Permeability Estimates & Saturation Height Functions: A talk of two halves

Dr Joanne Tudge
LPS Petrophysics 101 Seminar
17th March 2016
Outline

• **Permeability:**
  • What is it?
  • How do we measure it?
  • Why do we need it?

• **Saturation Height Functions:**
  • What are they?
  • How do we use them?
  • Some field examples…
Permeability \((k)\): “The ease of flow of a Newtonian fluid through a medium under pressure”
Permeability ($k$):

“The ease of flow of a Newtonian fluid through a medium under pressure”

“A rocks ability to conduct fluids”

Permeability Estimates
“A rocks ability to conduct fluids”

- Darcy’s Law
- Units: *Darcy* (D) or *milliDarcy* (mD)
- Breaks down under certain circumstances:
  - Turbulent Flow (high flow velocity)
  - Gas flow at low pressure (Klinkenberg effect)

\[ Q = \frac{kA\Delta P}{\mu L} \]

*Where:*

- \( Q \) = volumetric flow rate
- \( A \) = cross sectional area
- \( \Delta P/L \) = pressure drop
- \( \mu \) = the viscosity of the fluid

**Permeability - \( k \)**
Permeability - $k$

"A rock's ability to conduct fluids"

- Depends on:
  - Effective Porosity
  - Grain Size
  - Grain Shape
  - Grain Size distribution (sorting)
  - Grain Packing
  - Cementation / Consolidation
  - Clay type

- Primary Permeability
  - Deposition & Lithification
- Secondary Permeability
  - Compaction
  - Cementation
  - Fracturing
  - Solution

[after Schlumberger]
“A rock's ability to conduct fluids”

- 3 Types of permeability:
  - **Absolute** \((k)\) – rock fully saturated with one fluid type (e.g. water, or oil)
  - **Effective** \((k_o, k_g, k_w)\) – immiscible fluids present – permeability of each fluid
  - **Relative** \((k_r)\) – ratio of Effective to Absolute for each fluid phase: e.g.:
    \[
    k_{ro} = k_o/k \text{ (oil)} \\
    k_{rg} = k_g/k \text{ (gas)} \\
    k_{rw} = k_w/k \text{ (water)}
    \]

Permeability \(-k\) [after Schlumberger]
Methods to estimate $k$

- Log measurements
  - Stoneley waves
  - Formation Testers (*not going to talk about these*)
  - NMR (*not going to talk about this*)
- Core measurements:
  - Permeability measurements
  - NMR (*not going to talk about this*)
- Porosity – Permeability relationships
Log: Stoneley waves

- Measures ‘dynamic’ permeability: because fluid is moved through the formation
- As Stoneley wave passes a permeable formation there is fluid movement between the formation & the borehole
- Attenuates the wave & changes the velocity
- Magnitude of effects are frequency dependant
- Models based on Biot poro-elastic theory relate the above

Methods to estimate $\kappa$
Core Permeability measurements:

\[ Q = \frac{kA\Delta P}{\mu L} \]

Where:
- \( Q \) = volumetric flow rate
- \( A \) = cross sectional area
- \( \Delta P/L \) = pressure drop
- \( \mu \) = the viscosity of the fluid

Methods to estimate \( k \)
Porosity – permeability relationships:

- Relationships can be variable
- Often good for specific beds / formations

Methods to estimate $\kappa$
Field Example #1

\[ y = 1.2643e^{0.2989x} \]
Field Example #1

$y = 2.4726e^{0.2667x}$

$y = 0.0304e^{0.7224x}$
Several uses:

- Predicting flow in the subsurface
- Interaction of fluids (Relative Perm curves)
- Inputs into numerical simulator's – reservoir behaviour
- Cut-offs
- RQI’s
- One use in particular is for *Saturation-Height Functions*

**Why do we need it?**
Saturation Height Functions

- What are they?
- How do we use them?
- Some field examples...

Saturation Height Functions
“A method of estimating Saturation based on the height above the free-water-level and capillary pressure”

What are they?
“A method of estimating Saturation based on the height above the free-water-level and capillary pressure”

Various different types:
- Skelt-Harrison
- Leverett-J Functions
- FOIL Functions
- …To name a few…

What are they?
Leverett-J function:

- Based on capillary pressure, porosity & permeability
- Calculated on Core data
- Transferable to the wireline-log scale

\[
J = J\text{-function} = \left[ \frac{0.217 P_{c_{\text{res}}}}{(\sigma \cos \theta)_{\text{res}}} \right] x \left[ \sqrt{\frac{k}{\phi}} \right]
\]

- \( P_{c_{\text{res}}} = \text{Capillary Pressure} \)
- \( \sigma = \text{Interfacial (surface) Tension} \)
- \( k = \text{Permeability (Core-derived)} \)
- \( \phi = \text{Porosity (Core-derived)} \)
Capillary Pressure

\[ P_c = \frac{h(\rho_w - \rho_{oil})}{2.309} \]
Field Example #2

<table>
<thead>
<tr>
<th>Capillary Pressure</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>8</th>
<th>16</th>
<th>35</th>
<th>64</th>
<th>128</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brine Saturation</td>
<td>1.00</td>
<td>0.87</td>
<td>0.87</td>
<td>0.87</td>
<td>0.82</td>
<td>0.74</td>
<td>0.63</td>
<td>0.53</td>
<td>0.52</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Porosity 0.09
Permeability 0.59
Field Example #2

**Porosity**: 0.09
**Permeability**: 0.59

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Brine Saturation</td>
<td>1.00</td>
<td>0.872</td>
<td>0.872</td>
<td>0.867</td>
<td>0.817</td>
<td>0.736</td>
<td>0.632</td>
<td>0.528</td>
<td>0.515</td>
<td>0.486</td>
</tr>
<tr>
<td>C.P. Res</td>
<td>0.0</td>
<td>0.4</td>
<td>0.7</td>
<td>1.4</td>
<td>2.9</td>
<td>5.8</td>
<td>12.6</td>
<td>23.1</td>
<td>46.2</td>
<td>65.0</td>
</tr>
<tr>
<td>Height</td>
<td>0.0</td>
<td>6.0</td>
<td>11.9</td>
<td>23.8</td>
<td>47.6</td>
<td>95.3</td>
<td>208.5</td>
<td>381.2</td>
<td>762.3</td>
<td>1072.0</td>
</tr>
<tr>
<td>J-Function</td>
<td>0.000</td>
<td>0.010</td>
<td>0.019</td>
<td>0.038</td>
<td>0.077</td>
<td>0.153</td>
<td>0.335</td>
<td>0.613</td>
<td>1.227</td>
<td>1.725</td>
</tr>
</tbody>
</table>
Field Example #2

\[ S_w = 0.4924 J^{-0.128} \]
Sandstone 1: $S_w = 0.4301J^{-0.129}$

Sandstone 2: $S_w = 0.566J^{-0.098}$

Sandstone 3: $S_w = 0.8202J^{-0.044}$

Field Example #2
Field Example #2
Field Example #2

SW? (3330.5m)

FWL (3349.3m)
Field Example #2

- **FWL** (3349.3m)
- **SW?** (3330.5m)
- Porosity = 0.309
- Permeability = 1913 mD
Field Example #2

SW? (3330.5m)
Porosity = 0.309
Permeability = 1913 mD

FWL (3349.3m)
ρ_o = 1.045
ρ_w = 1.19
\[
P_c = \frac{h(\rho_w - \rho_{oil})}{2.309}
\]
\[
P_c = 748.8631
\]

Porosity = 0.309

Permeability = 1913 mD

\[
\rho_o = 1.045
\]
\[
\rho_w = 1.19
\]

Field Example #2
Field Example #2

Porosity = 0.309
Permeability = 1913 mD

\[ P_c = 748.8631 \]

\[ J = \left[ \frac{0.217 P_{c_{res}}}{(\sigma \cos \theta)_{res}} \right] \times \left[ \sqrt{\frac{k}{\phi}} \right] \]

\[ \rho_o = 1.045 \]
\[ \rho_w = 1.19 \]
Field Example #2

Porosity = 0.309
Permeability = 1913 mD

\( P_c = 748.8631 \)

\[
J = \left[ \frac{0.217 P_{c_{res}}}{(\sigma \cos \theta)_{res}} \right] x \left[ \sqrt{k} \right]
\]

\( J = 266.3785 \)

\( \rho_o = 1.045 \)
\( \rho_w = 1.19 \)

FWL (3349.3m)

SW? (3330.5m)
Field Example #2

Porosity = 0.309
Permeability = 1913 mD

\[
P_c = 748.8631
\]
\[
J = \left[ \frac{0.217 P_{c_{res}}}{(\sigma \cos \theta)_{res}} \right] x \left[ \sqrt{k} \phi \right]
\]
\[
J = 266.3785
\]

Sandstone 1: \( S_w = 0.4301 J^{-0.129} \)
$J = \left[ \frac{0.217 P_{c_{res}}}{(\sigma \cos \theta)_{res}} \right] x \left[ \frac{k}{\phi} \right]$

$J = 266.3785$

Porosity = 0.309

Permeability = 1913 mD

$\rho_o = 1.045$

$\rho_w = 1.19$

Sandstone 1: $S_w = 0.4301 J^{-0.129}$

$S_w = 0.65$
**Permeability:**
- Permeability is the ease with which a fluid flows through a rock
- Estimated from core, often estimated from porosity-permeability relationships for rock-types
- Used in saturation height functions

**Saturation Height Functions:**
- Saturation height functions method of estimating $S_w$ based on height above the FWL & Capillary Pressure
- Core & Log scale options

**Summary**
Questions?