Designing of horizontal and vertical separators and optimizing by varying vessels internal diameter

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Abstract: Separators are used in every GGS (group gathering station). They are used to separate the liquid and gaseous fractions. Gases being lighter are recovered from the top of the separator and liquid part from the bottom of the separator. There are two types of separators used in the petroleum industry. First one is two-phase separator and the other one is three phase separator. Two phase separator splits the crude oil into gaseous and liquid components. Three phase separator splits the liquid components into crude oil and water. Both two phase and three phase separators are further divided into horizontal and vertical separators. Designing of separators plays a crucial part in the petroleum industry. Improper sizing of the separators can lead to damaging of the vessel internals and can reduce the efficiency of the separators. Designing of the separators is defined as choosing appropriate Lss and internal diameter. It helps in determining the cost of the separator. In this paper, two cases have been taken, firstly horizontal separator and then vertical separators and the results have been discussed.

1. Introduction

Separators are the backbone of the oil and gas industry [1]. They are used to separate out oil and water stream on the basis of their density. They should be designed properly because the crude oil while entering a GGS (Group Gathering Station) has to pass through separators primarily [2]. There are basically two types of separators illustrated in figure 1. First is a two-phase separator and second is three phase separator [3]. The purpose of a two phase separators is to separate gas stream from the liquid stream and a three phase separator is used to separate the liquid stream into the crude oil and water stream [1,3]. These, two phase and three phase separators are further divided into horizontal and vertical types. In Horizontal Separator, fluid comes in direct contact with the inlet diverter. The liquid settles at the bottom and the gas migrates upwards. The gas contains small liquid droplets which are separated when gas passes through the mist extractor [4]. The phenomenon for the vertical separator is same except that the liquid enters from side and then it passes through the inlet diverter where the gross separation of the liquid takes place. Then, the gas passes through the mist extractor before leaving the vessel [5]. Horizontal separators are less expensive than vertical separators. Horizontal separators have more plan area to perform the same operation as compared to vertical separators. They have less liquid surge capacity as compared to the vertical separator [4,6]. Vertical separators also have some limitations. Some of the components are difficult to service without the use of special ladders and platforms [5]. More precisely horizontal separators are economical for normal oil gas separation [6]. Vertical separators are most commonly used in low GOR wells [7].

Fig 1: Types of Separators

The above described horizontal and vertical separators are for the two-phase separators. Now, the three phase separators. Three phase separators are divided into horizontal and vertical separators as illustrated in fig1. Horizontal separators are used in two designs in oil and gas industry [8]. First one is weir design. The weir control the oil level whereas the interface controller or the level controller controls the water level. The produced water flows through the nozzle located upstream of the oil weir. The oil water interface should be maintained at the desired height. To maintain the desired height amount of water leaving the separator should be controlled, which is done by liquid interface controller [9]. Second design is the bucket and weir design. Oil water interface is controlled by a simple displacer float. Oil is collected into the oil bucket.
when it overflows the oil weir and the water flows over the oil bucket and water weir [9]. Thus this design eliminates the use of liquid interface controller. In vertical separators liquid enters from side into the inlet diverter. The only difference between the two phase and three phase vertical separator is that the three phase makes the use of chimney that is used to equalize the pressure between the lower water settling section and the gas section [10].

In the current work, emphasis has been given over understanding the methodology that should be used for designing two phase horizontal and vertical separators and understanding which one should be used according to incoming influx from wells and the prevailing on-ground situations.

Separator sizing is defined as the process of selecting seam to seam length and diameter [11]. The choice must be made for gas capacity so that liquid drops fall from gas as it moves over the effective length of the vessel. Liquid drops should be given sufficient retention time to come in equilibrium. Parameters governing the horizontal separators are gas capacity, liquid capacity, seam to seam length and slenderness ratio. For the vessel 50% full and the liquid drops of 100 micron size equation given below can be applied [12].

**GAS CAPACITY**

\[
d_{L_{eff}} = 420 \left[ \frac{TZQ}{P} \right] \left[ \left( \frac{\rho_g}{\rho_l} - 1 \right) \frac{c_v}{d_m} \right]^{1/2}
\]

\[
d^2 = 5040 \left[ \frac{TZQ}{P} \right] \left[ \left( \frac{\rho_g}{\rho_l} - 1 \right) \frac{c_v}{d_m} \right]^{1/2}
\]

**LIQUID CAPACITY**

\[
d^2 L_{eff} = \left( \frac{t_1 Q_1}{0.7} \right)
\]

\[
d^2 h = \left( \frac{t_1 Q_1}{0.12} \right)
\]

**SEAM TO SEAM LENGTH:**

\[
L_{seam} = L_{eff} + (d/12) \text{ for gas cap}
\]

\[
L_{seam} = (4/3) L_{eff} \text{ for liquid cap}
\]

\[
L_{seam} = (h + 76)/12 \text{ or } (h + d + 40)/12
\]

The length of the separator divided by its diameter is defined as slenderness ratio. Mostly separators have a slenderness ratio in between 3 to 4. It should always be equal or greater than 1. Larger the slenderness ratio more will be its cost. Equations 1, 3, 5 and 6 are valid only for horizontal separators while equation 2, 4, 7 are valid for vertical separators.

### 1.2 Methodology used for designing two phase horizontal separators

![Horizontal separator diagram](image)

The parameters required for sizing a horizontal separator are flow rate of gas and oil, operating pressure and temperature.

Firstly it is required to calculate drag coefficient denoted by \(C_D\). It is a dimensionless quantity used to calculate the resistance of any object in fluid environment such as air or water. Firstly is required to calculate density of liquid given by

\[
\rho_l = 62.4 \left[ \frac{144.5}{131.5 + 0.5 \text{API}_{\text{liquid}}} \right]
\]

Then density of gas is calculated given by

\[
\rho_g = 2.70 \left[ \frac{S \cdot P}{T \cdot Z} \right]
\]

Compressibility factor (\(Z\)) can be calculated using Standing and Katz chart. The drop diameter \(d_m\) which needs to be separated is assumed above 100 microns. The viscosity \(\mu\) is again calculated using viscosity curve. In the next step the drag coefficient is assumed. In next step terminal velocity \(V_t\) is calculated which is given by

\[
V_t = 0.119 \left[ \frac{(\rho_l - \rho_g)}{\rho_g} \frac{dm}{CD} \right]^{1/2}
\]

Next step is to determine Reynolds number given by the equation

\[
Re = 0.0049 \left[ \frac{d_m V_t \rho_g}{\mu} \right]
\]

Now in the next step \(C_D\) is calculated by using the assumed \(C_D\). It is given by the following formula

\[
C_D = \left[ \frac{d R_e}{t_0 / (R_e)^{1/2}} \right] + \text{assumed } C_D
\]

Iterate \(C_D\) till it gives the same value. Now calculate gas capacity constraint using equation 1. Then calculate liquid capacity constant using equation 3. Compute combination of \(d\) and \(L_{eff}\) for gas and liquid capacity. Calculate seam to seam length by changing \(d\) using equation 5 and 6. Calculate slenderness ratio given by 12 \(L_{seam}/d\). Choose a reasonable size with a diameter and length combination above both the gas capacity and the liquid capacity constraint lines. A 36-in. X 10-ft separator provides about 3 minutes retention time.
1.3 Methodology used for designing two phase vertical separators

Fig 3: vertical separator

The parameters used for horizontal separators are same as vertical separators.

The drag coefficient $C_D$ in the same manner as described for horizontal separators. Now calculate gas capacity constraint using equation 2. Then calculate liquid capacity constant using equation 4. Compute combination of $d$ and $h$ for various retention time. Calculate seam to seam length by changing $d$ using equation 7. Calculate slenderness ratio given by $12L_{ss}/d$. Choose a reasonable size with a diameter greater than that determined by the gas capacity. A 36-in. X 10-ft separator provides slightly more than three minutes retention time with a diameter greater than 21.8 in. and a slenderness ratio of 3.2.

2. Calculations

2.1 Calculations for horizontal separators

<table>
<thead>
<tr>
<th>S.No</th>
<th>Name of the parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flow rate of gas</td>
<td>11 MMscfd at 0.6 specific</td>
</tr>
<tr>
<td>2</td>
<td>Flow rate of oil</td>
<td>2100 bopd at 40⁰API</td>
</tr>
<tr>
<td>3</td>
<td>Operating pressure</td>
<td>1000 psia</td>
</tr>
<tr>
<td>4</td>
<td>Operating temperature</td>
<td>50⁰F</td>
</tr>
</tbody>
</table>

Table 1: Input data for horizontal separators

Step 1: determine $C_D$

$ρ_l = 62.4[(144.5/(131.5+40))]$
$ = 51.5 lb/ft^3$
$ρ_g = 2.70[(0.6*1000)/510*.82]$
$ = 3.87$

The value of $Z$ has been calculated using fig 3 at operating pressure and temperature.

Assume $d_m = 140$ microns

$μ = .00864$ (by Carr’s atmospheric gas viscosity correlation and Carr’s viscosity ratio correlation)

$Re = 0.847$

Figure 3: Standing and Katz chart

Assume $C_D = 0.34$

$V_c =..0119[ (51.5-3.87/3.87)140/0.34]^{1/2}$
$ = 0.847$

$R_e = 0.0049[140*0.847*3.87/.00864]$
$ = 265.79$

Figure 4: Carr’s atmospheric gas viscosity correlation

Figure 5: Carr’s viscosity ratio correlation.
On 3 iterations the value of \( C_D \) comes equal to 0.693. Therefore, \( C_D = 0.693 \).

STEP 2: Calculate gas capacity constraint

\[
\frac{dL_{\text{eff}}}{dL_{\text{eff}}} = 420 \left[ \frac{510 \times 82 	imes 11}{1000} \right] \times 0.02
\]

\( dL_{\text{eff}} = 38.64 \)

STEP 3: Calculate liquid capacity constraint

\[
d^2 L_{\text{eff}} = (3 \times 2100)/0.7
\]

\( d^2 L_{\text{eff}} = 9000 \)

STEP 4: Calculate \( L_{\text{eff}} \) gas, \( L_{\text{eff}} \) liquid, \( L_{ss} \), and slenderness ratio for various \( d \).

<table>
<thead>
<tr>
<th>( d ) (in.)</th>
<th>( L_{\text{eff}} ) gas (ft.</th>
<th>( L_{\text{eff}} ) liquid (ft.</th>
<th>( L_{ss} ) (ft.</th>
<th>( 12 L_{ss}/d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>2.41</td>
<td>35.15</td>
<td>46.86</td>
<td>35.145</td>
</tr>
<tr>
<td>20</td>
<td>1.92</td>
<td>22.50</td>
<td>30.00</td>
<td>18</td>
</tr>
<tr>
<td>24</td>
<td>1.61</td>
<td>15.62</td>
<td>20.82</td>
<td>10.41</td>
</tr>
<tr>
<td>30</td>
<td>1.28</td>
<td>10.00</td>
<td>13.33</td>
<td>5.332</td>
</tr>
<tr>
<td>36</td>
<td>1.07</td>
<td>6.94</td>
<td>9.44*</td>
<td>3.14</td>
</tr>
<tr>
<td>42</td>
<td>0.92</td>
<td>5.10</td>
<td>7.6*</td>
<td>2.17</td>
</tr>
<tr>
<td>48</td>
<td>0.80</td>
<td>3.90</td>
<td>6.4*</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Table 2: Output table for horizontal separators

\[ *L_{ss} = L_{\text{eff}} + 2.5 \]

2.2 Calculations for vertical separators

<table>
<thead>
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<td>3.</td>
<td>Operating pressure</td>
<td>1000 psia</td>
</tr>
<tr>
<td>4.</td>
<td>Operating temperature</td>
<td>50^0F</td>
</tr>
</tbody>
</table>

Table 3: Input data for vertical separators

Step 1: determine \( C_D \)

\[
\rho_l = 62.4[144.5/(131.5+40)] = 51.5 \text{ lb/ft}^3
\]

\[
\rho_g = 2.70[0.6*1000/510*.82] = 3.87
\]

The value of \( Z \) has been calculated using fig 3 at operating pressure and temperature.

Assume \( d_{in} = 140 \) microns

\[
\mu = 0.00864 \text{ (by Carr’s atmospheric gas viscosity correlation and Carr’s viscosity ratio correlation)}
\]

Assume \( C_D = 0.34 \)

\[
V_t = 0.0119 \left[ (51.5-3.87/3.87)140/3.4 \right]^{1/2} = 0.847
\]

\[
R_e = 0.0049[140*0.847*3.87/0.00864] = 265.79
\]

\[
C_D = [d/R_e + t_r/(R_e)^{1/2}] + \text{assumed } C_D
\]

On 3 iterations the value of \( C_D \) comes equal to 0.693. Therefore, \( C_D = 0.693 \).

STEP 3: Calculate gas capacity constraint

\[
d^2 = 5040 \left[ \frac{510 \times 82 	imes 11}{1000} \right] \times 0.02
\]

\( d^2 = 463.68 \)

\( d = 21.53 \) inch

STEP 3: Calculate liquid capacity constraint

\[
d^2 h = (t_r Q_1)/0.12
\]

STEP 4: Varying \( d, t_r \) obtain different values of \( h, L_{ss} \) and slenderness ratio.

<table>
<thead>
<tr>
<th>( t_r ) (min)</th>
<th>( d ) (in.)</th>
<th>( h ) (in.)</th>
<th>( L_{ss} ) (ft.</th>
<th>( 12 L_{ss}/d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>24</td>
<td>91.94</td>
<td>13.93</td>
<td>6.965</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>58.33</td>
<td>11.19</td>
<td>4.476</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>40.51</td>
<td>09.71</td>
<td>3.23</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>29.76</td>
<td>08.81</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>22.78</td>
<td>08.23</td>
<td>2.05</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>60.76</td>
<td>11.39</td>
<td>5.695</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>38.88</td>
<td>09.57</td>
<td>3.828</td>
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<td></td>
<td>36</td>
<td>27</td>
<td>08.58</td>
<td>2.86</td>
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<tr>
<td></td>
<td>42</td>
<td>19.84</td>
<td>07.98</td>
<td>2.28</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>13.50</td>
<td>07.45</td>
<td>2.486</td>
</tr>
</tbody>
</table>

Table 3: Input data for vertical separators

3. Results and conclusion

In case of horizontal separator, the 5th case has the best results obtained with \( d = 36 \) inch and \( L_{ss} = 9.44 \) inch. In this case, the value of gas capacity is above the obtained value of gas capacity in step two of horizontal separators. Moreover, the slenderness ratio is 3.14 which is firstly greater than 1 and is in range of 3 to 4. While in case of vertical separators the best results are shown by \( d = 36 \) inch and \( L_{ss} = 9.71 \). In this case, the value of gas capacity is above...
the obtained value of gas capacity in step two of vertical separators. Moreover, the slenderness ratio is 3.23 and is in the range of 3 and 4. The chosen retention time in this case is 3 minutes.

4. Nomenclature

- $d =$ vessel internal diameter, in.
- $L_{eff} =$ effective length of the vessel where separation occurs, ft
- $L_S =$ Seam to seam length, ft
- $T =$ operating temperature, °R
- $Q_g =$ gas flow rate, MMscfd
- $P =$ operating pressure, psia
- $Z =$ gas compressibility
- $C_D =$ drag coefficient
- $d_w =$ liquid drop to be separated, micron
- $\rho_g =$ density of gas, lb/ft³
- $\rho_l =$ density of liquid, lb/ft³
- $t_r =$ desired retention time for the liquid, min
- $Q_l =$ liquid flow rate, bpd
- $R_e =$ Reynolds number
- $\mu =$ viscosity

5. References


