( k_S \) from Table 1); set \( U_p = 0.75 \) \( U_{\text{LH}} \); calculate the heavy liquid boot diameter:

\[
D_B = \sqrt[4]{\frac{4 \times 12Q_{\text{HL}}}{\pi U_p}}
\]
HORIZONTAL SEPARATORS

**design procedure:**

---

**weir**

---

**HORIZONTAL DESIGN PROCEDURE: WEIR**

1- Calculate the vapor volumetric flow rate, $Q_v$, using Eq. 5.

$$Q_v = \frac{W_v}{3600\rho_v}$$  \hspace{1cm} (5)

2- Calculate the light and heavy liquid volumetric flow rates, $Q_{LL}$ and $Q_{HL}$, using Eqs. 9 and 10.

$$Q_{LL} = \frac{W_{LL}}{60\rho_L}$$  \hspace{1cm} (9)

$$Q_{HL} = \frac{W_{HL}}{60\rho_H}$$  \hspace{1cm} (10)
HORIZONTAL DESIGN PROCEDURE: WEIR

3- Calculate the vertical terminal velocity, $U_T$, using Eq. 4. (select a $K$ value from Table 2) and set $U_V = 0.75 U_T$.

$$U_T = K \left( \frac{\rho_H - \rho_L}{\mu} \right)^{0.5} \quad (4)$$

4- Select holdup and surge times from Table 6 and calculate the holdup and surge volumes, $V_H$ and $V_S$, (unless surge is otherwise specified, such as a slug volume):

$$V_H = T_H Q_L \quad (18)$$

$$V_S = T_S Q_L \quad (19)$$

5- Obtain L/D from Table 7 and initially calculate the diameter according to:

$$D = \left( \frac{16(V_H + V_S)}{0.6 \pi (L / D)} \right)^{1/3} \quad (20)$$

Then calculate the total cross-sectional area, $A_T$, using eq. 21.

$$A_T = \frac{\pi}{4} D^2 \quad (21)$$

Table 7: L/D ratio guidelines

<table>
<thead>
<tr>
<th>Vessel operating pressure, psig</th>
<th>L/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 &lt; P \leq 250$</td>
<td>1.5–3.0</td>
</tr>
<tr>
<td>$250 &lt; P &lt; 500$</td>
<td>3.0–4.0</td>
</tr>
<tr>
<td>$500 &lt; P$</td>
<td>4.0–6.0</td>
</tr>
</tbody>
</table>
**Horizontal Design Procedure: Weir**

6- Set the vapor space height, \( H_V \), to the larger of 0.2D or 2 ft (1 ft if there is no mist eliminator). Using \( H_V/D \) in Table 3, obtain \( A_V/A_T \), and calculate \( A_V \).

7- Calculate the low liquid level in the light liquid compartment using Eq.44 or read it from Table 9.

\[
H_{LLL} = 0.5D + 7 \tag{44}
\]

where \( D \) is in feet and \( H_{LLL} \) in inches (round up to nearest in.).

If \( D \leq 4.0 \) ft, then \( H_{LLL} = 9 \) in.

Using \( H_{LLL}/D \) in Table 3, Calculate \( A_{LLL} \).

<table>
<thead>
<tr>
<th>Vessel dia., ft</th>
<th>Vertical LLL, in.</th>
<th>Horizontal LLL, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤4</td>
<td>&lt; 300 psia</td>
<td>&gt; 300 psia</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

8- Calculate the weir height:

\[
H_W = D - H_V \tag{45}
\]

If \( H_W < 2 \) ft, increase \( D \), and repeat the calculations from Step 6.

9- Calculate the minimum length of the light liquid compartment to accommodate holdup/surge. \( L_2 \) in Figure 2:

\[
L_2 = \frac{V_{ll} + V_s}{A_T - A_V - A_{LLL}} \tag{46}
\]

Round to the nearest 1/2 ft.

The minimum for \( L_2 = d_H + 12 \) in.
**Horizontal Design Procedure: Weir**

10- Set the interface at the height $H_{w}/2$, obtaining the heights of the heavy and light liquids, $H_{HL}$ and $H_{LL}$.

11- For the liquid settling compartment, calculate the cross-sectional area of the heavy liquid, using $H_{HL}/D$ in Table 3 and calculate the cross-sectional area of the light liquid from:

$$A_{LL} = A_{T} - A_{V} - A_{HL} \quad (24)$$

12- Calculate the settling velocity of the heavy liquid out of the light liquid phase, $U_{HL}$, and the light liquid out of the heavy liquid phase, $U_{LH}$, using Eqs 7 and 8 (find $k_s$ from Table 1).

$$U_{HL} = \frac{k_s (\rho_H - \rho_L)}{\mu_L} \quad (7)$$

$$U_{LH} = \frac{k_s (\rho_H - \rho_L)}{\mu_H} \quad (8)$$

13- Calculate the settling times of the heavy liquid out of the light liquid phase and the light liquid out of the heavy liquid phase:

$$t_{HL} = \frac{12H_{LL}}{U_{HL}} \quad (48)$$

$$t_{LH} = \frac{12H_{HL}}{U_{LH}} \quad (49)$$

14- Calculate minimum $L_1$, to facilitate liquid-liquid separation as the larger of:

$$L_1 = \max \left( \frac{t_{LH} Q_{HL}}{A_{HL}}, \frac{t_{HL} Q_{LL}}{A_{LL}} \right) \quad (50)$$

Round to the nearest 1/2 ft.

15- Find L:

$$L = L_1 + L_2 \quad (51)$$
16- Calculate the liquid dropout time, \( \phi \), using eq. 23.
\[
\phi = \frac{H_v}{U_v}
\]  
(23)

17- Calculate the actual vapor velocity, \( U_{VA} \), using eq. 24.
\[
U_{VA} = \frac{Q_v}{A_v}
\]  
(24)

18- Calculate the minimum length required for vapor-liquid disengagement, \( L_{MIN} \), using eq. 25.
\[
L_{MIN} = U_{VA} \phi
\]  
(25)

19- If \( L < L_{MIN} \) then set \( L = L_{MIN} \) (Vapor/liquid separation controls). This simply results in some extra holdup. This simply results in some extra holdup and residence time.

If \( L << L_{MIN} \), then increase \( H_v \) and recalculate \( A_v \) and repeat from the step 6.

If \( L > L_{MIN} \), the design is acceptable for vapor/liquid separation.

If \( L >> L_{MIN} \), liquid holdup controls. \( L \) can only be reduced and \( L_{MIN} \) increased if \( H_v \) is reduced.

\( H_v \) may only be reduced if it is greater than the minimum specified in the step 9.

With reduced \( H_v \) recalculate \( A_v \) and repeat the procedure from step 9.
HORIZONTAL DESIGN PROCEDURE: WEIR

20- Calculate L/D.
   If L/D << 1.5, decrease D (unless it is already at its minimum) and repeat from step 6
   if L/D >> 6.0 then increase D; repeat from Step 5.

21- Calculate the thickness of the shell and heads according to Table 8.

22- Calculate surface area of the shell and heads according to Table 8.

23- Calculate the approximate vessel weight according to Table 8.

---

Table 8: Wall thickness, surface area, and approximate vessel weight

<table>
<thead>
<tr>
<th>Component</th>
<th>Wall Thickness, in.</th>
<th>Surface Area, ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>( \frac{PD}{2SE - 1.2P + t_c} )</td>
<td>( \pi DL )</td>
</tr>
<tr>
<td>2:1 Ellipsoidal Heads</td>
<td>( \frac{PD}{2SE - 0.2P + t_c} )</td>
<td>( 1.09 D^2 )</td>
</tr>
<tr>
<td>Hemispherical Heads</td>
<td>( \frac{PD}{4SE - 0.4P + t_c} )</td>
<td>( 1.571D^2 )</td>
</tr>
<tr>
<td>Dished Heads</td>
<td>( \frac{0.885PD}{SE - 0.1P + t_c} )</td>
<td>( 0.842D^2 )</td>
</tr>
</tbody>
</table>

Approximate Vessel Weight

\[ W = \left( \frac{400 \text{ lb}}{ft^2} \right) \left( \frac{L}{12} \right) \left( A_{\text{outside}} + 2A_{\text{inside}} \right) \]

Notes: The design pressure, \( P \), is typically either the operating pressure with 15 to 30 psi added to it or the operating pressure + 10%, whichever is greater. For the allowable stress, \( S \), see Reference 33. The joint efficiency, \( E \), ranges from 0.6 to 1; use 0.85 for spot-examined joints, and 1 for 100% X-rayed joints. The corrosion allowance, \( t_c \), typically ranges from \( \frac{1}{16} \) to \( \frac{1}{16} \) in. The vessel wall thickness, \( t \), is the larger of \( t_s \) and \( t_c \) up to the nearest \( \frac{1}{16} \) in.
24- Increase or decrease the diameter by 6-in. increments and repeat the calculations until L/D ranges from 1.5-6.0.

25- With the optimum vessel size (minimum weight), calculate normal and high liquid levels:

\[ L_i = \max \left( \frac{t_{IL} Q_{IL}}{A_{IL}}, \frac{t_{IL} Q_{IL}}{A_{IL}} \right) \]  

(50)

23- Calculate the approximate vessel weight according to Table 8.

---

23- with the optimum vessel size (minimum weight), calculate the normal and high liquid levels:

\[ H_{HLL} = D - H_v \]  

(38)

\[ A_{NLL} = A_{LLV} + \frac{V_H}{L} \]  

(39)

Determine \( H_{NLL} \) using Table 3 with the value of \( A_{NLL}/A_T \).

24- Design the heavy liquid boot:

Set the height of the heavy liquid, \( H_{HLL} \), calculate the rising velocity of the light liquid out of the heavy liquid phase, \( U_{LH} \), using Eq. 8 (find \( k_s \) from Table 1); set \( U_p = 0.75 U_{LH} \); calculate the heavy liquid boot diameter:

\[ D_B = \sqrt{\frac{4 \times 12 Q_{HL}}{\pi U_p}} \]  

(39)
HORIZONTAL SEPARATORS

design procedure:

BUCKET AND WEIR

1- Calculate the vapor volumetric flow rate, \( Q_V \), using Eq. 5.

\[
Q_V = \frac{W_V}{3600 \rho_V}
\]  

(5)

2- Calculate the light and heavy liquid volumetric flow rates, \( Q_{LL} \) and \( Q_{HL} \), using Eqs. 9 and 10.

\[
Q_{LL} = \frac{W_{LL}}{60 \rho_L}
\]  

(9)

\[
Q_{HL} = \frac{W_{HL}}{60 \rho_H}
\]  

(10)
3- Calculate the vertical terminal velocity, $U_T$, using Eq. 4. (select a $K$ value from Table 2) and set $U_V = 0.75 U_T$.

$$U_T = K \left( \frac{\rho_H - \rho_L}{\mu} \right)^{0.5}$$

4- Select residence times for light and heavy liquids, $\theta_{LL}$ and $\theta_{HL}$.

For sour water stripper feed drums, $\theta_{HL} = 60$ min for refinery service, or 10-15 min for chemical-plant service.

For amine regenerator feed drums, $\theta_{HL} = 10-15$ min.

5- Obtain $L/D$ from Table 7 and initially calculate the diameter according to:

$$D = \left( \frac{4(Q_{LL}\theta_{LL} + Q_{HL}\theta_{HL})}{0.7\pi (L/D)} \right)^{1/3}$$

Then calculate the total cross-sectional area, $A_T$, using eq. 21.

$$A_T = \frac{\pi}{4} D^2$$

**Table 7: L/D ratio guidelines**

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<td>$500 &lt; P$</td>
<td>4.0–6.0</td>
</tr>
</tbody>
</table>
**HORIZONTAL DESIGN PROCEDURE: WEIR**

6- Set the vapor space height, \( H_V \), to the larger of 0.2D or 2 ft (1 ft if there is no mist eliminator). Using \( H_V / D \) in Table 3, obtain \( A_v / A_p \), and calculate \( A_v \).

7- Calculate \( L_1 \):

\[
L_1 = \frac{Q_{ll} \theta_{ll} + Q_{ml} \theta_{ml}}{A_T - A_v}
\]  
\( (55) \)

8- Calculate the liquid dropout time, \( \phi \), using eq. 23.

\[
\phi = \frac{H_V}{U_V}
\]  
\( (23) \)

9- Calculate the actual vapor velocity, \( U_{VA} \), using eq. 24.

\[
U_{VA} = \frac{Q_V}{A_V}
\]  
\( (24) \)

**HORIZONTAL DESIGN PROCEDURE: BUCKET AND WEIR**

10- Calculate the minimum length required for vapor-liquid disengagement, \( L_{MIN} \), using eq. 25.

\[
L_{MIN} = U_{VA} \phi
\]  
\( (25) \)

11- If \( L_1 < L_{MIN} \), then set \( L_1 = L_{MIN} \) (Vapor/liquid separation controls). This simply results in some extra holdup. This simply results in some extra holdup and residence time.

   If \( L_1 < L_{MIN} \), then increase \( H_V \), recalculate \( A_v \), and repeat the calculations from the step 7.

   If \( L_1 > L_{MIN} \), the design is acceptable for vapor/liquid separation.
### Horizontal Design Procedure: Weir

12- Calculate the light liquid layer thickness based on the heavy liquid settling out:

\[ H_{LL} = \frac{0.00128 \theta_{LL} (\Delta S_g) D_p^2}{\mu_L} \]  

(56)

where \(D_p\) is in microns

13- Calculate the difference in height between the light and heavy liquid weirs:

\[ \Delta H = H_{LL} \left( 1 - \frac{\rho_L}{\rho_H} \right) \]  

(57)

14- Design the light liquid bucket:

Set the top of light liquid weir = \(D - H_v\); assume the bottom is at 0.125\(D\); assume a holdup/surge (typically, 5-15 min.); assume \(H_{LL}\) is 6 in. below the weir height and \(L_{LL}\) is 6 in. above the bottom of the bucket.

Using Table 3 with \(H_{HLL}/D\) and \(H_{LLL}/D\), calculate \(A_{HLL}\) and \(A_{LLL}\). Calculate \(L_2\):

\[ L_2 = \frac{(T_H + T_S)Q_{LL}}{A_{HLL} - A_{LLL}} \]  

(58)
**HORIZONTAL DESIGN PROCEDURE: WEIR**

15- Assume $L_3$ is the larger of $D/12$ or 12 in.

16- Design the heavy liquid compartment:

Set the top of the heavy liquid weir = $D - H_v - \Delta H$; assume a holdup/surge (typically, 5-15 min);

assume $H_{LL}$ is about 6 in. below the weir height and $L_{LL}$ is about 6 in. above the bottom of the vessel.

Using table 3 with $H_{HLL}/D$ and $H_{LLL}/D$, calculate $A_{HLL}$ and $A_{LLL}$.

Calculate $L_4$:

$$L_4 = \frac{(T_h + T_s)Q_{HLL}}{A_{HLL} - A_{LLL}}$$  \hspace{1cm} (59)

---

**HORIZONTAL DESIGN PROCEDURE: BUCKET AND WEIR**

17- Calculate $L = L_1 + L_2 + L_3 + L_4$.

18- Calculate $L/D$.

If $L/D << 1.5$, decrease $D$ (unless it is already at its minimum) and repeat from step 5.

if $L/D >> 6.0$ then increase $D$; repeat from Step 5.

19- Calculate the thickness of the shell and heads according to Table 8.

22- Calculate surface area of the shell and heads according to Table 8.

23- Calculate the approximate vessel weight according to Table 8.
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<thead>
<tr>
<th>HORIZONTAL DESIGN PROCEDURE: BUCKET AND WEIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>24- Increase or decrease the diameter by 6-in. increments and repeat the calculations until L/D ranges from 1.5-6.0.</td>
</tr>
</tbody>
</table>