How can new P&A technologies ever demonstrate they are good enough to meet industry requirements?

Astrimar Ltd

How good does a well barrier need to be?

- DCR Regulations: Prevent escape of fluids on a permanent basis
  - How long is permanent? - eternal implication
  - Prevent escape: Does this mean zero leakage?

- What if the barrier leaks?
  - Life will depend on leak acceptance criteria
  - Which acceptance criteria are appropriate?

- What is the barrier Life?
  - Prediction and/or
  - Long term monitoring

- Flow rate = 20,000 m³/yr
  API 14B acceptance level
- Flow rate = 1650 m³/yr
  Expected HPHT well
- Flow rate = 20 m³/yr
  Natural fugitive rate
- Flow rate = 10⁻³ m³/yr
  Equivalent to cap rock
- Flow rate = 0 m³/yr
  Time to R/C breakthrough
  Regulation implication
How good do new plug materials need to be?

- Regulatory acceptance required
- OGUK require evidence that the new plug material has:
  - Acceptable sealing performance
  - Durability: 3000 years

**Durability:** the ability of a physical product to remain functional, without requiring excessive maintenance or repair, over its required lifetime.

- What are the barriers to entry of new plug materials into P&A market
  - As good or better sealing performance than a good cement
  - Lower installation/deployment cost, time and resources than cement

**How can new P&A technologies ever demonstrate they are good enough to meet industry requirements?**

- Evidence provided through qualification of plug materials
  - OGUK (2015): Guidance on qualification of materials for the abandonment of wells

OGUK (2015) Qualification of Materials for Well P&A

- **Required characteristics of barriers**
  - Very low bulk permeability
  - Good interface seal
  - Remain in place
  - Resistance to down hole fluids
  - Suitable material/mechanical properties
  - Long term integrity

<table>
<thead>
<tr>
<th>Example Metallic Plug Recommended Tests</th>
<th>OGUK Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry mass (corrosion weight loss) after ageing</td>
<td>&lt; 3%</td>
</tr>
<tr>
<td>Expansion/swelling during hardening</td>
<td>&lt;1% linear expansion</td>
</tr>
<tr>
<td>Shrinkage during hardening</td>
<td>&lt;1% linear shrinkage</td>
</tr>
<tr>
<td>Differential thermal expansion relative to casing</td>
<td>within $10^{-6}$ K$^{-1}$</td>
</tr>
<tr>
<td>Creep</td>
<td>&lt;1% linear strain</td>
</tr>
<tr>
<td>Ultimate Compressive Strength before ageing</td>
<td>&gt;1.4MPa</td>
</tr>
<tr>
<td>Ultimate Compressive Strength after ageing</td>
<td>&gt;1.4 MPa</td>
</tr>
<tr>
<td>Tensile strength after ageing</td>
<td>&lt; 50% reduction</td>
</tr>
<tr>
<td>Shear bond strength before ageing</td>
<td>&gt;1MPa</td>
</tr>
<tr>
<td>Shear bond strength after ageing</td>
<td>&gt;1MPa</td>
</tr>
<tr>
<td>Decomposition temperature</td>
<td>Non-melting at well Temp</td>
</tr>
</tbody>
</table>

- Interpret measured material characteristics
- Translate to expected performance
- Provide assurance of meeting regulatory expectations

- The only realistic approach is to use Predictive models with a lot of support from qualification testing data
Materials and Plug Performance Questions

• Long term barrier performance - a major challenge
  – Metal barriers (excluding noble metals) will eventually corrode and return to more stable hydrated oxides, hydroxides and sulphides (plugs and casing)
  – Cements in contact with well fluids and formation fluids react to form more stable compounds

• Degradation rate
  – How fast? Over decades, centuries, millennia?

• Impact of degradation on leak rate?
  – Does corrosion increase the permeability/leak rate of metal plugs?
  – How much does cement degradation affect permeability/leak rate?

• How does sudden or slowly changing stress impact plug performance?
  – If it yields, does leak rate increase?

• Need more emphasis on understanding rate of degradation and impact of ageing on barrier performance

Plug Technology Readiness Questions

• Do laboratory measurements accurately reflect field conditions?
  – Material property tests ok to achieve TRL4
  – Small scale prototype plugs ok to achieve TRL5
  – Full scale rigs and/or field trials needed to demonstrate TRLs 6 to 8
  – Long term monitoring with acceptable reliability needed to demonstrate TRL9

• Common for developers to jump to full scale TRL 6 testing before doing ground work to achieve TRLs 4 and 5

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic principles observed. Science research translated into applied R&amp;D</td>
</tr>
<tr>
<td>2</td>
<td>Technology concept formulated. Technology reviewed - paper studies</td>
</tr>
<tr>
<td>3</td>
<td>R&amp;D initiated as proof of concept. Simple experimental tests conducted</td>
</tr>
<tr>
<td>4</td>
<td>Materials tested and plug concept demonstration initiated</td>
</tr>
<tr>
<td>5</td>
<td>Prototype plug developed and tested in the laboratory</td>
</tr>
<tr>
<td>6</td>
<td>Full scale plug validated in a suitable full scale test facility</td>
</tr>
<tr>
<td>7</td>
<td>Operational plug system Integration tested in a suitable full scale test facility</td>
</tr>
<tr>
<td>8</td>
<td>Plug system installed and commissioned</td>
</tr>
<tr>
<td>9</td>
<td>Plug system operating with acceptable reliability</td>
</tr>
</tbody>
</table>
**Data input to Predictive Models**

- **Well and Plug Design** → **Workshop Trials** → **Material Qualification Tests** → **Predictive Model** → **Plug Performance**
  - **INPUTS**
    - **Q-FMECA**
    - **Material database**: qualification test data, existing published data
    - **Plug and Well data**: Well condition, annulus cement condition, plug design, well design
  - **MODEL**
    - **Predictive models**: integrate accepted theory with experimental materials data and well specific data
  - **OUTPUTS**

**Using STEM-flow to assess Bi alloy plugs**

- **Astrimar supporting RECL in the qualification of bismuth alloy as part of Innovate UK funded research programme**
  - Q-FMECA and identification of qualification tests
  - Develop models to predict seal performance, plug and well life
    - Annulus plugs, casing plugs
  - **STEM-flow tool developed by Astrimar**
    - Predict barrier and well system performance
    - All barrier elements modelled
    - Materials Database
Use of STEM-flow in Bi alloy Plug Qualification

- Developed to enable forecast of plug and well leak rates, volume released and plug life
- Model parameters are based on
  - measured barrier characteristics such as those defined in OGUK guidelines
  - Specified acceptance criteria
  - Plug design
- MCS routines are used to address uncertainty in parameters
- Generates distribution of plug/well life
- Qualification test data used to reduced the uncertainty in predicted performance
- Compare new plug material performance with existing cement performance

Predicted Life for Various P&A Scenarios

<table>
<thead>
<tr>
<th>Good cement, logged annulus</th>
<th>Low shrinkage cement, logged annulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000ft Unlogged annulus combination barrier</td>
<td>10 ft Bismuth plug, logged annulus</td>
</tr>
</tbody>
</table>
How can new P&A materials ever demonstrate they are good enough to meet industry requirements?

These material and design parameters will deliver plugs with the required life.

Giving Life > 3000 yr.

Benefits of Qualification of Structural Bismuth Alloy Annulus Plug

Impact on Bi Alloy life uncertainty following TRL 4 extensive testing

Life expectation for an unqualified Bi Alloy annulus plug密封 against cap rock

Large uncertainty in predicted leak rate and life

Life expectation for a qualified Bi Alloy annulus plug sealing against cap rock

Marked improvement in leak rate and life performance
Conclusions

• Performance depends on requirements
  – H/C Breakthrough, maximum leak rate or volume released

• Barrier material properties:
  – Do not directly relate to required barrier performance
  – Interface properties more important than bulk material properties
  – Modelling is required to translate measured properties to performance

• Significant life performance uncertainty around the impact of long term material degradation on bulk and annulus barrier leakage

• Without qualification data – performance uncertainties are large

• Qualification reduces performance uncertainty but may still not meet requirements

• STEM-flow is being used to determine the barrier material properties, design and well conditions that will deliver a 3000 year leak free life

Thank you for listening

Questions?

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