Testing and Verification of Thermite Barrier Technology in a UKCS Well Abandonment Scenario - A Case Study

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The P&A Challenge & Thermite

Well abandonments - the future is now
Population of older wells increasing worldwide
Increasing costs compared to previous estimates
ABEX is a concern for operators and governments
Low commodity price environment

Why & How did Spirit Energy got involved with Thermite
• Thermite was a JIP by Interwell P&A, AkerBP and Equinor
• Field trials required but no wells were available.
• Spirit Energy offered to find suitable wells in Canada

The Challenge
• Introduction of Technology needs a new approach
• Innovative application of “old” technology with “revolutionary” approach
• Engaged with OGA and OGTC to develop the opportunity
Thermite Reaction

History
Hans Goldschmidt inventor of the Goldschmidt reaction in 1893
Aluminothermic Process patent no. 96317 in 1895 and THERMIT® Registrated Trademark in 1900

Chemical reaction
Aluminium (Al) reduces the oxide from iron oxide (Fe2O3), to form Aluminium Oxide (Al2O3) and pure iron (Fe)
Reaction energy ~4000 kJ/kg
Reaction temperature ~2500 ºC

Original thermite reaction
Fe2O3 + 2 Al → 2 Fe + Al2O3 + ΔH
Hematite, rust, red color

What is an Exothermic Reaction;
Any mixture of two or more chemicals that produces heat when activated.

Why thermite is preferable;
Self sustained oxygen source (Iron Oxide)
High energy potential in both materials
Self sustained reaction after activation
Thermite Plug Deployment

Thermite’s original P&A Cartoon

A wireline conveyed tool containing heat generating material is lowered into well and ignited.

A column of molten magma is created - which will melt all wellbore elements and solidify into a permanent barrier in hours.

Thermite Technology aims to restore the caprock by forming a high integrity permanent barrier.
Thermite barrier deployment video
Thermite Deployment Experience

- World’s first field trial in 2016 in Whitehorse in Alberta Canada, followed by another in Benjamin.
- First European trial in England (Caythorpe) in May 2018.
- All three wells onshore with thermite set in 7 inch casing without tubing in the hole.
- Imperial, Shell, Eni, West Lake, Canlin, CNR have also carried out onshore trials
- First Offshore Deployment on Spirit Energy’s Audrey platform in the North Sea
- Extensive deployment experience (18 trials in total). Focus now on ‘verification like cement’….
Challenging process ahead

- Resistance to new technology
- Qualify ‘new’ material
- No access to wells for field trials
- Lack of funding for technology development
- Competing with cement
- Establish Common Industry Approach
- A new education process
Thermite Pre/Post Deployment Barrier Verification
Thermite Barrier Verification

establishing what ‘good’ looks like

Baseline phase
• Tubing pressure tests (pre-work)
• Casing integrity survey (wireline)
  • Ultra-Sound cement bond mapping
  • Passive Spectral Acoustic and High Precision temperature logging
  • Production logging using mechanical and heat exchange flowmeters

Deployment phase
• Tool ignition signature (pressure wave)
• Positive pressure test (deferred as heatshield packer is used)

Post-Deployment phase
• Positive pressure test (drop off test = 122 bar static dP)
• Extended inflow test
• Thermite Barrier inspection
  • Camera survey
  • Ultra-Sound cement bond mapping
  • Passive Spectral Acoustic and High Precision temperature logging
  • Production logging using mechanical flowmeters
Deployment verification - Ignition Signature

Well pressure increased to 880 psi / 2520 psi downhole
Thermite tool ignited
Pressure increased from reaction
Choke operated keeping pressure between 900 and 1,000 psi
Maintained pressure on the well between 900 and 1,000 psi
Deployment verification - Cement Bond

Cement bond & Ultra sound survey:
- Well bounded, heterogeneous, cement around the entire annulus with non-connected liquid pockets
- Well immediately above the plug un-affected by Thermite reaction
Deployment verification - Reservoir Isolation

Baseline Chorus Survey
Conclusion:

- No flow-related activity observed on Chorus (SNL)
- No flow-related activity observed on High Precision Temperature
- No flow-related activity observed on Indigo PLT log
Deployment verification - Thermal modelling
Failure models comparison

- Cement model
- Thermite model
Chorus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Temperature rating</td>
<td>0 to 150°C (32 to 302°F)</td>
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<tr>
<td>Pressure rating</td>
<td>100 MPa (14 500 psi)</td>
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<tr>
<td>H₂S resistance</td>
<td>&lt;30%</td>
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<td><strong>Frequency range</strong></td>
<td><strong>8-60 000 Hz</strong></td>
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<td><strong>Dynamic range</strong></td>
<td><strong>100 dB</strong></td>
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<td>Recording time (mem. mode)</td>
<td><strong>70h</strong></td>
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<tr>
<td>Tool OD</td>
<td>38/42mm (1.5 / 1 11/16&quot;)</td>
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<tr>
<td>Length</td>
<td>80cm (2.6')</td>
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<tr>
<td>Weight</td>
<td>7 kg (15.4 pounds)</td>
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Noise (Chorus) Pattern Interpretation Library

Thermite Barrier Post Deployment Verification

- **Reservoir flow**
  - Fractures
  - Large Pores
  - Medium Pores
  - Tight Formations

- **Borehole flow**
  - Channelling behind the casing

- **Channelling behind Casing**

- **Fracture Flow**

- **Matrix Flow**

The diagram illustrates different flow patterns and their underlying geological features, including permeability and frequency ranges associated with various flow conditions.
Post Well Schematics - Examples

Plug Failure

Plug Successful

Baseline (Shut-in)

Verification (Bleed-off)

Baseline (Shut-in)

Verification (Pressure-up)
Caythorpe CA02 Thermite Trial
Caythorpe 2 Thermite Trial – BDF 28
Key Objectives of Onshore Thermite Trial

- First UK / European deployment of the Thermite plug, as part of the phased technology development programme (following the 2017 trials in Canada).
- Engage with EA, OGA and HSE to obtain regulatory consent to use the equipment onshore.
- 1st trial for setting Thermite plug in Halite formation, common cap rock in UKCS SNS.
- Establish common application method and verification programme for Thermite P&A technology.
- Share the results with the Thermite Collaboration Forum to accelerate adoption of new P&A technology in the UKCS.

Case study: Caythorpe CA02 Thermite Trial
Case study: Caythorpe CA02 Thermite Trial

The CA02 schematic is the planned well schematic following the Thermite trial. This is subject to change once the actual operation becomes completed.
Well Re-entry & Preliminary results

- Positive pressure test
- Displaced Well to Nitrogen
- Extended inflow test
- 14 psi / hr PBU rate
- (equivalent of 5 SCF/min leak)
Audrey B1z Thermite Trial
Audrey B1z Thermite Trial
Key Objectives of Offshore Trial (Top 5)

- First (global) offshore deployment of the Thermite plug, as part of the phased technology development programme.
- Engage with OGA, OPRED/BEIS and HSE to obtain regulatory consent to use the equipment offshore.
- 2nd trial for setting Thermite plug in Halite formation, at lower angle compared with CA-02 (common SNS Caprock).
- Share the results with the Thermite Collaboration Forum to accelerate adoption of new P&A technology in the UKCS.
- Progress Industry Common Verification road map for new P&A technology and barrier material.
Well Schematics - Planned P&A

Case study: Audrey B12 Thermite Trial
Interim Well Status

Suspension
- (100bbl/hr losses observed prior to setting Heatshield packer assembly)
- BVS w/ gauges & micro-smart valves set below Thermite plug
- Suspend B1z with deepset Interwell plug above Thermite, and shallow set Archer plug as 2nd barrier.

Next
- Verify integrity of Thermite plug with BVS receiver and repeat TGT SNL log.
- Continue with ‘Standard’ abandonment programme
Well Re-entry & Preliminary results

Re-entry
- Moved back to B1z & pulled suspension plugs
- Monitored wells for statics losses – 6 bbl/hr
- Decision made to curtail verification programme (exit strategy)
- Cancelled TGT Spectral Noise Log
- Cancelled Run BVS receiver log & pressure test
- Continued with P&A programme

Preliminary results
- Thermite successfully permitted / shipped offshore
- Successfully deployed without incident
- Losses at 100 bbl/hr prior to thermite plug
- Reduced to 6 bbl/hr after setting thermite plug
- Unable to carry out pressure test
- Washup & review with Interwell ongoing
Thank you

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### Micro-annulus cell - test with gas

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<th>Depth (cm)</th>
<th>Well Sketch</th>
<th>0.06 (10 bar)</th>
<th>0.30 (19.4 bar)</th>
<th>0.60 (29.5 bar)</th>
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- 10 bar, 0.9 L/min
- 19.4 bar, 3.0 L/min
- 29.5 bar, 12.0 L/min
"Good" cement induced micro-annulus – test with water

60bar, 1.3mL/min  
80bar, 1.7mL/min  
100bar, 3.6mL/min  
120bar, 9.7mL/min  
140bar, 31 mL/min