A novel method to determine NMR petrophysical parameters from drill cuttings
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NMR params from cuttings

- Motivation
- Determining cutting size
- Estimating porosity
- Estimating permeabilities
- Summary & outlook
Outline

- **Motivation**
- Determining cutting size
- Estimating porosity
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NMR measurements

- Have become a great contribution to medical science
- Allow petrophysical parameter derivations:
  - Logs (WL and LWD)
  - Cores
- Why not extend to low cost environments?
The trick in this presentation...

- Take the measurements from the borehole back to the lab = mud logging cabin
- Improved hardware, tightly couple acquisition w/ hardware and focus on application
- Derive special petrophysical models for automated interpretation.
NMR parameter from cores vs cuttings

**Cores pro:**
- Accurate NMR parameter estimation
- Work done in laboratory under controlled condition

**Cores con:**
- Characterizes only selected part of well
- Characterization after drilling
- Turn around time
- Cost
**Why NMR parameters from drill cuttings?**

**In the past:**
- Small particles of cuttings - small signal - impossible to separate signal from noise
- Sample preparation took too much time for well site applications

**Suggested solution:**
- New tool has high signal-to-noise ratio >200
- Optimized workflows include preparation, measurement and interpretation procedures.
- Reduce turn-around time
- Reduce cost
Technology development process

- Market evaluation
- Feasibility study w/ cutting from 1 to 6.35 mm
- Pilot experiments with solid samples and synthetic cuttings
- Pilot measurements (Canada, Russia, US and China)

Results:
- Automated process integrated into one instrument
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Process to find cutting size range

1. Obtain known rock samples
2. **Plugs:** determine total porosity, permeability and Swirr with direct methods.
3. Measure NMR parameters (Sw=100%)
4. Use similar samples for **synthetic cuttings**
5. Measure NMR parameters (Sw=100%)
6. Compare plug & cuttings results
7. Also group by filtration radius & grain size
Cumulative relaxation time
Berea SS (cores & cuttings).

Cores

Cuttings 3.35-6.25 mm

Cuttings 1-3.35 mm
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Porosity determination

- Most critical parameter is volume determination
- Determine hydrogen volume from weight/porosity measurements
- Compare with NMR measurements
- Repeat for light & heavy oil saturations
Hydrogen volume: weight versus NMR

Perfect fit

A

\[ y = 0.939x + 0.215 \]

\[ R^2 = 0.9514 \]

B

Model Number

1 4 7 10 13 16 19 22 25 28 31 34 37 40
Porosity by Archimedes vs. NMR Porosity.

\[ y = 0.9984x + 0.2249 \]

\[ R^2 = 0.9731 \]
Biggest error sources

- Accurate volume measurement

Porosity error
- ± 1.2% literature (Kenyon, 1992; Vinegar, 1995; Coates et al., 1999)
- Approx. 1% NMR from cuttings
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Process

• Determine Perm using standard models (i.e. Mean $T_2$ Model; Free Fluid Model)

$$\log(\text{PERM}) = a \times \Phi_{\text{eff}} + b$$

Pore size distribution and grain size dependent

Where $a$, $b$ are constants Khannin (1976)

We based our values for filtration radii between 5 and 2 µm and rock type (172 samples)
Verification of permeability models

• Models from samples from 6 fields

• Samples from different saturations
  water, oil +S_{wirr}, water+ S_{oil_res}.

• Oils saturated samples contained hydrocarbons with Visc<20cPs.

• The pore surface wettability was water wet, mixed and non-water wet.
Basics of MR-ML™ Model

$$\text{PERM} = a^* \ \theta_{\text{eff}} + b$$
a and b – Gs dependant coefficients

Four models were developed:

<table>
<thead>
<tr>
<th></th>
<th>Lithology</th>
<th>Grain size, mm</th>
<th>Grade</th>
<th>a, b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandstone</td>
<td>0.25-0.5</td>
<td>coarse</td>
<td>$a_1, b_1$</td>
</tr>
<tr>
<td>2</td>
<td>Sandstone</td>
<td>0.1-0.25</td>
<td>medium</td>
<td>$a_2, b_2$</td>
</tr>
<tr>
<td>3</td>
<td>Siltstone</td>
<td>0.05-0.1</td>
<td>fine</td>
<td>$a_3, b_3$</td>
</tr>
<tr>
<td>4</td>
<td>Siltstone</td>
<td>0.01-0.05</td>
<td>very fine</td>
<td>$a_4, b_4$</td>
</tr>
</tbody>
</table>
Perm results comparison

<table>
<thead>
<tr>
<th>Sample/cutting</th>
<th>Direct Perm</th>
<th>Porosity Min.</th>
<th>Porosity Max.</th>
<th>NMR Perm Min.</th>
<th>NMR Perm Max.</th>
<th>Cutting Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Berea-1</td>
<td>38, mD</td>
<td>9.6%</td>
<td>13.1%</td>
<td>18, mD</td>
<td>70, mD</td>
<td></td>
</tr>
<tr>
<td>Sample Berea-2</td>
<td>70.5, mD</td>
<td>12%</td>
<td>14%</td>
<td>45, mD</td>
<td>100, mD</td>
<td></td>
</tr>
<tr>
<td>Cutting Berea</td>
<td>38-70.5, mD</td>
<td>9.2%</td>
<td>13.5%</td>
<td>15, mD</td>
<td>80, mD</td>
<td>3.3 – 6.3</td>
</tr>
<tr>
<td>Cutting Berea</td>
<td>38-70.5, mD</td>
<td>7.3%</td>
<td>10.8%</td>
<td>7.5, mD</td>
<td>30, mD</td>
<td>1.0 – 3.3</td>
</tr>
<tr>
<td>Sample FCR</td>
<td>12.7, mD</td>
<td>8.3%</td>
<td>11.1%</td>
<td>10, mD</td>
<td>32, mD</td>
<td></td>
</tr>
<tr>
<td>Cutting FCR</td>
<td>12.7, mD</td>
<td>6.8%</td>
<td>10.2%</td>
<td>6, mD</td>
<td>22, mD</td>
<td>3.3 – 6.3</td>
</tr>
<tr>
<td>Cutting FCR</td>
<td>12.7, mD</td>
<td>7.5%</td>
<td>11.4%</td>
<td>8, mD</td>
<td>35, mD</td>
<td>1.0 – 3.3</td>
</tr>
</tbody>
</table>
PERM results comparison

Perfect fit

$y = 0.874x^{0.9354}$

$R^2 = 0.9278$
Perm comparison

A 100% water saturation

B Water & oil mixed
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Results from China

Porosity NMR vs Porosity from Customer

\[ y = 1.0997x + 0.812 \]

\[ R^2 = 0.8977 \]

Permeability NMR Kenyon vs Permeability from Customer
Results from Siberia

Porosity Arch vs POR-NMR (NNLS)

\[ y = 0.9984x + 0.2249 \]

\[ R^2 = 0.97 \]

PERM determination according to Criterion 3

\[ y = 0.874x^{0.9354} \]

\[ R^2 = 0.9278 \]
Conclusion

• Porosity, permeability can be determined from drill cutting > 1mm for clastics
• Carbonates require reservoir specific fine tuning of the model.
• Measuring the NMR parameters at the well site is a large cost saving
• As experience with the method increases, we can address other NMR parameters also.
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