Effect of LNG Tank Shape on Release Rates

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Effect of Tank Shape

• Release rates - first, and very important, step in consequence analysis
• LNG tanks - release driven by liquid head
• Variation of head, and rate, with time depends on tank size and shape

LNG Tank Shapes (side cross sections)

- Cylindrical
- Spherical
- Membrane
Bernoulli Equation (orifice equation)

\[ m_L = C_D A \rho \sqrt{\frac{2g \Delta P}{\rho}} + 2gH_L \]

Mass rate \hspace{1cm} Pressure term \hspace{1cm} Head term

Applies when liquid does not vaporize before leaving vessel
Spherical Tank

Reference level (e.g., waterline)

$V_s$

$R$

$L_{CL}$

$H$

$L$

$R$

Reference level (e.g., waterline)

$V_s$
Membrane Tank

Volumes

\( V_T \)
\( V_C \)
\( V_B \)

Reference level (e.g., waterline)

\( W_T \)
\( W_C \)
\( W_B \)

\( H_T \)
\( H_{TC} \)
\( H_B \)

\( L_{tnk} = \text{Length of tank (into page)} \)

\( L \)

\( L_{tnk} = \text{Length of tank (into page)} \)
When liquid level falls below top of hole

Replace flow area with liquid flow area
Can use vapor flow equation with vapor flow area

\[ A_{\text{seg}} = R^2 \cos^{-1} \left( \frac{d}{R} \right) - d \sqrt{(R - d)(R + d)} \]
## Calculation Procedure

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Rate (kg/s)</th>
<th>Efflux (kg)</th>
<th>Efflux (m³)</th>
<th>In Tank (m³)</th>
<th>Level (m)</th>
<th>Hole Area (m²)</th>
<th>Hole Pressure (kPa)</th>
<th>Hole Density (kg/m³)</th>
</tr>
</thead>
</table>

Equations in attachment of paper

Pressure + head

Level as a function of Volume in Tank:
- Spherical tank: cubic equation
- Membrane tank: quadratic equation for ends, linear in center

Integration

Bernoulli equation
Illustrative Predictions

Release just above waterline
### Spherical vs. Membrane Tank Tank

<table>
<thead>
<tr>
<th></th>
<th>Spherical</th>
<th>Membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG volume</td>
<td>25,000 m³</td>
<td>40,000 m³</td>
</tr>
<tr>
<td>% full</td>
<td>99 %</td>
<td>97 %</td>
</tr>
<tr>
<td>Initial LNG head above waterline</td>
<td>26.1 m</td>
<td>15.9 m</td>
</tr>
<tr>
<td>% of LNG above waterline</td>
<td>87%</td>
<td>67%</td>
</tr>
</tbody>
</table>

**Graphs:**
- **0.75-m diameter hole:** 
  - Level falls below top of hole
- **2-m diameter hole:** 
  - Liquid release rate over time for Membrane and Sphere
Actual Shape vs. Constant-Area

1-m diameter hole
Same initial head and volume

Sphere

Liquid release rate (tonnes/s)

Time (min)

0 1 2 3 4 5 6

Liquid release rate (tonnes/s)

Time (min)

0 1 2 3 4 5

Area increasing

Area decreasing

Membrane

Liquid release rate (tonnes/s)

Time (min)

0 1 2 3 4 5 6 7 8

Area increasing

Area constant

Membrane
Different Membrane Tanks

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Q Flex</th>
<th>Q Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG volume</td>
<td>40,000 m³</td>
<td>47,200 m³</td>
<td>58,800 m³</td>
</tr>
<tr>
<td>% full</td>
<td>97 %</td>
<td>98 %</td>
<td>98 %</td>
</tr>
<tr>
<td>Initial LNG head above</td>
<td>15.9 m</td>
<td>20.2 m</td>
<td>19.2 m</td>
</tr>
<tr>
<td>waterline</td>
<td>67%</td>
<td>71%</td>
<td>70%</td>
</tr>
</tbody>
</table>

1-m² Hole Area

- Conventional
- Q Flex
- Q Max

Release rate (tonnes/s) vs. Time (min)
Recommendations

• Use equations relating head to volume in tank, reflecting tank shape and size

• Use corrected hole area when liquid level falls below top of hole