Updating of Uncertainty in Fractured Reservoirs driven by Geological Scenarios

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Overwhelming complexity → Two Worlds

Models built by Geologists

example of complex DFN

Models used by Engineers

extreme, but real HM example
Scenario-driven workflow for Naturally Fractured Reservoirs

The Purpose:

- Uncertainty Quantification
- Uncertainty Updating / History Matching
- Dual-Medium description

The Challenge:

- Geologically consistent
- Field Scale (global!)
- Integration with existing Software
- Rapid
Naturally Fractured Reservoir

reservoir dimensions: 102 x 86 x 1 cells
cell dimensions: 600 x 600 x 25 ft
DFN-workflow

Complex & CPU intense

Fractures

Fracture Model

Dual-Medium model

Effective Properties

Flow Response

Upscaling: CPU intense
Uncertainties in DFN modeling

1 or 2 fracture sets

parameters

equiv. radius (length)

trend

full factorial experimental design

156 DFN models
DFN-Info
Fracture Intensity (P32): 0.6, lead to 12k fractures in model
Size distribution: min radius 400ft, exponent $\alpha=2$, truncated at 3000ft
Trend: E-W, Fisher distribution with $k=8$ -> high dispersion
Aperture: 300µm, Perm: 10D

Fractures colored by size
DFN-Info
Fracture Intensity (P32): 0.6, lead to 18k fractures in model
Aperture: 300µm, Perm: 10D

Set 1:
Size distribution: min radius 400ft, exponent $\alpha=2$, truncated at 3000ft
Trend: 0°, Fisher distribution with $k=8$ -> high dispersion

Set 2:
Size distribution: min radius 200ft, exponent $\alpha=2$, truncated at 3000ft
Trend: 30°, Fisher distribution with $k=8$ -> high dispersion

Fractures colored by set
Fractures colored by set

DFN-Info
Fracture Intensity (P32): 0.6, lead to 18k fractures in model
Aperture: 300µm, Perm: 10D

Set 1:
Size distribution: min radius 600ft, exponent α=2, truncated at 3000ft
Trend: 45°, Fisher distribution with k=8 -> high dispersion
Conditioned to curvature of fold

Set 2:
Size distribution: min radius 200ft, exponent α=2, truncated at 3000ft
Trend: 60°, Fisher distribution with k=8 -> high dispersion
Identification of Dual-Medium cells

Dual medium (DM) effective properties

Matrix

\( \phi_m, k_{mx}, k_{my}, k_{mz} \)

Fractures

\( \phi_f, k_{fx}, k_{fy}, k_{fz} \)

Single medium (SM) effective properties

Matrix only

\( \phi, k_x, k_y, k_z \)
Dual Medium pattern at field scale
DFN models → Dual Medium models

4 x 156 DFN

624 pattern
Selecting representative patterns using Modified Hausdorff Distance
Generating Dual-Medium realizations with MPS

9 Training Images

MPS/Dispat

270 Dual-Medium models

binary pattern

effective properties
DFN-workflow

- Fractures
- Fracture Model
- Dual-Medium model
- Effective Properties
- Flow Response

Complex & high CPU

Translate/replace

MPS-workflow

- Training image
- Dual-Medium model
- Effective Properties
- Flow Response

Fast

No flow simulation so far
Uncertainty Quantification*:
DFN-workflow ↔ MPS-workflow

156 DFN x 4 Realizations
9 TIs x 30 Realizations

* no production data
Scenario-driven updating of uncertainty with production data
Dual-Medium scenario uncertainty

\[
P(M \text{ model}, dualTI|D \text{ ata}) = \sum_k P(M|dualTI_k, D) P(dualTI_k|D)
\]

- **generate/find models matching production data**

- **update probabilities of scenarios**

- **eliminate/reject Dual-Medium scenario without HM**

- **HM with accepted (not eliminated) Dual-Medium scenarios**

\[
P(dualTI_k|D)
\]

\[
P(M|dualTI_k, D)
\]
Well configuration

reservoir dimensions: 102 x 86 x 1 cells
cell dimensions: 600 x 600 x 25 ft

depth

18 injectors                  27 producer
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<td>6</td>
<td>7</td>
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**Dual Medium Tis / scenarios**
Phase 1: Kernel Density Estimation
## Updating of scenario uncertainty

<table>
<thead>
<tr>
<th></th>
<th>phase 1</th>
<th>phase 1+2</th>
<th>phase 1+2+3</th>
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<tbody>
<tr>
<td>Ti 1</td>
<td>11% → 14%</td>
<td>0% →</td>
<td>0% →</td>
</tr>
<tr>
<td>Ti 2</td>
<td>11% → 0%</td>
<td>0% →</td>
<td>0% →</td>
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<tr>
<td>Ti 3</td>
<td>11% → 28%</td>
<td>90% →</td>
<td>100% →</td>
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<tr>
<td>Ti 4</td>
<td>11% → 34%</td>
<td>7% →</td>
<td>0% →</td>
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<td>Ti 5</td>
<td>11% → 1%</td>
<td>1% →</td>
<td>0% →</td>
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<tr>
<td>Ti 6</td>
<td>11% → 4%</td>
<td>0% →</td>
<td>0% →</td>
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<tr>
<td>Ti 7</td>
<td>11% → 0%</td>
<td>0% →</td>
<td>0% →</td>
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<tr>
<td>Ti 8</td>
<td>11% → 0%</td>
<td>0% →</td>
<td>0% →</td>
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<tr>
<td>Ti 9</td>
<td>11% → 19%</td>
<td>2% →</td>
<td>0% →</td>
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Forecasting:
without HM ↔ with HM

Field responses calculated using prior probabilities of dual TIs $P(\text{dualTI}_k)$
**Forecasting without HM**

using only $P\left(\text{dualTI}_k | D\right)$

**Forecasting with HM**

using both $P\left(\text{dualTI}_k | D\right)$ and $P\left( M | \text{dualTI}_k , D\right)$

147 runs

1069 runs

0 0 3000 3000 days
Forecasting without HM

using only 
\[ P(\text{dualTI}_k|D) \]

Forecasting with HM

using both 
\[ P(\text{dualTI}_k|D) \]
and 
\[ P(M|\text{dualTI}_k,D) \]

147 runs

1069 runs
Conclusions

- pattern-based approach to fractured reservoirs
- easy to implement with existing software
- rapid uncertainty quantification (MPS & SL)
- fast, scenario-based forecasting
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- Aaron Fox
- Glori Lee
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