Geophysical Research Abstracts
Vol. 16, EGU2014-14470, 2014
EGU General Assembly 2014

Dynamic Pore-Scale Imaging of Reactive Transport in Heterogeneous Carbonates at Reservior Conditions

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Sequestering carbon in deep geologic formations is one way of reducing anthropogenic CO_2 emissions. Carbon capture, Utilization, and Storage (CCUS) in carbonate reservoirs has the added benefit of mobilizing more oil for extraction, increasing oil reservoir yield, and generating revenue while also mitigating climate change. The magnitude, speed, and type of dissolution are dependent the intrinsic properties of the rock. Understanding how small changes in the pore structure affect dissolution is paramount for successful predictive modelling both on the pore-scale and for up-scaled reservoir simulations. We propose an experimental method whereby both 'Pink Beam' synchrotron radiation and a Micro-CT lab source are used in dynamic X-ray microtomography to investigate the pore structure changes in carbonate rocks of varying heterogeneity at high temperatures and pressures.

Four carbonate rock types were studied, two relatively homogeneous carbonates, Ketton and Mt. Gambier, and two very heterogeneous carbonates, Estalliades and Portland Basebed. Each rock type was imaged under the same reservoir and flow conditions to gain insight into the impact of heterogeneity. A 4-mm carbonate core was injected with CO_2-saturated brine at 10 MPa and 50oC for 2 hours. Depending on sample heterogeneity and X-ray source, tomographic images were taken at between 30-second and 20-minute time-resolutions and a 4-micron spatial resolution during injection. Changes in porosity, permeability, and structure were obtained by first binning and filtering the images, then binarizing them with watershed segmentation, and finally extracting a pore/throat network. Furthermore, pore-scale flow modelling was performed directly on the binarized image and used to track velocity distributions as the pore network evolved.

Significant differences in dissolution type and magnitude were found for each rock type. The most homogeneous carbonate, Ketton, was seen to have predominately uniform dissolution with minor dissolution rate differences between the pores and pore throats. This was not true for the heterogeneous carbonates, Estalliades and Portland Basebed, which formed wormholes. Pore-scale modelling of flow directly on the voxels showed the differences in the evolution of complex flow fields with changes in dissolution regime. The PDFs of normalized velocity for uniform dissolution showed that the maximum pore velocity within the system decreased as dissolution occurred. This is due to dissolution enlarging pores and pore throats. However, in the wormholing regime, there was a large increase in maximum velocity once the wormhole broke through the length of the core and a preferential flow path was created.

Additionally, this study serves as a unique benchmark for pore-scale reactive transport modelling directly on the binarized Micro-CT images. This dynamic pore-scale imaging method offers advantages in helping fully explain the dominant physical and chemical processes at the pore scale so that they may be up-scaled to the reservoir scale for increased accuracy in model prediction.