Examples of OPM-Flow usage at TNO

OPM Summit 2024

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Outline

• LGR test case

• Groningen case

• Applications at TNO
  • High-temperature seasonal heat storage (HT-ATES)
  • CO$_2$ storage in aquifers
  • Seismicity effect of depletion in aquifers

• Demand for new features at TNO
  • Thermal-phase change
  • H$_2$ storage and bio/geochemistry
  • Fractured reservoirs: dual-poro / dual-perm
LGR test case
LGR test case

SPE1

DX
300*1000 /
DY
300*1000 /
DZ
100*50 100*50 100*50 /

PERMX
100*500 100*50 100*200 /
PERMY
100*500 100*50 100*200 /
PERMZ
100*500 100*50 100*200 /

CARFIN
NAME   I1 I2 J1 J2 K1 K2 NX NY NZ
'LGR1'  5  6  5  6  1  3  6  6  9 /
ENDFIN

CARFIN
NAME   I1 I2 J1 J2 K1 K2 NX NY NZ
'LGR2'  8  9  8  9  1  3  6  6  9 /
ENDFIN
**LGR test case**

- **Validation of transmissibility values:**
  - Reporting values calculated by ref. simulator, comparing with values internally calculated in OPM by Antonella (incl. unit conversion)
  - Identifying need for correction factors (“reverse engineering”)
  - LGR-LGR transmissibilities:

<table>
<thead>
<tr>
<th>index</th>
<th>dx</th>
<th>dy</th>
<th>depth</th>
<th>permz</th>
<th>NTG</th>
<th>dz</th>
<th>DHS</th>
<th>DVS</th>
<th>DIPC</th>
<th>B</th>
<th>A</th>
<th>TransX(CPB)</th>
<th>TRANX(ft3)-Ar (CPB/D/PS)</th>
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- LGR-global transmissibilities:

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<th>dy</th>
<th>depth</th>
<th>permz</th>
<th>NTG</th>
<th>dz</th>
<th>A</th>
<th>B</th>
<th>TRANz(CPB/D)</th>
<th>TRANz(ft3)-Ar (CPB/D/PS)</th>
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Diagram: Reference simulator
## LGR test case

<table>
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<tr>
<th>Global Grid</th>
<th>Local Grid</th>
<th>Ref simulator (CPB/D/PS)</th>
<th>Ref simulator (m³) OPM(m³)</th>
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<tbody>
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</table>

<table>
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<tr>
<th>Local Grid</th>
<th>Local Grid</th>
<th>Ref simulator (CPB/D/PS)</th>
<th>Ref simulator (m³) OPM(m³)</th>
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<tr>
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<td>1502,7 4,0105E-10 4,0109E-10</td>
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</tbody>
</table>

### Notes:

- **Comparison of transmissibilities**
  - OPM-Flow vs. reference simulator
  - Local-local transmissibilities are in agreement
  - Mismatch in local-global X- and Y- transmissibilities (by same factor) → correction needed

![Image of a 3D model with grid and values]
LGR test case

Comparison of gas saturation distribution:

Reference simulator

OPM
LGR test case

• Adjusting test case:
  • Original case shows numerical artifacts (mobility of inject gas varies significantly based on vertical resolution of grid)
Groningen test case
Status large-scale test case

• **Approach:**
  • Build multi-million grid cell reservoir simulation model based on publicly available Groningen dataset (released by NAM / Shell)

• **Exporting static model:**
  • Two static models in Petrel: with 18 million and 38 million grid cells
  • Field extent: 40 × 50 km, gas column ~444 m
  • Average grid size: 100 × 100 × 5 m
  • 665 faults
  • 10 different GWC’s

• **Building dynamic model (on-going):**
  • Add regions (EQLNUM, PVNUM, and SATNUM)
  • Add 4 aquifers
  • Add PROPS
  • Add wells location, SCHEDULE and history of production
  • 300+ wells (gas and water producers)
Applications of OPM-Flow at TNO
Applications at TNO

High-temperature aquifer thermal energy storage (HT-ATES)
Temperature profiles HT-ATES

OPM-Flow vs. reference thermal simulator

Orange color: Ref. simulator
Temperature changes in grid cells – warm well

Orange color: Ref. simulator
Temperature changes in grid cells – cold well

50, 75, 6

51, 75, 6

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Reference thermal simulator vs. Jutul (Olav)
Applications at TNO

CO₂ storage in Dutch offshore aquifers: capacity study

- CO2STORE
- Dissolution trapping
- Dry-out effect
- Residual trapping

CO$_2$ distribution

Gas saturation after 20 years of injection

FWCD: CO$_2$ dissolved in water phase
FWIPG: Water in gas phase
FGCDM: CO$_2$ dissolved and mobile in gas phase
Applications at TNO

Seismic risk in the southern Lauwerszee Trough aquifer

Initial gas saturation distribution

Initial pressure distribution
Varying pressure boundary conditions

- Gas-water system
- The Groningen field on the east is implemented as a pressure boundary
- Time-varying pressure boundary condition of Groningen implemented via pressure-constrained production wells
Demand for new features at TNO
Thermal-compositional with phase change

CO₂ storage in depleted fields

H₂ storage with bio-/geochemical reactions

- Fully compositional / different cushion gas
- Bacterial activity (Monod type reaction)
- Geo-chemical reactions (in many applications such as H₂ and CO₂ Storage), coupling with PHREEQC / Reaktoro

- Methanogenic archaea:
  \[ 4H₂ + CO₂ \rightarrow CH₄ + 2H₂O \]
- Sulfate-reducing bacteria:
  \[ SO₄^{2-} + 5H₂ \rightarrow H₂S + 4H₂O \]

pyrite to pyrrhotite

\[ FeS₂ + H₂ \rightarrow FeS + H₂S \]
Geothermal fractured reservoirs

- Many reservoirs exhibit dual-porosity behaviour, in particular in geothermal production.
- Fractured carbonates like the Californie site in The Netherlands and Balmatt site in Belgium, which are both in the Zeeland Formation of the Carboniferous.
- Magmatic sites like in Iceland and Los Humeros in Mexico
- Enhanced Geothermal Systems like in the Upper Rhine Graben
- Paris basin
- For some applications and conditions, representing the fractured, dual porosity medium as a normal porous medium works well, however this is not true for:
  - Large fracture distance
  - Heterogeneous fracture networks
- In particular this is important to model the distribution of the cold front and the uncertainty, which in turn is crucial for understanding seismicity.
- Progress of cold water front to the producer → prediction of timing of cold water breakthrough
Summary and discussion

• LGR
  • Testing and comparing with the fine grid model

• Groningen field
  • Building large-scale dynamic model for numerical performance benchmark purposes
  • Test with OPM

• Applications
  • Improve thermal simulation in OPM: possible to add energy related keywords to summary? (Energy Injection/Production rate, Energy Injection/Production total)

• Demand for new features
  • Thermal-phase change
  • H₂ storage and bio/geochemistry
  • Fractured reservoirs: dual-poro / dual-perm
  • Also needed by other groups?
Thank you
Questions?

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TNO innovation for life