Pore Pressure Estimation Using Mechanical Specific Energy (MSE) and Drilling Efficiency

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Pore Pressure
- Lower bound of Drilling Window
- Collapse Pressure (wellbore stability)
- Fracture Gradient

Pore Pressure Estimation
- Direct Measurements (permeable formations)
  - FPWD, MDT, DST,..
  - Kicks, influx and gas data...
- Indirect estimates (for shales)
  - Logs (Sonic, Resistivity, GR,…)
  - Drilling Mechanics data (ROP, RPM, WOB, Torque..)
OUTLINE

• Pore pressure and drilling mechanics data
• d-exponent method
• Mechanical Specific Energy (MSE)
• MSE and pore pressure
• Drilling Efficiency and Pore pressure Workflow
• Field Example
• MSE-based Pore Pre. vs dx-base Pore Pressure
• Downhole vs. Surface data
• Torque @ bit measurement & MSE
Pore Pressure & Drilling Performance

EFFECT OF DIFFERENTIAL PRESSURE ON DRILLING RATE,

HUGHES TOOL CO.
SPE, AIME 1094-G, 1959
d-Exponent Method

Bingham drilling model, 1965  

\[ ROP = K \times RPM \left( \frac{WOB}{d_{bit}} \right)^{dx} \]

Jorden and Shirley in 1966  

\[ dx = \frac{\log \left( \frac{ROP}{60 \text{ RPM}} \right)}{\log \left( \frac{12 \text{ WOB}}{d_{bit}} \right)} \]

Rehm and McClendon, 1971 (corrected for Mud Weight used)  

\[ dXc = \frac{\rho_n}{\rho_w} dX \]

\[ p = \frac{dXc}{dXc} \cdot n \cdot p_n \]
Mechanical Specific Energy (MSE)

Energy required to destroy a unit volume of rock.

\[
MSE = \frac{480 \times T \times RPM}{d_{bit}^2 \times ROP} + \frac{4 \times WOB}{\pi d_{bit}^2}
\]

Teale (1965)

- **T**: Torque, ft.lb
- **WOB**: weight on bit, lbf
- **ROP**: rate of penetration, ft/hr
- **RPM**: revolutions per minute, min^{-1}
- **d_{bit}**: Bit diameter, in
- **MSE**: mechanical specific energy, psi
Pore Pressure & MSE: Experimental Work

University of Tulsa
Rafatian 2009 & Akbari 2014
Pore Pressure from MSE (previous work)

J. Cardona et al. (2011)

Texas A&M University (BP sponsored)

\[
P_P = \frac{OB}{D} - \left[ \frac{OB}{D} - \left( \frac{P_P}{D} \right)_N \right] \left( \frac{MSE_N}{MSE} \right)^\eta
\]
Confined Compressive Strength (CCS)

\[ CCS = UCS + \Delta p \left( \frac{1 + \sin \theta}{1 - \sin \theta} \right) \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
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<tbody>
<tr>
<td>UCS</td>
<td>Unconfined Compressive Strength, psi</td>
</tr>
<tr>
<td>( \theta )</td>
<td>angle of Internal friction, Rock property</td>
</tr>
<tr>
<td>( \Delta p )</td>
<td>Confining Pressure, psi</td>
</tr>
<tr>
<td>CCS</td>
<td>Confined Compressive Strength, psi</td>
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</tbody>
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Drilling Efficiency:

\[ DE = \frac{\text{Rock Strength (insitu)}}{\text{Energy required to break}} = \frac{CCS}{MSE} \]

\[ \Delta p = ECD - PP \]
Drilling Efficiency (DE) and Pore Pressure

\[
DE = \frac{\text{Rock Strength (insitu)}}{\text{Energy required to break}} = \frac{CCS}{MSE}
\]

\[
DE_p = \frac{CCS_p}{MSE}
\]

\[
\Delta DE = DE_p - DE_{trend}
\]

\[
DE_{trend} = a \theta^b
\]

Normal compaction porosity trendline

\[
p = ECD - DE_{trend} \times MSE - UCS \times \left(1 - \sin \theta \right) \left(1 + \sin \theta \right)
\]

\[
p = p_n + \Delta DE \times MSE \times \left(1 - \sin \theta \right) \left(1 + \sin \theta \right)
\]
Pore Pressure from MSE Work-Flow

**Drilling Parameters**
(Torque, WOB, ROP, RPM, bit size)

**Sub-surface data**
Sonic Log/Seismic (Vp, ...)
Bottomhole Pressure (ECD, Mudweight)

**MSE**

**UCS & IFA**
(Rock Strength)

**Drilling Efficiency Trendline, DE_{trend}, (from Porosity NCT)**

Optional for trendline comparison only

- CCS
- Pseudo Drilling Efficiency, DE_p
- MSE_n
- $\Delta$DE = DE_p - DE_{trend}

**Pore Pressure**
Field Example: Deepwater Gulf of Mexico
Downhole vs. Surface Data

Use downhole data!
Torque vs. WOB

\[
\text{MSE} = \frac{480 \times T \times \text{RPM}}{d^2 \times \text{ROP}} + \frac{4 \times \text{WOB}}{\pi d^2}
\]

pay attention to downhole Torque!
d-exponent vs. MSE based Pore Pressure
Final Remarks

- The proposed energy based approach (**MSE-based**) provides new insight into pore pressure estimation from drilling mechanics data (real-time pp detection @ bit).

- **Insitu rock strength** was considered in order to obtain pore pressure from MSE and drilling mechanics data (=> **drilling efficiency**).

- **Downhole data** are recommended to be used for pore pressure estimations. Surface data could be misleading for pore p. estimation.

- Since **Torque @ bit** dominates the MSE, PP estimation is much more sensitive to the **Torque @ bit** rather than **WOB**.

- The **MSE-based** Pore Pressure approach has great advantages over the dXc in terms of reduced subjectivity in the **trend line** and capturing the physics of cutting action by taking into account **torque** and in-situ **rock strength**.
Thank You

Questions?