Simultaneous Uncertainty Analysis for SCAL Data Interpretation

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InterPore 2022
30 May – 2 June 2022

Abstract ID: 468, Session: Parallel Session 2: MS14
Situation

Rock properties must be measured at great expense:
- Water flooding for Oil production (water/oil)
- Production of deep geothermal systems (water/steam)
- Geological storage of CO2 (water/CO2)

Concerns and limitations:
- Takes month and delays investment decisions
- Abundance of rock types
- Spatial variation in the geological reservoir
- Results from only sample under investigation without statistical variations

Two-phase Darcy:
\[
\tilde{q}_i = -\frac{K k_{r,i}(S_W)}{\mu_i} (\nabla P_i - \rho_i \vec{g})
\]

Fluid mobility

Relative permeability

\[ P_C(S_W) = P_o - P_w \]

Capillary pressure
Simulation Domain and Equations

- **Non-proprietary/non-commercial**
- **SCAL-data interpretation tool**
- **Immiscible-incompressible flow in 1D implemented in MRST**

\[
\phi \partial_t (S_\alpha) + \nabla \tilde{q}_\alpha = Q_\alpha
\]

\[
\tilde{q}_\alpha = -\frac{K k_{ra}}{\mu_\alpha} (\nabla p_\alpha - \rho_\alpha g) \quad \alpha = o, w
\]

\[
P_{right} = P_0 + \Delta \rho g_{CF} L
\]

\[
g_{CF} = \omega^2 r_m
\]
Synthetic Data Set – Benchmark

Synthetic input → forward simulation

Benchmarked against synthetic dataset from Lenormand et al. (2017)

Scores
Sendra
...

Implementation in MRST

Steady State

Unsteady State

Centrifuge

Water saturation $S(w)$

$P_C ($bar$)$

$k_r$ ($-$)

$\Delta P$ (MPa)

average $S_w$

Time (h)

Drainage

Imbibition
Simulation Strategy

**Experiment**
e.g. SS and centrifuge

**Compute analytical solutions**
Initial
\[ k_r(S_w), p_c(S_w) \]

**Compare and choose representation of** \( f(S_w) \)

Starting point for numerical simulation
\[ k_r(S_w), p_c(S_w) \] parametrized

\[
\begin{align*}
k_{rw} &= k_{rw}(S_{or}) \left( \frac{S_w - S_{wc}}{1 - S_{wc} - S_{or}} \right)^{n_w} \\
k_{ro} &= k_{ro}(S_{wc}) \left( \frac{1 - S_w - S_{or}}{1 - S_{wc} - S_{or}} \right)^{n_o}
\end{align*}
\]
Simulation Strategy

Experiment
e.g. SS and centrifuge

Compute analytical solutions

Compare and choose representation of \( f(S_W) \)

Minimizing objective function simultaneous for multiple data sets

Starting point for numerical simulation \( k_r(S_w), p_c(S_w) \) parametrized

MATLAB Optimization Toolbox

MRST
Simulation Strategy

Experiment
e.g. SS and centrifuge

Relative permeability

Water saturation

Simulation Strategy

Experiment
e.g. SS and centrifuge

Relative permeability

Water saturation

Input for stochastic reservoir modeling and data bases

Compute analytical solutions

History matching

Uncertainty analysis

Compare and choose representation of $f(S_w)$

Minimizing objective function simultaneous for multiple data sets

$J = \frac{\sum_{i=1}^{N_{obs}} (d_i - y_i)^2}{N_{obs}}$

MATLAB MRST

ParaMonte Library

MATLAB Optimization Toolbox

Darcy
Hassler-Brunner etc.

Corey
LET point-by-point etc.

Starting point for numerical simulation $k_r(S_w), p_c(S_w)$ parametrized

MATLAB

Optimization Toolbox

MCMC sampling using likelihood estimation function with constant errors

Result

$J = \frac{\sum_{i=1}^{N_{obs}} (d_i - y_i)^2}{N_{obs}}$

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Synthetic Data Set – Benchmark (History match)

Benchmarked against synthetic dataset from Loeve, et al., 2011
- Simultaneous USS and Centrifuge imbibition
- Corey for kr and Skjaeveland for pc
Development of DPE SCAL simulator
Conventional laboratory analysis

- Analytical data evaluation = insufficient
- Analysis done in sequence causing inconsistent results
- Different representations for complex saturation functions
- Uncertainty modeling → robust input to stochastic RE modeling

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Development of DPE SCAL simulator
Conventional laboratory analysis

Estailades Carbonate

Simultaneous Interpretation of SCAL Data with Different Degrees of Freedom and Uncertainty Analysis

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Under review

*Open source to be a part of the main MRST package
Omidreza Amrollahi
Siroos Azizmohammadi
Holger Ott

Pit Arnold, Jos Maas and Steffen Berg
are acknowledged for helpful discussions

Questions?

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