REVOLUTIONARY P&A
Melting rock using Thermite

MIKE RICHARDSON – Spirit Energy
With input from Interwell
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• Traditional P&A is a Pain – problems associated with traditional P&A which make it expensive

• A New Idea for an Old Technology – creating an in situ barrier using thermite

• Thermite Chemistry – how thermite works

• Creating a Barrier – the operational part – running the tool and creating the barrier

• Does it Work – field trials so far

• Verification – consistent approach to assess effectiveness

• Collaboration – accelerating acceptance

• Forward plan
Why and how Spirit got involved

• This P&A project is a JIP by Interwell P&A, BP and Statoil with the Norwegian Research Council

• The project required a test well for field trials but there were none available

• Spirit (Centrica) were interested in reducing abandonment liabilities

• Offered to find suitable wells in Canada which would be cheaper and easier than the North Sea

• Agreed Spirit would provide the wells, management and well engineering, Interwell P&A would cover external costs

• Value to Spirit can only be realised if the technique is recognised as being acceptable –stakeholder management critical
The Problem

Well Abandonments - The future is now

- Increasing costs compared to previous estimates

- ABEX (Abandonment Expense) concern for operators and governments

- Effectiveness & long term integrity

- Low commodity price environment

- Population of older wells increasing worldwide
Traditional P&A is a Pain

• Well construction techniques not perfect

• Well records sometimes inaccurate / incomplete

• Progressive deterioration

• A life time of integrity issues need to be resolved during the P&A phase
  - Pulling casing
  - Section milling
  - Cement squeeze

• It’s time consuming and expensive
A New Idea for an Old Technology

• The thermite reaction discovered in 1893 by German chemist Hans Goldschmidt.

• The first commercial application was the welding of tram tracks in Essen in 1899.
A New Idea for an Old Technology

• Thermite generates intense heat

• The heat creates molten magma

• The magma solidifies bonded to the formation

• The cooled magma creates a pressure barrier
A New Idea for an Old Technology

• Non explosive
• Exothermic reaction
• Creates ≈2500-3000 degC.
• Melts wellbore components and surrounding rock
Surface Testing

Aluminium Oxide

Schist/Slate

Iron
A New Idea for an Old Technology

**Conventional P&A (Cement)**

- Cement plugs placed with rig
- Tried and tested technique
- Access to annuli to re-establish integrity
- Expensive and time consuming

**Thermite P&A**

- Wireline deployed with no rig
- Recreate the cap rock
- Melt the well components and adjacent formation
- Quick, easy, cheap and effective

**Thermite Chemistry**

- **Strongly exothermic reaction**
- **Oxygen in the Iron Oxide is taken up by the Aluminium**
- **Temperatures vary according to exact composition**
- **Typical reaction temperature is 2500-3000 deg C**
  Reaction energy ~4000 kJ/kg
- **Exothermic but not violent, relatively slow reaction**
- **Heat localised to within a few metres**
- **Very stable components. Require significant heat to initiate reaction**

**Original thermite reaction**

\[
\text{Fe}_2\text{O}_3 + 2 \text{Al} \rightarrow 2 \text{Fe} + \text{Al}_2\text{O}_3 + \Delta H
\]

Hematite, rust, red color

**Alternative thermite reaction**

\[
3\text{Fe}_3\text{O}_4 + 8 \text{Al} \rightarrow 9 \text{Fe} + 4\text{Al}_2\text{O}_3 + \Delta H
\]

Magnetite, millscale, black color

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**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
Typical Rock Composition

<table>
<thead>
<tr>
<th>Mineral Composition</th>
<th>Granite %</th>
<th>Basalt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>70.2</td>
<td>49.1</td>
</tr>
<tr>
<td>Al2O3</td>
<td>14.4</td>
<td>15.7</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>1.6</td>
<td>5.4</td>
</tr>
<tr>
<td>FeO</td>
<td>1.8</td>
<td>6.4</td>
</tr>
<tr>
<td>MgO</td>
<td>0.9</td>
<td>6.2</td>
</tr>
<tr>
<td>CaO</td>
<td>2.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Na2O</td>
<td>3.5</td>
<td>3.1</td>
</tr>
<tr>
<td>K2O</td>
<td>4.1</td>
<td>1.5</td>
</tr>
<tr>
<td>H2O</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Rest</td>
<td>0.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Thermite Chemistry

Final plug composition is a mixture of the thermite reaction products and the in-situ material.

- Aluminium Oxide
- Iron
- Silicon Dioxide
- Iron Oxide
- Magnesium Oxide
- Calcium Oxide
- Sodium Oxide
- Potassium Oxide
Thermite Chemistry

- Thermite reaction takes place in water or with water present
- Instead of producing steam, the high pressure (hydrostatic) and the high temperature produce Super Critical Water
- Under these conditions water becomes a fluid with unique properties. The fluid has a density between that of water vapour and liquid at standard conditions
- Result is less expansion than if steam was generated – reduced pressure surge
- Currently testing in sub critical conditions
Test tank - Trondheim
Creating a Barrier

Key Features

• The thermite plug is run on top of a bridge plug
• The bridge plug is protected with a thermal barrier
• The thermite is conveyed on normal electric line
• The container is a thin walled 6 metre aluminium and steel tube
• The ignition system is electrical
• The thermite mixture has pore space between the grains
• The pore space is filled with Nitrogen at a pressure similar to the hydrostatic pressure at setting depth
• The conveyance tube includes a pressure equalisation system, instrumentation and data recording
• Most of the tube is consumed in the thermite reaction. The top part with data store is (hopefully) recovered
• It takes about 5 minutes for the reaction to take place
• The downhole pressure is controlled at >220 Bar (hydrostatic + applied)
Creating a Barrier

Surface Equipment

- During the testing phase, small test package deployed on site to handle any pressure surges

- In practice the pressure has been very easy to handle with a low volume bleed off and pressures well under the capacity of the well pressure envelope

- High sampling frequency, high accuracy pressure gauges with data transmission have proved invaluable

- Most of the work is done with the electric line unit. Small workover rigs have been used for well preparation (tubing pulling etc)

- Wireline pressure control equipment

- Office and coffee machine for observers!
Basic Programme

1. 7 inch casing in well

2. Pull tubing

3. Fill or partially fill well with fresh water

4. Run Anchor (leaky bridge plug)

5. Run Heat Shield

6. Confirm Reservoir and barrier setting depth in communication

7. IWPA deployment tool

8. Monitor pressures

9. Carry out verification program
Ignition Pressure Graph

≈20 Bar above initial surface pressure

≈80 Bar above initial surface pressure

≈40 Bar above initial surface pressure
### Does it Work?

Field Testing Phase Ongoing

<table>
<thead>
<tr>
<th>Operator</th>
<th>Location</th>
<th>Well</th>
<th>Date</th>
<th>Objectives Met</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrica (Spirit)</td>
<td>Canada</td>
<td>Whitehorse</td>
<td>August 2016</td>
<td>✔️</td>
</tr>
<tr>
<td>Centrica (Spirit)</td>
<td>Canada</td>
<td>Benjamin</td>
<td>September 2016</td>
<td>✔️</td>
</tr>
<tr>
<td>Imperial</td>
<td>Canada</td>
<td>High River</td>
<td>August 2017</td>
<td>✔️</td>
</tr>
<tr>
<td>Imperial</td>
<td>Canada</td>
<td>Okotoks</td>
<td>August 2017</td>
<td>✔️</td>
</tr>
<tr>
<td>Shell</td>
<td>Canada</td>
<td>Ground Birch</td>
<td>October 2017</td>
<td>✔️</td>
</tr>
</tbody>
</table>
Centrica – Benjamin 20

Sept 16 - Feb 17
• Gas influx - no H2S

Feb-17
• Displaced well to water
• Pressure test failed

Sept-17
• Sampled fluid above barrier - no H2S
• Water level at 410m

Conclusion Sept 2017:
• Reservoir is sealed
• Communication with caprock
• Both wells on longterm monitoring
• Currently no influx
• Gas sampling planned Jan-18
• Hope to conclude Feb-18

Preliminary conclusion:
• Reservoir sealed on both wells
• Communication with caprock
• Flawless execution
• Well is overpressured - left with water
• Potential wellhead pressure with water is 22 bar
• Small pressure build-up - currently 7 bar

Preliminary conclusion:
• Reservoir sealed
• Evidence of gas at surface containing H2S from caprock (reservoir is sweet)
• Jan 4: Currently performing carbon isotope analysis
Verifying is key part of developing the new technology.

Product development overseen by DNV-GL.

Integrity of barrier assessed in several ways.

Impact on well of setting process on well pressure envelop also critical.

Developed a set of verification tools.

Verification Road Map in progress.
# Verification

<table>
<thead>
<tr>
<th>Test</th>
<th>Objective</th>
<th>Acceptance</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition signature</td>
<td>Did the tool operate as planned?</td>
<td>?</td>
<td>OK</td>
</tr>
<tr>
<td>Tag</td>
<td>Was a physical barrier created?</td>
<td>5 T weight test</td>
<td>OK</td>
</tr>
<tr>
<td>+ve Pressure Test</td>
<td>Does the barrier contain pressure?</td>
<td>15 mins within 350kPa</td>
<td>OK</td>
</tr>
<tr>
<td>-ve Pressure Test</td>
<td>Does the barrier contain pressure?</td>
<td>15 mins within 350kPa</td>
<td>OK</td>
</tr>
<tr>
<td>CBL</td>
<td>Is there any damage to the cement bond casing / formation?</td>
<td>Before / After comparison independent log analysis</td>
<td>OK</td>
</tr>
<tr>
<td>Casing log</td>
<td>Is there any damage to the casing?</td>
<td>Before / After comparison independent log analysis</td>
<td>OK</td>
</tr>
<tr>
<td>Gas Migration</td>
<td>Is there evidence of gas migration around the surface location?</td>
<td>Before / After comparison</td>
<td>OK</td>
</tr>
<tr>
<td>Vent flow</td>
<td>Is there any change to the well annulus pressures?</td>
<td>Before / After comparison</td>
<td>OK</td>
</tr>
<tr>
<td>Seismic event</td>
<td>Was there any potentially damaging shockwave transmitted to surface?</td>
<td>Before / After comparison</td>
<td>OK</td>
</tr>
<tr>
<td>Extended Inflow Test</td>
<td>Long term verification of pressure barrier and isolation of reservoir</td>
<td>Ongoing dialogue</td>
<td></td>
</tr>
</tbody>
</table>
What is a good pressure test? Long term tests of the well pressure envelope are not normal in our industry.

Long term inflow test is a good benchmark verification – but what is an acceptable acceptance criteria?

- Establish robust pressure test base line for well prior to setting thermite plug.
- Require a common approach to verification. - Verification road map.
- Positive dialogue with regulators UK and Norway with a view to establish acceptance criteria.

### Pressure test

<table>
<thead>
<tr>
<th>Surface pressure</th>
<th>Diff across barrier</th>
<th>Duration</th>
<th>Leak-off rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 bar</td>
<td>190 bar</td>
<td>8 hours</td>
<td>0.007 bar/10min</td>
</tr>
<tr>
<td>70 bar</td>
<td>120 bar</td>
<td>1 hour</td>
<td>0.16 bar/10min</td>
</tr>
<tr>
<td>70 bar</td>
<td>120 bar</td>
<td>1 hour</td>
<td>0.5 bar/10min</td>
</tr>
<tr>
<td>90 bar</td>
<td>70 bar</td>
<td>30 min</td>
<td>0.65 bar/10min</td>
</tr>
</tbody>
</table>

### Longterm inflow test

<table>
<thead>
<tr>
<th>Diff across barrier</th>
<th>Duration</th>
<th>Build rate</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 bar</td>
<td>122 days</td>
<td>0.07 bar/day</td>
<td>0.0005 bar/10min</td>
</tr>
<tr>
<td>70 bar</td>
<td>150 days (ongoing)</td>
<td>0.06 bar/day</td>
<td>0.0004 bar/10min</td>
</tr>
<tr>
<td>70 bar</td>
<td>140 days (ongoing)</td>
<td>0.4 bar/day</td>
<td>0.003 bar/10min</td>
</tr>
<tr>
<td>22 bar</td>
<td>30 days (ongoing)</td>
<td>0.24 bar/day</td>
<td>0.0017 bar/10min</td>
</tr>
</tbody>
</table>

Ongoing, stable pressure pr Jan-2018
Ongoing, declining pressure trend Jan-2018
Ongoing pr Jan-2018
## Thermite Verification Road Map

<table>
<thead>
<tr>
<th>Threat</th>
<th>CAUSE</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not all thermite ignited</td>
<td>Energy expired early</td>
<td>High Volume of Water dissipated energy</td>
<td>Fracturing at rock interface</td>
<td>Settling to Low Side of deviated well</td>
<td>Seismic Activity</td>
<td>Environmental Conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Annular Bond</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Through Barrier</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Term Stability of Barrier</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Verification

- Pressure Differential (Top to Bottom)
- Pressure Differential (Bottom to Top)
- Temperature Probe above
- Weight Tag
- Camera Run to Top of Fishneck
- Camera Run inside Barrel
- Camera Run inside Barrel
- Camera Run inside Barrel
- Camera Run inside Barrel
- Camera Run inside Barrel
- Camera Run inside Barrel
- Camera Run inside Barrel

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**Spirit Energy**

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Collaboration

- Sharing plans and experience can have a dramatic effect on the speed of product maturation
- Urgent need in the North Sea to improve P&A efficiency
- Collaborative need identified but no ‘neutral platform’
- OGTC facilitate the forum and provided a loose legal framework

Some of the organisations who have been keen to collaborate
Forward plan

Forward trial plan:

• 4 Feb 2018 – Spirit Energy – onshore England – 1 well

• Mid Feb 2018 – Eni – onshore Sicily – 1 well
Way forward  (Pilot Testing and Field Implementation)

- **2016**
  - **Tank testing**
  - 2 x trials
  - (7" csg)
  - Integrity behind pipe
  - Supercritical

- **2017**
  - 3 x onshore trials
  - One string 5.5"
  - Deviation
  - Gas migration behind pipe
  - Subcritical

- **2018**
  - **Onshore wells**
    - One string various sizes
    - Deviation
    - Gas migration behind pipe
    - Subcritical
  - **Offshore wells**
    - One string various sizes
    - Deviation
    - Gas migration behind pipe
    - Subcritical
  - **Onshore or offshore wells**
    - Two strings (7" x 9-5/8")
    - Gas migration behind pipe
    - No cement
    - Subcritical

- **2019**
  - Onshore or offshore wells
  - Various 2 strings config
  - Gas migration behind pipe
  - No cement
  - Subcritical

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JIP I | JIP II | JIP III
**Major Reservoir Seals**

**Zechstein top seal**
- Ultimate top seal of thick, impermeable salt, >600 ft
- Major fault displacements, several hundred feet throw
- No direct fault pathway to surface

**Leman**
- Juxtaposed against Zechstein salts to north
- Shaley non-reservoir Carboniferous to south
- Smaller throw across north-south faults with less sealing potential

**Kirkham Abbey formation (KAF)**
- Blanketed by Zechstein salts and local anhydrite
- Basal limestone to KAF – bottom/side seals, KAF more limestone dominated to west
- Pressure separated from Leman

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Caythorpe Site Information
**Caythorpe 2 (B2)**

**Well History**
- Drilled in 1989 by Kelt UK
- Tested Leman and KAF, minor gas flow
- Completed and brought on production in 1992 as a Leman producer
- Recompleted as a KAF producer in 2002

**Well Status**
- Well left suspended with 3 x plugs
- Upper part of tree removed

**Formation isolation required**
- Leman,
- Kirkham Abbey formation (KAF)

**Total Well Depth**
- 7,600 ft MDRT 6,416 ft TVDRT

**Maximum Inclination**
- Vertical section til 3,829 ft
- 43.9 deg (6,427 ft MD)