Holistic Uncertainty Analysis for the Evaluation of Hydrocarbon Pore Volume from Petrophysical Data

Presentation by

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The Petrophysicists Contribution to Calculating HIP

- More of the parameters used in the calculation of HIP are provided by Petrophysics than any other discipline!

\[
HIP = GRV \cdot \frac{N}{G} \cdot \phi \cdot (1 - S_w)
\]

Where,
- HIP = Hydrocarbon in Place
- GRV = Gross rock volume.
- Net = Net Reservoir
- Gross = Gross Reservoir
- \( \phi \) = Porosity
- \( S_w \) = Water Saturation

For single well:
- Hydrocarbon Pore Thickness

\[
HPT = \phi \cdot S_o \cdot h
\]
Log Evaluation Workflow

- Lithology
- Clay Volume Estimation
- Porosity Computation
- Water Saturation Calculation
- Fluid Zones
- Permeability Determination
- Net Pay / Net Reservoir Quantification

**Petrophysical Parameters:**
- Clean Point (GR, Neu, Den, Son)
- Clay Point (GR, Neu, Den, Sonic)
- Clay Conductivity (Rtclay, CEC etc)
- Archie exponents (a, m, n etc.)
- Water Salinity (Rw, Temp)
- Cutoff Selection
- etc

**Logs:**
- Gamma Ray
- Neutron
- Density
- Sonic
- Resistivity
- etc

Reality check
Errors inherent in Petrophysical analysis.

**Sources of Error**

- Input Log Curves
- Selection of Interpretation Parameters
- Petrophysical Model

**Sources of Error**

- Calibration
- Measurement
- Environmental
- Resolution

**Test Well 1**

\[ S_w = \left( \frac{a}{\phi^m} \cdot \frac{R_w}{R_t} \right)^{\frac{1}{n}} \]

- Lithology
- Laminated
- Choice of:
  - Porosity Equation
  - Sw Equation

**Measured Parameters**

- Water sample
- Core Analysis
- Uncertainty in parameter pick
Uncertainty in the Calculation of HPVOL

- Characterising Uncertainty
  - Sensitivity analysis of input parameters
  - Error Analysis using partial derivative analysis
  - Monte-Carlo Simulation
Error / Uncertainty Distributions

- Square Distribution
  - High Shift
  - Low Shift
  - Probability
  - Start Value

- Triangular Distribution
  - High Shift
  - Low Shift
  - Start Value

- Gaussian Distribution
  - High Shift
  - Low Shift
  - Start Value
  - 4 Standard deviations

- Probability:
  - Square, equal probability that the true value lies within the range of uncertainty
  - Triangular, strong confidence that input value is correct
  - Gaussian (or Normal), often used to represent distributions in nature
Random Selection of Values from Distribution

Individual probability distributions for each input and parameter represent the range in error:
- Gaussian
- Triangular
- Square

Random number generated (0-1) to select a value from the Cumulative Distribution

\[ F(a) = P(X < a) \]
Random Selection of Values from Distribution

Individual probability distributions for each input and parameter represent the range in error

- Gaussian
- Triangular
- Square

Random number generated (0-1) to select a value from the Cumulative Distribution
Random Selection of Values from Distribution

Individual probability distributions for each input and parameter represent the range in error
- Gaussian
- Triangular
- Square

Random number generated (0-1) to select a value from the Cumulative Distribution
Monte Carlo Uncertainty Analysis

INPUTS

GR Clean

GR Clay

GR Tool

OUTPUTS

Simulation Clay Volume

VCLGR

Number of Points


Sometimes a Petrophysicist wants to assess the sensitivity of the Petrophysical results to cut-offs.

The Monte Carlo module is ideal for doing this.

The result display shows the statistical sensitivity to the cut-offs in one easy to analyze report.

Traditionally

- Run various sensitivity cases
  - 8, 10, 12% porosity, 40, 60, 80% Sw, 30, 40, 50% Vcl
  - End up with 27 sets of results. Difficult to analyse.

Monte Carlo

- Run thousands of cases
- Program analyses the summations and automatically generates P10, P50, P90 results

<table>
<thead>
<tr>
<th>Zone Name</th>
<th>Top</th>
<th>Bottom</th>
<th>Gross</th>
<th>Net</th>
<th>N/G</th>
<th>Av Phi</th>
<th>Av Sw</th>
<th>Av Vcl Ari</th>
<th>Av K Geo</th>
<th>Phi*H</th>
<th>PhiSo*H</th>
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<tbody>
<tr>
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<td>0.207</td>
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<td>0.064</td>
<td>347.559</td>
<td>20.62</td>
<td>14.15</td>
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<td>95.93</td>
<td>0.210</td>
<td>0.218</td>
<td>0.312</td>
<td>0.067</td>
<td>372.043</td>
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<td>14.40</td>
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<tr>
<td>Mean</td>
<td>77.50</td>
<td>0.170</td>
<td>0.209</td>
<td>0.365</td>
<td>0.096</td>
<td>224.097</td>
<td>17.18</td>
<td>11.42</td>
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<tr>
<td>10.</td>
<td>95.50</td>
<td>0.209</td>
<td>0.218</td>
<td>0.314</td>
<td>0.066</td>
<td>343.921</td>
<td>20.94</td>
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<td>50.</td>
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<td>0.227</td>
<td>0.255</td>
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<tr>
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</tbody>
</table>
Monte Carlo Error Analysis - Setup

• Define the analysis work flow
  • Use deterministic analysis modules
  • Use probabilistic analysis module
  • User formulas
  • User programs
• Setup the errors associated with each selected input parameter and input log curve
• Select output curves to analyse
  • Porosity, Sw, Vcl
  • Any other curve can be selected (Permeability ?)
• Start the simulations running
### Monte Carlo Error Analysis – Setup

#### Input Curves Example

<table>
<thead>
<tr>
<th>Use</th>
<th>Curve Name</th>
<th>Type</th>
<th>Shift Distribution</th>
<th>Low Value</th>
<th>High Value</th>
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<tbody>
<tr>
<td>✓</td>
<td>RHOB</td>
<td>Linear</td>
<td>Gaussian</td>
<td>0.02</td>
<td>0.02</td>
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<tr>
<td>✓</td>
<td>DTLN</td>
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<td>Gaussian</td>
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<td>2</td>
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<tr>
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<td>TNFH</td>
<td>Percent</td>
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<tr>
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<td>0.03</td>
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<tr>
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<td>Gaussian</td>
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<td>Linear</td>
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<tr>
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<td>Gaussian</td>
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#### Porosity/Sw Parameters Example

<table>
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<th>Use</th>
<th>Parameter Name</th>
<th>Type</th>
<th>Shift Distribution</th>
<th>Initial Value</th>
<th>Low Value</th>
<th>High Value</th>
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</thead>
<tbody>
<tr>
<td>✓</td>
<td>Rw</td>
<td>Percent</td>
<td>Gaussian</td>
<td>0.251</td>
<td>20</td>
<td>20</td>
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<tr>
<td>✓</td>
<td>Rmf</td>
<td>Percent</td>
<td>Gaussian</td>
<td>0.172 - 0.174</td>
<td>20</td>
<td>20</td>
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<tr>
<td>✓</td>
<td>Rho mud_filt</td>
<td>Linear</td>
<td>Gaussian</td>
<td>1.02178 - 1.02</td>
<td>0.02</td>
<td>0.02</td>
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<tr>
<td>✓</td>
<td>Hc Den</td>
<td>Linear</td>
<td>Gaussian</td>
<td>0.45 - 0.8</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>✓</td>
<td>a factor</td>
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<td>2</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>
To illustrate co-dependency the following crossplots show:

- an 'm' and 'n' dependency correlation of 0.5
- and a 'Neu Wet Clay' and 'Rho Wet Clay' dependency correlation of -0.8.

Note: Within the petrophysical model calculation dependencies also exist.
E.g. Increased Clay Volume will result in Decreased Effective Porosity.
At the start of each simulation the module randomly applies a shift to input parameters/curves.

- The petrophysical analyses are then re-run.
- The results for each simulation are accumulated and a distribution of the results made.
- Typical simulation run 1000+
Monte Carlo Error Analysis - Results
Monte Carlo Error Analysis – Tornado Plot

- Helps visualise the influence of individual input parameters on the results
- 2 work flow runs are made for each parameter.
  - High side, Low side
  - Other parameters kept at default value
Individual summation reports are collected after each MC simulation. Summation reports are ranked from highest to lowest and percentile results selected.

Change input parameters and curves using random numbers

Run Analysis Workflow

Save results of Summation Report and add Output Curve results to curve statistics

Update Output Graphics

More Simulations?

Yes

No

Return Parameters and Curves to defaults and Output final results
Reservoir SUMMARY

<table>
<thead>
<tr>
<th>Zn</th>
<th>Zone Name</th>
<th>Top</th>
<th>Bottom</th>
<th>Gross</th>
<th>Net</th>
<th>N/G</th>
<th>Av Phi</th>
<th>Av Sw</th>
<th>Av Vcl</th>
<th>Av K</th>
<th>Phi*H</th>
<th>PhiSo*H</th>
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<tbody>
<tr>
<td>#</td>
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<td>7784.00</td>
<td>8727.00</td>
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<tr>
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<tr>
<td>50.</td>
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</tr>
</tbody>
</table>

Note: The Mean and Percentile results are calculated for each individual parameter.

Therefore, the Net/Gross P50 multiplied by the Gross interval will not necessarily equal the Net P50 result, but it will be quite close.
Conclusions

• Errors and Uncertainty exist with input data and parameters
• HPVOL is normally calculated using a deterministic workflow
• Monte Carlo can encompass the complete Petrophysical workflow in a holistic approach to calculate an uncertainty distribution
• Novel workflows can be included
• Co-dependencies between parameters can be honoured
• Identifying key uncertainties allow for the development of a data collection program that can potentially de-risk the HIP estimate
Thanks to the following:

• Simon Stromberg (Senergy Oil and Gas – Technical Head of Petrophysics)
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• Tim Walmsley (Senergy Oil and Gas – Lead Petrophysicist)