Wireline Production Services & Pulsed Neutron PNX

Michel Claverie
London Petrophysical Society; 21-Jan-2016
Wireline PS & Slickline - a union of complementary expertises

**Wireline Production Services**
- 4,500 people
- Measurement & conveyance expertise
- > 1400 units

**Slickline**
- 2,300 people
- Mechanical intervention expertise
- > 600 units

**Leader in the cable conveyed production and intervention market**
Wireline ES & PS conveyance

- **Wireline**
  - heptacable
  - mono- & coaxcable
- **Drillpipe conveyed (TLC)**
- **Tractor**
  - Cased hole: MaxTrac & TuffTrac
  - Open hole: UltraTrac
- **Coil tubing**: memory, eCoil, ACTive
- **Pump-down**
- **ThruBit**
StreamLine cable – Production Services

- Polymer encapsulated
- Smooth outer jacketed
- Solid inner & stranded outer armors
- Temperature: -40 to 375 degF
- Safe working load: 5000 lbf

40% lower friction and tension → access deeper and more deviated holes
StreamLine cable – Production Services

- Polymer encapsulated
- Smooth outer jacketed
- Solid inner & stranded outer armors
- Temperature: -40 to 375 degF
- Safe working load: 5000 lbf

1. 1500 bend cycles over sheave
2. Outer jacket cuts
3. 1000 additional cycles → no appreciable cut propagation
StreamLine cable – Production Services

- Polymer encapsulated
- Smooth outer jacketed
- Solid inner & stranded outer armors
- Temperature: -40 to 375 degF
- Safe working load: 5000 lbf

- Reduced foot print
- Less rig up height required → enables longer tool string
PNX - Pulsed Neutron

Ref.: “An Innovative Slim Pulsed Neutron Logging Tool”
David Rose *et al.*, SPWLA paper XXXX, 2015
PNX overview

Measure point
9 ft

175 degC
15K psi

Deep (YAP)
Far (LaBr3)
Near (LaBr3)

PNG & CNM

1.72 in. OD
18.3 ft length
NACE compliant

Measurements

• HI, Sigma, Inelastic Gas (GSH)
  - Challenging cased hole environments
  - Gas in borehole
  - Complex completions
  - Differentiate gas-filled porosity from tight

• Carbon/Oxygen, Capture Spectroscopy (IC)
  - Cased hole spectroscopy
  - High temperature C/O
  - C/O logging time reduced

• WFL, 3-Phase Holdup

Key Technologies

• High output smart PNG
• Near & Far (LaBr3) and Deep (YAP) GR detectors
• Compact neutron monitor (CNM)
PNX Answer Products for Formation Evaluation

**OH FE**
- Resistivity
- Density
- TNPH
- Spectroscopy
- Carbon Meas.
- Gamma ray

**Application Examples**
- Water Saturation
- Porosity (Gas X-over)
- Porosity (Gas X-over)
- Lithology
- HC Saturation (TOC)
- Shale Indicator

**RST CH FE**
- Formation Sigma
- TPHI
- Spectroscopy
- Carbon Yield (C/O)
- Gamma ray

**PNX CH FE**
- Formation Sigma
- GRat
- TPHI
- Spectroscopy
- Spectroscopy *
- Carbon Yield (C/O)*
- Gamma ray

* Under development
PNX provides independent formation measurements & properties

- Inelastic Gas (GRat)
  - FNXS (Fast Neutron Cross Section – 14MeV Elastic Scattering XSection)

- Sigma
  - Capture Cross Section

- TPHI
  - Neutron Porosity (HI)

- Spectroscopy
  - Elemental Concentration
PNX provides independent formation measurements & properties

- **Inelastic Gas (GRat)**
  - FNXS (Fast Neutron Cross Section – 14MeV Elastic Scattering XSection)
- **Sigma**
  - Capture Cross Section
- **TPHI**
  - Neutron Porosity (HI)
- **Spectroscopy**
  - Elemental Concentration

Elastic scattering
- any neutron in
- neutron out
Open hole gas detection

- 1.5 pu water-filled limestone
- 10 pu gas-filled limestone
- 10 pu water-filled limestone

TNPH: 0.45 ft³/ft³ - 0.15 ft³/ft³
RHOB: 1.95 g/cm³ - 2.95 g/cm³
Current cased hole gas detection

<table>
<thead>
<tr>
<th>SIGM</th>
<th>0</th>
<th>cu</th>
<th>TPHI</th>
<th>0.45 ft³/ft³</th>
<th>-0.15</th>
<th>IRAT</th>
<th>0.5</th>
<th>0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>10</td>
<td>1.5 pu water-filled limestone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>10</td>
<td>10 pu gas-filled limestone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>-20</td>
<td>10 pu water-filled limestone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>
PNX cased hole gas detection

1.5 pu water-filled limestone

10 pu gas-filled limestone

10 pu water-filled limestone
GSH - Gas, Sigma, HI - burst scheme

Sequence of bursts
- charges the formation with source neutrons, as a long burst does
- provides access to thermal neutron at early time → substantial benefits for FNXS and TPHI

Bursts 2 to 21 are stacked

Packets

GSH Packet

Short Sigma Burst Gas Bursts Long Sigma Decay

1 2 3 21 22

Delay Burst Off Background

Inst CR

0 200 400 600 800 1000 1200
time (us)

10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}

0 2

3

4

5

6

10^0

10^1
GRat and FNXS Algorithms (1/2)

Objectives of GRat:
- HI sensitivity (huge)
- Borehole effects (big)
- Gas sensitivity (small)

- HI sensitivity (tiny)
- Borehole effects (big, HI free)
- Gas sensitivity (small)

\[ GRAT = \frac{DeepA - a \cdot DeepB}{NMTCR} \]

- DeepA: deep detector count rate A Gate
- DeepB: deep detector count rate B Gate
- NMTCR: neutron monitor count rate

Measure point

175 degC
15K psi

Deep (YAP)
Far (LaBr3)
Near (LaBr3)

PNG & CNM

1.72 in. OD
18.3 ft length
NACE compliant
GRat and FNXS Algorithms (2/2)

Correlation GRat vs. FNXS for various lithologies and fluids

**FNXS**
- Neutron Elastic Scattering Cross Section at source energy (14MeV)
- New formation property
- Volumetric mixing (like Sigma)

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cc)</th>
<th>TPHI</th>
<th>FNXS (1/m)</th>
<th>SIGMA (cu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>2.65</td>
<td>-.03</td>
<td>6.84</td>
<td>4.55</td>
</tr>
<tr>
<td>Limestone</td>
<td>2.71</td>
<td>0</td>
<td>7.51</td>
<td>7.08</td>
</tr>
<tr>
<td>Dolomite</td>
<td>2.87</td>
<td>.03</td>
<td>8.51</td>
<td>4.70</td>
</tr>
<tr>
<td>Water</td>
<td>1.00</td>
<td>1</td>
<td>7.80</td>
<td>22.20</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.83</td>
<td>1.1</td>
<td>7.85</td>
<td>23.84</td>
</tr>
<tr>
<td>CH4 (0.15g/cc)</td>
<td>0.15</td>
<td>0.21</td>
<td>2.01</td>
<td>7.50</td>
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PNX provides independent formation measurements & properties

- Inelastic Gas (GRat)
  - FNXS (Fast Neutron Cross Section – 14MeV Elastic Scattering XSection)
- Sigma
  - Capture Cross Section
- TPHI
  - Neutron Porosity (HI)
- Spectroscopy
  - Elemental Concentration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Borehole and Casing</td>
<td>Hole Size</td>
</tr>
<tr>
<td></td>
<td>(Casing OD (in.), Casing Weight (lbm/ft))</td>
</tr>
<tr>
<td>4.125</td>
<td>openhole, (2.875, 6.4), (3.5, 12.7)</td>
</tr>
<tr>
<td>6</td>
<td>openhole, (4.5, 10.5), (5, 18)</td>
</tr>
<tr>
<td>8</td>
<td>openhole, (5.5, 15.5), (7, 23), (7, 32), (4.5, 11.6)</td>
</tr>
<tr>
<td>8.5</td>
<td>openhole, (5, 23.2), (6.625, 20), (7, 23), (7, 32)</td>
</tr>
<tr>
<td>10</td>
<td>(5.5, 15.5), (7, 32), (7.625, 26.4)</td>
</tr>
<tr>
<td>12</td>
<td>(7.625, 26.4), (9.625, 32.3), (9.625, 53.5)</td>
</tr>
<tr>
<td>Lithology</td>
<td>Sandstone, Limestone, Dolomite,</td>
</tr>
<tr>
<td>Porosity</td>
<td>Zero, Medium, High</td>
</tr>
<tr>
<td>Formation Salinity (wt ppk)</td>
<td>0, 70, 140, 210</td>
</tr>
<tr>
<td>Borehole Salinity (wt ppk)</td>
<td>Air, Pseudo-gas, Pseudo-light-oil, 0, 25, 50, 100, 200</td>
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GSH (GRat-Sigma-HI) interpretation crossplot
### Theoretical formation Neutron properties

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Example 1 – North Texas, US Land

- New pay zone to complete in old well?
- No open hole logs
- RST recorded
- PNX logged at 1000 ft/h
- 8.75 in. OH / 5.5 in., 20 lb/ft casing
- Water in borehole
Example 1 – Current difficulties in low porosity or gas zones

Are the zones with low Sigma, low TPHI and high IRAT
• gas zones or
• very low porosity?
Example 1 – Solution with PNX 14MeV Elastic Cross-Section - FNXS

Differentiates gas zone from 0 p.u. zone

Burst ratio response using Deep detector not very different from Near/Far → gas or low porosity?

- Lowering cost per barrel
- Improving financial performance
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- Sigma
  - Capture Cross Section

- TPHI
  - Neutron Porosity (HI*)

- Spectroscopy
  - Elemental Concentration
Example 1 - Standalone PNX petrophysical interpretation

- Si and Ca weight %
- Tool logged at 1000 ft/h
- Q-ELAN linear solver; weighted by input statistical precision
Example 3

- open hole logs available
- no RST
- 8.75 in. bit size
- 7 in., 26 lb/ft casing
- water in borehole
- PNX logged @ 1000 ft/h
Example 3 - Open hole vs. standalone PNX comparison

(OH ELAN calculates shale at 8180 ft due to high 5000 GAPI GR, likely a hot dolomite)
Example 3 - Open hole vs. standalone PNX comparison

Reliable anhydrite indicator from CYS cutoff
Wireline Production Services & Pulsed Neutron PNX

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