

# Multiscale Modeling of Calcite Cementation in Porous Media with Application to the Crystal Geyser Formation

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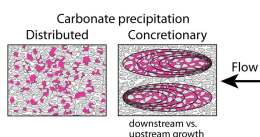
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## Abstract

During CO<sub>2</sub> transport, pore-scale reactions can result in precipitation of calcite and cementation of pores. The hypothesis of this work is that cementation results in the formation of preferential pathways for CO<sub>2</sub> to flow to the earth's surface.

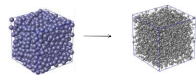
In this work we model CO<sub>2</sub> flow and reactive transport in porous media using pore-scale network models. The networks represent heterogeneous sandstones. As fluid flows through pores, calcite precipitates and cements the porous medium. Our transient pore-level model includes pore-level equations of reaction and change in throat conductivity. As time progresses, throat conductivity and therefore flow distributions change in the network model. We observe that at large times the model cements in a way that flow approaches uniformity throughout the network.

Additionally, we attempt to model flow and transport at larger scales by coupling several network models together. Finite Element Mortars are used as the mathematical tool to ensure continuity of pressures and fluxes is preserved at model boundaries. We show that throat conductivities in high perm regions approach the same distribution as the low-permeability regions.



## Pore-Scale Modeling of Calcite Precipitation

Pore-scale network models can be obtained directly from real media or from computer generated models. In the last few decades they have become more representative of real media and more detailed transport physics are included.



Predictive networks can be used to obtain macroscopic properties such as permeability. Here, our goal is to model transient, reactive transport. Mathematically, the problem is solved using an operating splitting approach. At each time step pressures and fluxes are solved by ensuring mass balance at each pore:

$$\text{Mass conservation at each pore: } Q_i = \sum_{j \in \text{Neighbors}} q_{ij} = 0$$

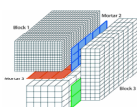
$$\text{solution to the momentum equations in each pore throat: } q_{i,j} = \frac{k_{t,i,j}}{\mu} (p_j - p_i)$$

At the end of each time step, throat conductivities are reduced as a result of precipitation. We assume the conductivity change is a function of the flow rate in the pore throat. Therefore the following equation is used to decrease the conductivity.

$$\frac{g}{g_0} = \exp\left(-\frac{q}{q_0} dt\right)$$

Although the model is simple, it gives insight into how the pore-size and conductivity distribution change with time as calcite precipitates. Future work will focus on complex transport models in pore throats.

## Mortar Coupling of Pore Network Models

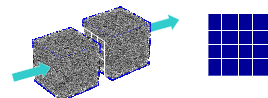


2D FEM mortar spaces are used at interfaces to iteratively match pressures at fluxes

Designed to allow for coupling of different models, physics, and scales

Improve accuracy by using finer meshes and higher-order mortars

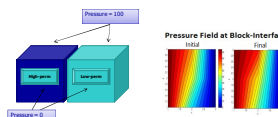
Until recently, mortars were used exclusively to couple domains in continuum simulators. Here, we couple pore-scale network models to other pore-scale or macro-scale models to ensure the correct boundary conditions are imposed



The FEM mortars iteratively determine boundary conditions in such a way that the pressure and flux fields match in a weak sense. The below figure shows that pressure field at the interface obtained using mortars is a good approximation to the true solution.

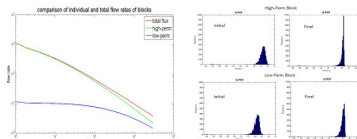
## Results of Multi-block Models

In order to properly model cementation and the development of preferential flow paths, behavior at multiple length scales must be included. In particular, the effect of varying permeability and pore-size distribution must be included. Mortars can be used to couple any number of network models. Here we demonstrate the capabilities by coupling two networks with a large difference in permeability.



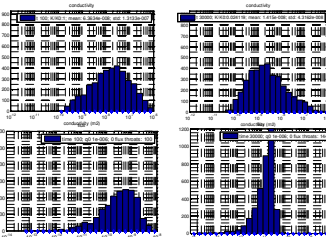
A high-perm pore network was coupled to a low-perm network in parallel and the following were observed:

- 1) Faster decrease in permeability of the high-perm block
- 2) Equalization of pore throat flux distributions in both blocks at later times
- 3) Convergence of the individual outflow fluxes of the blocks



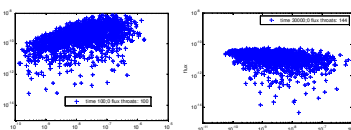
## Results of single block model

Objective is to investigate calcite precipitation and cementation with time. Specifically, we want to observe changes in the throat conductivity distribution, flow distribution, and total permeability.

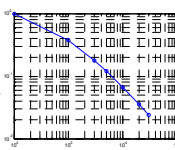


Two trends are observed on throat conductivity and flux histograms:

1. All throat conductivities and fluxes are decreased
2. Throats conductivities and fluxes approach uniformity in time



Initially, positive correlation between flux and throat conductivities is observed. However, at final state, such positive correlation no longer exists. Furthermore, throat fluxes are 'chopped' at a maximum flux rate at final stage.



$$\ln \frac{K(t)}{K_0} = C \ln(t)$$

C is constant

Permeability reduction bear linear correlation with time on log-log scale. This further confirm that network throat conductivities approach uniformity with time.

## Conclusions

The simple governing equation utilized in here for modeling of calcite cementation in sandstone media exhibited a characteristic behavior in the way the conductivities of the blocks changed through time:

Not only the pore throat fluxes approached uniformity in any individual block but also in an assembly of blocks of highly differing permeability, pore throat fluxes all over the medium converged towards a uniform value after long times. This shows that the medium homogenizes eventually, in terms of pore throat fluxes, regardless of how locally heterogeneous the medium initially is. That being said more research needs to be conducted to examine effects of much higher spatial heterogeneity.

## Future Work

Although the preliminary results are interesting and promising, several additional complexities must be added in order to properly predict cementation in the Crystal Geyser formation. New models for reaction and precipitation that are based on fundamental transport must be derived. The model may depend on limiting regimes (e.g. reactive versus convective transport).

Additionally, larger models than spat over greater length scales must be included. This will require coupling hundreds of models together in various geometries. The large scale problem will require high performance computing and advanced numerical techniques. A feedback loop with Tasks 3 and 4 will therefore be required.

## Acknowledgements

This material is based upon work supported as part of Frontiers of Subsurface Energy Security, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0001111 .