SIMULATION OF REACTIVE TRANSPORT PROCESSES: ACIDIZING TREATMENTS IN CARBONATE RESERVOIRS

Interpore Valencia 2019

Jens-Oliver Schwarz, Liping Cheng, Tom Cvjetkovic, Andreas Wiegmann
**MOTIVATION – REACTIVE FLOW**

- Reactive Flow: HCl injection into carbonate
- Effect: Dissolution, enlargement of the pore space (permeability enhancement)
- Establish a higher permeability
- Keep mechanical stability
- Use numerical simulation to optimize the process parameters, e.g. acid concentration, injection velocity, ...
WHY DO WE NEED A NEW NUMERICAL MODEL?

- Lesson learned from digital rock physics: structure at the pore scale influences rock properties at the core scale.
- Simulations at the pore scale require REV and so large computational domains.
- Need for efficient solvers and simple rules for structure manipulation.
- We developed a simple numerical model which can be applied to large computational domains (REV).
Model Description and Implementation

Simulate HCl injection into a carbonate sample
MODEL WORKFLOW – STEP 1

- Compute the flow field in the structure
- For a given fluid velocity or pressure drop
- Stokes or Navier-Stokes equations
- Export streamlines
- This step is implemented in GeoDict
Model Workflow – Step 2

- Compute particle movement
- Particle transport is a combination of advective and diffusive motion (Streamlines + Brownian motion)
- A particle behaves like a single $H^+$ Ion, while it represents a larger number of ions (we call this concept Multiplicity).
- We keep track of the collision points with the rock interface
- This step is implemented in GeoDict
MODEL WORKFLOW – STEP 3

- Model the chemical reaction
- One particle represents a given number of H⁺ ions
- At every collision point a given number of H⁺ ions are transferred to the solid voxel
- We keep track of the consumed H⁺ ions in the particles and solid voxels
- This step is implemented as a Matlab function
MODEL WORKFLOW – STEP 4

- Update rock structure
- Remove dissolved voxels
- The new structure is saved for the next iteration
- It can be used to analyze properties like: Mechanical stability (Bulk Modulus), Conductivity, Permeability
- This step is implemented as Matlab function

Remove voxels which have “collected” enough H+ Ions for a complete dissolution
- Particle/Continuum approach
- Fluid flow as continuum (Stokes/ Navier-Stokes)
- Reactants (e.g. H+ ions) as particles
- One particle behaves like a single H+ ion, but represents a larger number
- Upon collision, H+ ions dissolve the rock (CaCO₃):
  \[
  CaCO₃ + H^+ \rightarrow Ca^{2+} + HCO_{3}^{-}
  \]
- Keep track of consumed H⁺ and dissolved volume
WORKFLOW - OVERVIEW

1. Import µCT scan
   Create 3D voxel structure

2. Fluid flow simulation
   Compute flow field

3. Compute particle movement

4. Simulate chemical reaction
   Update structure, remove dissolved voxels

5. Analyze updated 3D structure

Simulation time reached?

No, continue with next time step

Yes, Stop Simulation
Simulation on a real rock structure
CARBONATE SAMPLE

- Grosmont formation, Alberta, Canada
- Dimensions: 1024x1024x1024 voxel
- Resolution: 2.02µm
- Porosity: 21%, permeability range: 150 mD – 470 mD -> heterogenous pore space
- Data set is published in DRP benchmark paper (Andrae et al. 2013)
CARBONATE SAMPLE - SUBVOLUME

- Computational domain 256x256x362 voxel
- Porosity of subdomain: 21.9 %
- Homogeneous pore distribution
MODEL EVALUATION

- Goal: Replicate characteristic dissolution patterns

Images from Maheshwari et al. 2013
**Simulation settings:**
- Domain: 256x256x512 voxel
- Runtime: 50 h
- Average velocity: 0.001 m/s
- pH value: 3.2
- Simulation time: 700s
- Number of particles: ~2000

**Material Information:**
- ID 00: Porespace [invis.]
- ID 01: Dissolved Structure
- ID 02: Original Structure
COMPARISON FACE DISSOLUTION PATTERN

GeoDict simulation

Maheshwari et al. 2013
Simulation settings:
Domain: 256x256x362 voxel
Runtime: 36 h
Average velocity: 0.01 m/s
pH value: 3.2
Simulation time: 100s
Number of particles: ~2000

Material Information:
- ID 00: Porespace [invis.]
- ID 01: Dissolved Structure
- ID 02: Original Structure
Comparison Conical Wormhole Pattern

GeoDict simulation

Maheshwari et al. 2013
Simulation settings:
Domain: 256x256x362 voxel
Runtime: 28 h
Average velocity: 0.1 m/s
pH value: 3.2
Simulation time: 20s
Number of particles: ~2000
COMPARISON WORMHOLE PATTERN

GeoDict simulation

Maheshwari et al. 2013
Simulation settings:
Domain: 256x256x362 voxel
Runtime: 29 h
Average velocity: 0.1 m/s
pH value: 2.8
Simulation time: 20 s
Number of particles: ~2000
COMPARISON UNIFORM DISSOLUTION PATTERN

GeoDict simulation

Maheshwari et al. 2013
POROSITY ANALYSIS

Face Dissolution

Conical Wormhole

Wormhole

Uniform Dissolution

Porosity $\phi$

Z-Slice
PERMEABILITY ANALYSIS

PERMEABILITY OVER POROSITY
Simulation settings:
Domain: 512x512x768 voxel
Average velocity: 0.1 m/s
pH value: 3.2
Simulation time: 20 s
Number of particles: ~10,000
Runtime: 120 h (16 cores, <20 GB Memory)
CONCLUSION & OUTLOOK

- We presented a numerical model to simulate reactive flow
- We evaluated the model by reproducing characteristic dissolution patterns
- Based on the commercially available DRP software GeoDict
- Using very efficient reliable numerical solvers, the simulations can be run on a state of the art desktop workstation
- We are currently working on incorporating the Matlab functions into GeoDict to reach computational domains of $>2000^3$ voxels
THANK YOU FOR YOUR ATTENTION

Please come to our booth for more information about GeoDict®

REFERENCES

