Chapter 10 - Neutron logs

Lecture notes for PET 370
Spring 2012
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Neutron Log

- Determination of porosity / Lithology
- Delineation of porous formations
- Gas detection (with other logs)
- Estimation of shale content (w/ other logs)
Emitted neutrons interact with matter by:

**Elastic scattering**
- Elastic collisions involving some loss of energy (small nucleus) and no loss of energy (heavy nucleus).

**Inelastic scattering**
- Inelastic scattering where target nucleus absorbs fast neutrons and emits a slower neutron and gamma rays.

**Neutron Capture**
- Neutrons captured by a nucleus, results in a heavier isotope in an excited state.
Neutron Log

Life of a neutron

Source neutrons
4 MeV or greater, depending on type of source

Epithermal neutrons
- 0.1 to 100 eV

Thermal neutrons
peak at 0.025 eV; in thermal equilibrium with surroundings

Capture gamma ray
Effect of target size on energy loss

• Energy lost by collisions is dependent on mass difference

• The heavier the nucleus, the less energy lost

• Hydrogen approximately same mass as neutron, thus highest loss of energy (67%) per collision

<table>
<thead>
<tr>
<th>Hydrogen content</th>
<th>HI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water, oil</td>
<td>1.0</td>
</tr>
<tr>
<td>gas</td>
<td>0.5 - 0.75</td>
</tr>
<tr>
<td>shale</td>
<td>0.17 - 0.42</td>
</tr>
<tr>
<td>clean rock</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Neutron Log

- Neutrons emitted from radioactive source
- Collide and lose energy (Billiard ball effect)
- Primarily dependent on hydrogen concentration or index
- Detect either epithermal neutrons, thermal neutrons, capture gamma rays or combination
- Thus, measures the formations ability to attenuate the passage of neutrons

Principle of Operation

Single detector neutron tool in borehole
• GNT (obsolete)

• SNP (limited)
  – borehole effects minimized
  – automatic corrections
  – applicable to empty holes
  * Rugosity and mudcake effects

• CNL (widespread)

• DNL (next generation)
  – Improved gas detection in shaly reservoirs
  – Improved porosity values due to less matrix effect
Neutron Log

CNL-Compensated Neutron Log

Diagram showing a borehole with a formation, a source, a near detector, a far detector, and an other sonde.
Neutron Log

- thermal neutron detection instrument
- Two detectors minimize borehole effects
- Vertical resolution - 2 ft
- Radial investigation f(porosity) No porosity - 1ft.; High porosity less
- Cased or openhole
- Statistical in nature, logging speed 20-30 fpm
- Can be run with other logs
Neutron Log

- Neutron count rate to porosity relationship developed by lab measurements

- $f$ (porosity, lithology)

- Lithology equivalence curves

- Log calibrated to assumed matrix

CNL response in sandstone, limestone and dolomite formations
Example of a Cased-hole CNL From Prudhoe Bay
Compensated Neutron Log

Dolomite: $\phi_{corr} = \phi_a - 6$, when $\phi_a \geq 12$

$\phi_{corr} = 0.0476\phi_a^2 - 0.0714\phi_a$

Sandstone: $\phi_{corr} = \phi_a + 4$

Sidewall Neutron Log

Dolomite: $\phi_{corr} = 0.00384\phi_a^2 + 0.824\phi_a - 1.240$

Sandstone: $\phi_{corr} = -0.00311\phi_a^2 + 1.106\phi_a + 2.696$

Neutron Equivalence Chart
Western Atlas (1995)
• **Standard Calibrations**
  – 7 7/8 “ borehole
  – Fresh water in borehole and formation
  – no mudcake or standoff
  – 75 deg. F
  – Atm Press
  – Tool eccentered in hole

• **Corrections tedious and net difference small**

• **Automatic processing available**
### Neutron Log

#### Comparison between SNP and CNL

<table>
<thead>
<tr>
<th></th>
<th>SNP</th>
<th>CNL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tool</strong></td>
<td>Pad-type Single detector</td>
<td>Mandrel-type 2 detectors</td>
</tr>
<tr>
<td><strong>Detects</strong></td>
<td>Epithermal neutrons</td>
<td>Thermal Neutrons</td>
</tr>
<tr>
<td><strong>DI</strong></td>
<td>Shallow, 8”</td>
<td>Deeper, 12”</td>
</tr>
<tr>
<td><strong>Borehole effect</strong></td>
<td>Sensitive to mudcake and rugosity</td>
<td>Minimized by compensation</td>
</tr>
<tr>
<td><strong>Depth resolution</strong></td>
<td>16”</td>
<td>10”</td>
</tr>
<tr>
<td><strong>Limitation</strong></td>
<td>Open hole only</td>
<td>Open &amp; cased hole</td>
</tr>
<tr>
<td><strong>Porosity</strong></td>
<td>Count rate $\propto \phi$</td>
<td>Ratio $\propto \phi$</td>
</tr>
<tr>
<td><strong>Advantage</strong></td>
<td>Insensitive to thermal neutron absorbers, e.g., Cl, Boron, Barite</td>
<td>Insensitive to borehole environment</td>
</tr>
</tbody>
</table>

**Advantage:**
- SNP is insensitive to thermal neutron absorbers, e.g., Cl, Boron, Barite.
- CNL is insensitive to borehole environment.
References

  
  Chapter 2, Sec 9-12

  Chapter 9

- Schlumberger, Log Interpretation Charts, Houston, TX (1995)
- Schlumberger, Log Interpretation and Principles, Houston, TX (1989)

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- Western Atlas, Introduction to Wireline Log Analysis, Houston, TX (1995)

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