Casing Connection Selection for Geothermal Applications Using Input From HPHT and Thermal Wells Testing Protocols

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Agenda

- Geothermal Operation
- Connection Testing
- Connection Selection
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• Connection Selection
Geothermal Operation

» AXIAL LOAD CYCLING – TENSION COMPRESSION CYCLES

» Caused by temperatures cycle during injection – shut-in – production cycles, involving huge temperature span (RT to more than 200°C – reaching up to 350°C).

» Thermal cycles lead to expansion and contraction of pipes, imposing compression and tension loads on the joints.
Geothermal Operation

1. During initial heating, the material is compressed elastically until the elastic limit is reached near 200°C.

2. Further heating leads to plastic deformation from constrained thermal expansion.

3. As the temperature is held constant at 275°C, stress relaxation occurs from creep strain.

4. As the confined string cools, the axial load gradually becomes tensile.
Agenda

• Geothermal Operation
• Connection Testing
• Connection Selection
Objective

✓ To perform a minimum design verifications on connections simulating the worst geometries in accordance with the specified range of tolerances.

Types of Qualification Programs

✓ Full Scale Tests : Actual samples manufactured on steel pipes. **Advantage**: Real data / **Disadvantage**: Cost and Time

✓ Finite Element Analysis : Numerical simulations. **Advantage**: Lots of data at low cost / **Disadvantage**: Some variables cannot be modeled.
Connection Qualification & Testing

• Full Scale Tests (FST) – Different Types

1) ISO 13679 / API RP 5C5
2) ExxonMobil Connection Evaluation Program
3) TWCCEP (Thermal Wells Casing Connection Evaluation Protocol) / ISO PAS 12835
3) Customer specifications:
   ✓ Fatigue
   ✓ Extra torque
## ISO 13679:2002 testing protocol

### GALLING RESISTANCE EVALUATION
**MAKE AND BREAK TESTS**

### SEALABILITY EVALUATION
**COMBINED LOAD TESTS**

### FAILURE TESTS

#### Structural tests
- **CAL IV & VIII**
  - Failure test $p_a > T$ to $F$ 7.5.1
  - Failure test $C_{op}$ to $F$ 7.5.2
  - Failure test $p_a + T$ to $F$ 7.5.3

#### 3 MONTHS TESTING AT FULL LAB CAPACITY
Full scale test execution
ISO 13679:2002 testing protocol

- Severity defined as **CONNECTION APPLICATION LEVELS (CAL)**
- **CAL I**: 3 samples - 2 Quadrants (Liquid) only Internal pressure – Bending optional – No thermal cycles
- **CAL II**: 4 samples - 2 Quadrants (Gas) only Internal pressure – Bending optional – 5 thermal cycles for tubing – Temperature 135°C (275°F)
- **CAL III**: 6 Samples - 4 Quadrants (Gas) – Bending optional – 10 thermal cycles for tubing – Temperature 135°C (275°F)
- **CAL IV**: 8 Samples – 4 Quadrants (Gas) – Bending required – 100 thermal cycles for tubing – Temperature 180°C (356°F)
- Loads based on **actual Minimum Yield Strength and actual minimum wall thickness.**
Full scale test execution

TEST POINTS

SEALABILITY

Compression

Connection Test Load Envelope

Pipe Resistance Envelope (Yield)

Q II

Q I

Q III

Q IV

External pressure

Internal pressure

Tension
ISO 13679:2002 testing protocol

Test Series C:
Mechanical cycles both at ambient and elevated temperature with axial tension loads combined with internal pressure
New API RP 5C5 (2017?) testing protocol

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Thread / Seal Thread Taper</th>
<th>Make and Break Test</th>
<th>Bake-out</th>
<th>90% Level Sealability Testing</th>
<th>90% Level</th>
<th>95% Level Sealability Testing</th>
<th>95% Level</th>
<th>Limit Load Testing</th>
<th>End of Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thread / Seal Thread Taper</td>
<td>FMU A End</td>
<td>FMU B End</td>
<td>FMU Bake-out</td>
<td>FMU</td>
<td>FMU</td>
<td>FMU</td>
<td>FMU</td>
<td>FMU</td>
</tr>
<tr>
<td>1</td>
<td>XH-XL PS-BF</td>
<td>A End</td>
<td>B End</td>
<td>Bake-out</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>XH-XL PS-BF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L-H PF-B5</td>
<td>M&amp;B x 2 A End</td>
<td>M&amp;B x 2 B End</td>
<td>Bake-out</td>
<td>FMU A End</td>
<td>FMU A End</td>
<td>FMU A End</td>
<td>FMU B End</td>
<td>FMU B End</td>
</tr>
<tr>
<td>4</td>
<td>L-L PS-BF</td>
<td>M&amp;B x 2 A End</td>
<td>M&amp;B x 2 B End</td>
<td>Bake-out</td>
<td>FMU A End</td>
<td>FMU A End</td>
<td>FMU A End</td>
<td>FMU B End</td>
<td>FMU B End</td>
</tr>
<tr>
<td>5</td>
<td>H-H PF-B5</td>
<td>M&amp;B x 2 A End</td>
<td>M&amp;B x 2 B End</td>
<td>Bake-out</td>
<td>FMU A End</td>
<td>FMU A End</td>
<td>FMU A End</td>
<td>FMU B End</td>
<td>FMU B End</td>
</tr>
</tbody>
</table>

Test Series B:
- Test Series A: @180° C / 90% 5x Q1-Q3-Q1 Cycles Room Temp. / 90%
- Test Series C: 10 Thermal Cycles 5 Mechanical Cycles

Test Series C:
- Test Series A: @180° C / 90% 5x Q1-Q3-Q1 Cycles Room Temp. / 90%
- Test Series C: 10 Thermal Cycles 5 Mechanical Cycles

Test Series A:
- Test Series A: @180° C / 90% 5x Q1-Q3-Q1 Cycles Room Temp. / 90%
- Test Series C: 10 Thermal Cycles 5 Mechanical Cycles

Test Series B:
- Test Series A: @180° C / 90% 5x Q1-Q3-Q1 Cycles Room Temp. / 90%
- Test Series C: 10 Thermal Cycles 5 Mechanical Cycles

Limit Load Testing:
- T + IP To Failure
- 70% IP + C To Failure
- 95% IP + T To Failure
- 50% C + EP To Failure

End of Testing:
- Complete Complete Complete Complete Complete
• multi-client project, sponsored by operators and connection manufacturers involved in thermal-well operations in Canada.

• both analytical and experimental procedures to assess performance of a candidate connection under conditions typical of service in thermally-stimulated wells.

• Connections are subjected to compressive stresses beyond yield at high temperature and to tensile stresses during the cooling phase.
TWCEP/ ISO PAS 12835: 2013
Test Protocol

Galling Resistance

- Galling Resistance Test
- Make and Break Properties
- Amount Thread Compound/Torque shown in each block

Thermal Cycles

- Thermal Cycle Test
- Limit Strain Test

Limit

- Limit Strain Test 12.5
TWCCSEP/ ISO PAS 12835: 2013
Application Severity Level

<table>
<thead>
<tr>
<th>ASL</th>
<th>Maximum operating temperature</th>
<th>Lower-bound temperature</th>
<th>Upper-bound temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not applicable (*)</td>
<td>180</td>
<td>5</td>
<td>180</td>
</tr>
<tr>
<td>240</td>
<td>181 - 240</td>
<td>5</td>
<td>240</td>
</tr>
<tr>
<td>290</td>
<td>241 - 290</td>
<td>5</td>
<td>290</td>
</tr>
<tr>
<td>325</td>
<td>291 - 325</td>
<td>5</td>
<td>325</td>
</tr>
<tr>
<td>350</td>
<td>326 - 350</td>
<td>5</td>
<td>350</td>
</tr>
</tbody>
</table>

Source: TWCCSEP/ISO PAS 12835: 2013
First two thermal cycles of ASL 290 test
## Connection Testing Summary

<table>
<thead>
<tr>
<th>Application</th>
<th>ISO 13679:2002 CAL IV</th>
<th>API 5C5 2012 CAL IV</th>
<th>TWCCCEP</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Samples</td>
<td>8</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Max. Temperature</td>
<td>180° C</td>
<td>180° C</td>
<td>Up to 350° C</td>
</tr>
<tr>
<td>Max.# M&amp;Bs Csg / Tbg</td>
<td>2 / 9</td>
<td>3 / 10</td>
<td>3 / -</td>
</tr>
<tr>
<td>T, C, IP &amp; EP</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>T,C, IP &amp; Bending (RT or ET)</td>
<td>Max 20° Only RT</td>
<td>Max 20° RT &amp; ET</td>
<td>NO</td>
</tr>
<tr>
<td>Thermal Cycles Csg / Tbg</td>
<td>10 / 100 + 10 MC RT &amp; 5 MC ET</td>
<td>10 / 10 + 5 MC AT</td>
<td>10 + IP and fixed ends</td>
</tr>
<tr>
<td>Failure Tests</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>
Agenda

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• Connection Selection
Connection Selection: API Buttress

**Advantages**
- Easy manufacture
- Easy running
- High Tensile resistance

**Disadvantages**
- Poor sealability
- Compression
- Non-flush ID
Proprietary Connections

• Typical Design Requirements

  **Functional**
  - ✓ Runnability (Makes & Breaks)
  - ✓ Sealability under combined loads

  **Structural**
  - ✓ Efficiencies (tension, compression)

  **Geometry:**
  - ✓ Coupled, integral, flush, semi-flush
  - ✓ Box OD, Drift

  **Others:**
  - ✓ Fatigue
  - ✓ Overtorque
Connection Selection
Premium Connection Features

- Metal to Metal Seal
- PIN
- Thread Form
- BOX
- Torque Shoulder
Connection Selection
Compression

Jump-In

API Buttress

Premium
Connection Selection
Flow Characteristic
Connection Selection
Sealability

Fluid Leak

API Buttress

Premium
Questions

» When to switch from API BTC to proprietary connection?

» How many thermal cycling?

» Enhancing flow, more steam more power generation $\rightarrow$ larger borehole. Prevent mass and heat loss by using metal seal connection?
Thanks!