# Oil & Natural Gas Technology

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# Quarterly Progress Report

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# Mechanisms Leading to Co-Existence of Gas and Hydrate in Ocean Sediments

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**Office of Fossil Energy**

# MECHANISMS LEADING TO CO-EXISTENCE OF GAS AND HYDRATE IN OCEAN SEDIMENTS

CONTRACT NO. DE-FC26-06NT43067

**QUARTERLY PROGRESS REPORT**
**Reporting Period: 1 Jul 07 – 30 Sep 07**

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**Summary**

Work during this quarter focused on developing the methods for modeling stress-strain behavior of unconsolidated sediments and for modeling the displacement of water by gas in such sediments.

**Activities in This Reporting Period**

**Task 5.0 – Compute Grain-Scale Gas/Water Geometry**

We extracted physically representative network models of the pore space in several of the model sediments created in Task 3. The networks are irregular but periodic in all three directions, thereby rendering them "infinite-acting" in the sense that no intrinsic boundaries exist at the edges of the network. This enabled us to conduct the first simulations of drainage (gas invasion of the water-saturated sediment) that are free of boundary effects. We discovered that the irreducible wetting phase saturation $S_{w,irr}$ in these infinite-acting networks is larger than the $S_{w,irr}$ observed in simulations in conventional finite networks. The latter were obtained simply by declaring the pore throats at the face of the periodic cell to be connected to a notional external reservoir of fluid. The finite network simulations accurately reproduce the behavior observed in laboratory experiments, which are of course finite. We propose that the simulations in the infinite-acting networks are more representative of the situation in sediments in nature.

The growth of hydrate at the gas/water interface will depend on how much water and gas are available locally and on how much the chlorinity builds up in the available water. The value of $S_{w,irr}$ and the spatial configuration of that water will thus affect the predicted growth habit. Thus our discovery of an intrinsic, scale-independent value of $S_{w,irr}$ will be useful in comparing laboratory efforts to grow hydrate with field observations. These results will be presented at the AGU in Dec. 2007.

We have applied Progressive Quasi-Static (PQS) algorithm for determining gas/water interface locations in a variety of rough-walled fractures. These results indicate that capillarity in fractures can induce nonlinear, hysteretic behavior. The nature of the gas/water interface in a gas-pressure-induced fracture in the sediment will therefore differ if gas pressure decreases or increases after the fracture event. These results will be presented at the SPE ATCE in Nov. 2007 and at the AGU in Dec. 2007.

**Figure 1.** Drainage simulations in the infinite-acting (periodic physically representative) networks establish an upper bound on the value of irreducible wetting phase saturation $S_{w,irr}$ observed in laboratory experiments and simulated in conventional finite networks. This bound is likely to be more representative of the value occurring in natural sediments.

## Endpoint wetting phase saturation increases as exits are made available

| Type of network | Exit faces | $S_{w,irr}$ (number fraction) |
|---|---|---|
| Infinite-acting | N/A | 0.18* |
| Finite | One face of unit cell | 0.12 |
| Finite | All six faces of unit cell | 0.06 |

*Volume fraction = 0.12

Near-optimal upper bound on experiments in bead packs, sand packs

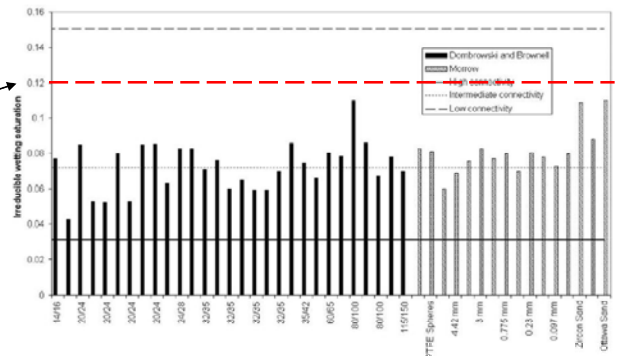
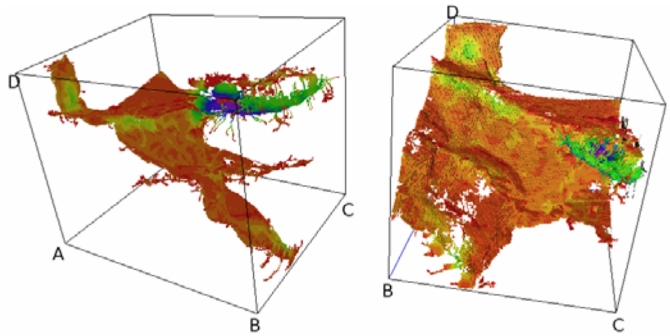
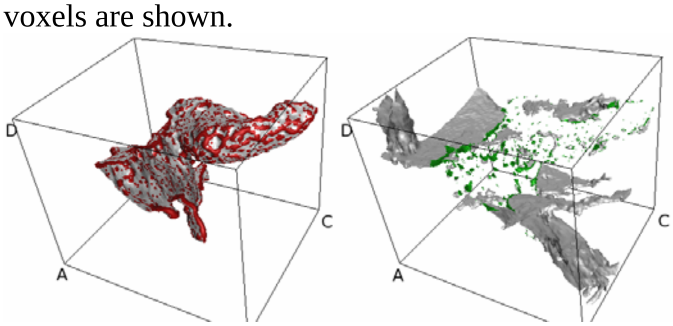


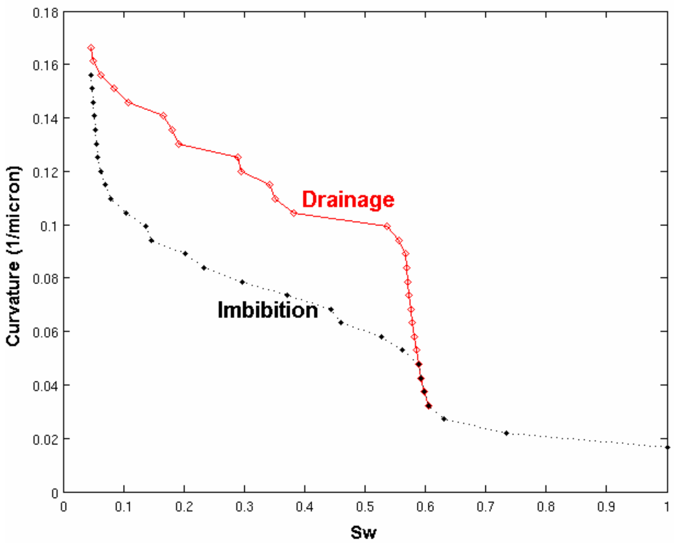
**Figure 2. (a)** Two views of a medial surface of a $190 \times 230 \times 200$ subvolume of a sample of fractured carbonate rock. Image voxels are cubes 3.1 microns on a side. Rainbow coloring reveals the distance to the closest grain voxels. Most of the surface is in a large, plane-like patch (mostly red color) and indicates the fracture. The white space “breaks” in the surface indicate areas in which the two fracture surfaces are in contact. Digitized curves indicate crevices (narrow channels) in the pore space. Finally, the non-planar green, blue and velvet part indicates a larger opening of the pore space, more vug-like than fracture-like.




**(b)** The non-wetting fluid configuration for curvature $C_{16} = 0.11\,\mu m^{-1}$ $(dx = 3.1\,\mu m)$ for the drainage simulation in the natural fracture of (a). (**Left**) Fluid-fluid interface is shown in red, and fluid-grain interface is shown in grey. The simulation started from the back face. Long red strips indicate the position of the interface in the fracture. Small red patches throughout the surface indicate where the non-wetting phase is in contact with pockets or patches of wetting phase on the rough fracture wall. (**Right**) The wetting fluid configuration for the same curvature. Fluid-fluid interface is shown in green, and fluid-grain interface is shown in grey. Small disconnected components correspond to wetting phase occupying nooks and crevices in the fracture face. Only components larger than 10 voxels are shown.



**(c)** Capillary pressure vs. saturation curves obtained from the level set method Progressive Quasi-static algorithm for the fracture.



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