Assessing the Risk of Overpressure from Liquid Thermal Expansion

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Wood Process Solutions
Outline

• **Introduction**
  – Liquid Thermal Expansion
  – Background on Metocean (Meteorology & Oceanography)

• **Modelling**
  – Methodology
  – Benchmarking against Field Data

• **Applications & Mitigation Measures**
  – Application 1: Subsea Tree Cavity
  – Application 2: Offshore Hydrotesting Activities
  – Application 3: Trapped Fluids during Operation
Introduction
Metocean – Location of Various Fields in WA

Metocean – Diurnal Tides

The Tidal Month

- New
- First Quarter
- Full
- Last Quarter
- New

- Spring High Tide
- Neap

- Average High Tide

The graph on the right shows the tidal height over 24 hours, with high tides occurring at approximately 0 and 12 hours, and low tides at 4 and 8 hours. The graph on the left illustrates the Earth's rotation relative to the Moon, showing the effect of tidal forces due to gravity and inertia.
Modelling
Contributing Factors to Liquid Thermal Expansion

- Seawater temperature variation
- Fluid properties
- Pipe properties

Liquid Thermal Expansion
**Fluid Properties**

<table>
<thead>
<tr>
<th>Liquids</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEG</td>
<td>• Commonly used as inhibitor to prevent/reduce hydrate formation</td>
</tr>
<tr>
<td></td>
<td>• Used for hydrotesting / leak testing</td>
</tr>
<tr>
<td></td>
<td>• Flooding medium after subsea installation</td>
</tr>
<tr>
<td>Water</td>
<td>• Used for hydrotesting / leak testing</td>
</tr>
<tr>
<td></td>
<td>• Flooding medium after subsea installation</td>
</tr>
</tbody>
</table>

**Required fluid properties:**

\[ \alpha_v \] is the cubic expansion coefficient of the liquid, expressed in \(1/°C\) (\(1/°F\));

\[ \chi \] is the isothermal compressibility coefficient of the liquid, expressed in \(1/kPa\) (\(1/psi\));
Pipe Properties

<table>
<thead>
<tr>
<th>Wall Material</th>
<th>Uses</th>
</tr>
</thead>
</table>
| Steel         | • Pipeline  
                • Main production system piping  
                • Umbilicals carrying inhibitors and chemicals for subsea injection |

Required pipe properties:

\[ \alpha_l \] is the linear expansion coefficient of metal wall, expressed in 1/°C (1/°F);

\[ d \] is the internal pipe diameter, expressed in metres (inches);

\[ \delta_w \] is the metal wall thickness, expressed in metres (inches);

\[ E \] is the modulus of elasticity for the metal wall at \( T_2 \), expressed in kPa (psi);

\[ \mu \] is Poisson’s ratio, usually 0.3;
Equation for Liquid Thermal Expansion

API 521 methodology used to give the pressure increase in a closed vessel due to thermal expansion

\[ p_2 = p_1 + \frac{(T_2 - T_1)(\alpha_v - 3\alpha_l) - \left( \frac{q_{\|} \cdot t}{V} \right)}{\chi + \left( \frac{d}{2E \cdot \delta_w} \right)(2.5 - 2\mu)} \]

where

- \( p_2 \) is the final gauge pressure of blocked-in, liquid-full equipment, expressed in kPa (psi);
- \( p_1 \) is the initial gauge pressure of blocked-in, liquid-full equipment, expressed in kPa (psi);
- \( T_2 \) is the final temperature of blocked-in, liquid full equipment, expressed in °C (°F);
- \( T_1 \) is the initial temperature of blocked-in, liquid full equipment, expressed in °C (°F);
- \( \alpha_v \) is the cubic expansion coefficient of the liquid, expressed in 1/°C (1/°F);
- \( \alpha_l \) is the linear expansion coefficient of metal wall, expressed in 1/°C (1/°F);
- \( \chi \) is the isothermal compressibility coefficient of the liquid, expressed in 1/kPa (1/psi);
- \( d \) is the internal pipe diameter, expressed in metres (inches);
- \( E \) is the modulus of elasticity for the metal wall at \( T_2 \), expressed in kPa (psi);
- \( \delta_w \) is the metal wall thickness, expressed in metres (inches);
- \( \mu \) is Poisson's ratio, usually 0.3;
- \( q_{\|} \) is the liquid leakage rate across the block valve seat (usually taken as 0), expressed in m³/s (in³/s);
- \( t \) is the elapsed time for leakage, expressed in seconds;
- \( V \) is the pipe volume, expressed in cubic metres (cubic inches).
Equation for Liquid Thermal Expansion

\[
 \chi = \left( \frac{d}{2E \cdot \delta_w} \right) (2.5 - 2\mu)
\]

Fluid Compressibility:

\[
 p_2 = p_1 + \frac{(T_2 - T_1)(\alpha_v - 3\alpha_l) - \chi}{\alpha_v}
\]

Fluid Thermal Expansivity:
Model Schematic

Ambient = Seawater

Pipe Wall Elasticity

Closed Node

100% liquid filled
MEG/water = 80/20 wt%

Insulation/Burial (optional)

Closed Node
### Benchmarking (Field Data vs Cubic EoS vs High Accuracy EoS)

<table>
<thead>
<tr>
<th></th>
<th>ΔP / ΔT (bar/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Field Data</td>
<td>9.7 – 11.1</td>
</tr>
<tr>
<td>Out of Box Standard Tools (e.g. Cubic EoS)</td>
<td>≈22 (CPA)</td>
</tr>
<tr>
<td>High Accuracy EoS</td>
<td>10.6 (CSMA)</td>
</tr>
</tbody>
</table>

### Pressure vs Time
- **Benchmarking - Pressure**
  - Measured Field
  - Cubic EoS
  - High Accuracy EoS

### Temperature vs Time
- **Benchmarking - Fluid Temperature**
  - Measured Field
  - Cubic EoS
  - High Accuracy EoS

A presentation by Wood.
Parameters

**Sensitive**
- Change in Fluid Temperature ($\Delta T$)
- Fluid Thermal Expansivity ($\alpha_v$)
- Fluid Compressibility ($\gamma$)
- Insulation Thickness

**Not Sensitive**
- Wall Elasticity ($E$)
- Diameter to Wall Thickness Ratio ($D/t$)
- Wall Coefficient of Expansion ($\alpha_l$)
Applications and Mitigation Measures
Application 1 – Subsea Tree Cavity

Challenge:
- Large $\Delta T$ experienced from hot production fluids heating up the tree cavity

Approach:
- CFD (complex geometries)
- Accurate fluid properties

Mitigation:
- In design: Account for liquid thermal expansion in design of subsea tree cavity. Remove actuated valves where not required.
- In operation: Avoid trapped liquid situations such as dual isolation.
Application 2 – Offshore Hydrotesting Activities

Requirement:
– Hydrotesting requires testing the system at high pressures for extended periods (e.g. 24 h at a holding pressure above design).

Challenge:
– Stabilizing pressure with varying seawater temperatures.
– Pressures above design, approaching burst limit.

Approach:
Seawater temperature variations + Accurate fluid properties = Pressure increase due to thermal expansion

Mitigation:
– **In design:** Account for liquid thermal expansion in design of subsea systems (e.g. pipelines, structures, valves).
– **In operation:** Address through bespoke procedures.
Application 3 – Trapped Liquids during Operation

**Challenge:**
- Unplanned shutdown of pumps / valves
- Seawater temperature swings $\rightarrow$ pressure increases $\rightarrow$ possibly exceed design pressure

**Approach:**
- As per Application 2.

**Mitigation:**
- **In operation:** Selecting an appropriate pump discharge PSV set point. Pressure / temperature monitoring and high alarms.
Liquid thermal expansion can lead to increase in pressures possible above design.

An approach was developed to assess extent of liquid thermal expansion & possible mitigations.

Challenge in varying seawater temperature / nearby hot production fluids resolved by:
- Appropriate modelling techniques & accurate input data
- Introducing mitigations