SEPARATION THEORY
Gas/Liquid Separation Theory

- **Liquid droplet settling**
  - Liquid drops separated from gas phase when its velocity reach terminal (settling) velocity
  - Terminal velocity when Drag Force = Buoyant Force
  - Drag Force depends on Drag Coefficient $C_D$

  - $Re < 10$ \[ C_D = \frac{24}{Re} \]
  - $Re > 1000$ \[ C_D = \frac{24}{Re} + \frac{3}{Re^{1/2}} + 0.34 \]
Terminal velocity equations for different conditions

- Re < 10
  \[ V_t = \frac{1.78 \times 10^{-6} (\Delta S.G.) d_m^2}{\mu} \]

- Re > 1000
  \[ V_t = 0.0199 \left[ \frac{\rho_l - \rho_g}{\rho_g} \right]^{1/2} \left( \frac{d_m}{C_D} \right) \]

- The value of \( C_D \) is estimated and then used in the calculation of gas capacity constraint.
But in production facility, flow almost always has $\text{Re} > 1000$. So how to find $C_D$?

- Start with $\text{Re} \gg 1000$ so that $C_D \approx 0.34$
- Use $C_D = 0.34$ to calculate $V_t$
- Use $V_t$ to calculate Re
- Use Re to calculate new $C_D$
- Repeat process until $C_D$ values beginning to be the same
- Use this latest $C_D$ value in the gas capacity equation…
Cont.

- **Liquid retention time**
  - Retention time is average time a liquid molecule is retained in vessel
  - To ensure liquid and gas reach equilibrium so that gas molecule can evolve from liquid phase
  - Retention time = \( \frac{\text{Volume of liquid storage in vessel}}{\text{Liquid flow rate}} \)
  - Usually 1 to 3 minutes
Oil/Water Separation Theory

- **Oil drop/water drop settling**
  - Flow around oil drops in water or water drops in oil is laminar – so water droplets fall at their terminal velocity

- **Oil/water retention time**
  - Need certain amount of oil storage so that oil reaches equilibrium, entrained gas liberated, and ‘free’ water coalesced to fall into water storage
  - Need certain amount of water storage for entrained large droplets of oil have time to coalesce and rise to oil-water interface
  - Retention time 3 – 30 minutes
SEPARATOR SIZING:
TWO-PHASE SEPARATOR
General sizing procedure

CALCULATE

1. Gas capacity constraint
   □ Minimum vessel diameter OR Relationship between diameter and effective length that satisfy gas capacity constraint

2. Liquid capacity
   □ Relationship between diameter and effective length OR height that satisfy liquid capacity constraint

3. Seam-to-seam length, \( L_{ss} \)
   □ For Gas capacity and Liquid capacity

4. Slenderness ratio
   □ For each \( L_{ss} \) calculated

SELECT reasonable vessel size (diameter and length)!
VERTICAL SEPARATOR

- **Seam-to-seam Length** $L_{ss}$
- **Diameter** $d$
- **Height** $h$
- **Gas outlet**
- **Mist extractor**
- **Inlet**
- **Liquid capacity**
- **Gas capacity**
- **Liquid Outlet**
Vertical separator sizing procedure

1. Determine $C_D$ using iterative procedure

2. Calculate $d$ for gas capacity constraint using

$$d^2 = 5040 \left[ \frac{T Z Q_g}{P} \right] \left[ \left( \frac{\rho_g}{\rho_l - \rho_g} \right) C_D \right]^{1/2}$$

3. Calculate $d^2 h$ for liquid capacity constraint

$$d^2 h = \frac{t_r Q_l}{0.12}$$
4. Set retention time $t_r$ to be 1, 2 and 3 minutes (usual case)

5. For each $t_r$, calculate and tabulate values of
   a) $d$
   b) $h$
   c) $L_{ss}$
      - OD < 36” $\rightarrow$ $L_{ss} = \frac{h + 76}{12}$
      - OD > 36” $\rightarrow$ $L_{ss} = \frac{h + d_{min} + 40}{12}$
   d) Slenderness Ratio (SR), $(12)L_{ss}/d$
Cont. vertical

- From table, select possible choices of separator size (d x $L_{ss}$) based on the values of $\frac{(12)L_{ss}}{d}$
  - Select $(12)L_{ss}/d$ values range 3 – 4
  - d values must be greater than the calculated minimum vessel diameter for gas capacity constraint (Step 2)

- Your final selection should be based on your judgment on the costs of each possible separator
Example of separator selection

<table>
<thead>
<tr>
<th>$t_r$ min</th>
<th>$d$ in.</th>
<th>$h$ in.</th>
<th>$L_{\text{in}}$ ft</th>
<th>$\frac{[12]L_{\text{in}}}{d}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>24</td>
<td>86.8</td>
<td>13.6</td>
<td>6.8</td>
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<tr>
<td></td>
<td>36</td>
<td>38.6</td>
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<td>3.7</td>
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<td>42</td>
<td>28.3</td>
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<td>2.5</td>
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<td>21.7</td>
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<td>9.4</td>
<td>3.8</td>
<td>3.8</td>
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<td>24</td>
<td>57.9</td>
<td>11.2</td>
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<td>30</td>
<td>37.0</td>
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<td>3.8</td>
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<td>25.7</td>
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</tr>
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<td>36</td>
<td>18.9</td>
<td></td>
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<td>9.4</td>
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<td>7.9</td>
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<td>18.5</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>12.9</td>
<td></td>
<td>2.5</td>
</tr>
</tbody>
</table>

Possible size:
- 36” x 10’
- 30” x 10’
- 30” x 10’ or 30” x 8’
HORIZONTAL SEPARATOR

Seam-to-seam Length $L_{ss}$

Diameter $d$

Gas capacity (50%)

Gas-oil interface

Effective Length $L_{eff}$

Liquid capacity (50%)

Inlet

Liquid Outlet

Gas outlet

Gas molecule flowing at average gas velocity, $V_g$

Liquid droplet dropping at settling velocity $V_t$ relative to gas phase
Horizontal separator sizing procedure

1. Determine $C_D$ using iterative procedure

2. Calculate $dL_{eff}$ for gas capacity constraint

\[
dL_{eff} = 420 \left( \frac{TZQ_g}{P} \right) \left[ \left( \frac{\rho_g}{\rho_l - \rho_g} \right) C_D \right]^{1/2}
\]

3. Calculate $d^2L_{eff}$ for liquid capacity constraint

\[
d^2L_{eff} = \frac{t_r Q_l}{0.7}
\]
4. Set retention time $t_r$ to be 1, 2 and/or 3 minutes (usual case)

5. For each $t_r$, calculate and tabulate values of
   a) $d$
   b) $L_{\text{eff}}$ for
      - $Gas \ capacity$ $\rightarrow$ from equation Step 2
      - $Liquid \ capacity$ $\rightarrow$ from equation Step 3
c) \( L_{ss} \) for
   - \textit{Gas Capacity} \( \Rightarrow \quad L_{ss} = L_{eff} + \frac{d}{12} \)

   - \textit{Liquid capacity} \( \Rightarrow \quad L_{ss} = \frac{4}{3} L_{eff} \)

d) Slenderness ratio (SR), \((12)\frac{L_{ss}}{d}\)
From table, compare the values of $L_{eff}$ for each gas and liquid capacity that governs the design of the separator

- The one with larger required length governs

Then, select possible choices of separator size $(d \times L_{ss})$ based on the values of SR

- Select SR values range 3 – 5
- $L_{ss}$ values selected are the one that governs the design
Example of separator selection

Use the liquid Lss values to select separator size

<table>
<thead>
<tr>
<th>t_r</th>
<th>d</th>
<th>Gas L_{eff}</th>
<th>Liquid L_{eff}</th>
<th>Gas L_{ss}</th>
<th>Liquid L_{ss}</th>
<th>SR</th>
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<td>28.5</td>
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<td>1.7</td>
<td>14.9</td>
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<td>19.9</td>
<td></td>
<td>9.9</td>
</tr>
<tr>
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<td>5.1</td>
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<td>1.1</td>
<td>6.6</td>
<td>9.1</td>
<td>3</td>
<td></td>
<td></td>
</tr>
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<td>4.9</td>
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<td>7.4</td>
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<td>2.1</td>
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<tr>
<td>48</td>
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<td>3.7</td>
<td></td>
<td>6.2</td>
<td></td>
<td>1.6</td>
</tr>
</tbody>
</table>

Use the liquid Lss values to select separator size

Possible size

36” X 10’

Liquid capacity constraint governs since it has the largest required length
That’s basically it.