Petrophysical studies of unconventional gas reservoirs using high-resolution rock imaging

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Project: 07122-22
Objective and technical approach

**Objective:**
(a) the physical mechanisms that limit gas recovery from tight rock formations
(b) the means of extending this recovery as far into the future as possible

**Approach:** acquire high-resolution 3D images of gas-bearing shale rocks using Advanced Light Source (ALS) facility and Focused Ion Beam (FIB) technology, and analyze these images using Maximal Inscribed Spheres-type (MIS) methods in order to estimate gas shale and tight sand flow properties at different conditions.
The tasks

4. 3D imaging of the pore space of shale using the FIB
5. 3D imaging of the pore space of tight sands using both ALS and FIB
6. A model of retrograde condensation at the matrix-fracture interface
7. Prediction of petrophysical rock properties from pore space geometry
8. Development of a depositional model for unconventional gas reservoir
Key personnel and industrial partners

• Key personnel:
  – PI; image processing and pore-scale modeling
    • Dmitriy Silin
  – Sample preparation and imaging
    • Liviu Tomutsa (co-PI)
    • Timothy Kneafsey
    • Jonathan Ajo-Franklin
    • Peter Nico
    • Andrew Mei

• Industrial partners
  – BP
  – Chevron
  – Schlumberger
Project deliverables

- Status reports by periodicity determined by RPSEA.
- A final report on the results of the Defined Effort.
- At least two presentations submitted to SPE Technical Conferences or similar meetings, and at least two publications submitted to peer-reviewed journals.

**Year 1**
- Sample selection.
- 3D images of shale samples.
- Codes simulating pore-scale gas flow with slip boundary conditions.

**Year 2**
- Sample selection and 3D images of 2 tight sand samples.
- MIS-based codes implementing a model of gas and gas condensate two-phase flow.
- New methods of high-resolution imaging of rock samples provided by the partners.
- Prepare for publication a paper on high-resolution imaging and image analysis of tight gas rocks.
- Prepare for publication a paper on pore-scale flow simulation in tight-gas reservoir rock.

**Year 3**
- Merging MIS and flow codes into a system for comprehensive analysis of tight gas sands and gas shales.
- High-resolution images of rock samples provided by the industrial partners.
- Prepare for publication a paper summarizing the work on the project: acquisition of high-resolution images, petrophysical analysis of these images using developed codes, and plugging-in the estimates into retrograde gas well model with retrograde condensation.
- Final report to RPSEA.
Project impact

• A better understanding of the mechanisms restricting gas flow in a tight formation
• Development of new strategies and tools to enhance gas production from tight formations:
  – Increased production and improved ultimate recovery for tight gas wells
  – Extended field life for unconventional gas wells
Progress to date

- Rock imaging
- Maximal inscribed spheres (MIS) method
- Tight sand samples
  - Fluid distribution
  - Capillary pressure curves
- Shale samples
Computer tomography

Tight sand

Shale
Microscopy

Tight sand

Shale

Zigzagged fracture tip

100 micron
Advanced Light Source Facility (ALS)
Sand and sand

Frio sandstone

Tight gas sand

1 voxel = 4.5 micron

1 voxel = 1.8 micron
Sand and shale
Focused Ion Beam (FIB)

Sample

Electron Beam

Sample

Mount

A
Maximal Inscribed Spheres

\[ P_c = p_{nw} - p_w = \frac{2\sigma}{r} \]
Maximal Inscribed Spheres

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Maximal Inscribed Spheres

\[ P_c = p_{nw} - p_w = \frac{2\sigma}{r} \]
MIS: pore-scale verification

CT image

MIS Calculations
Tight sand: thresholding

For a comparison

Low porosity $\rightarrow$ a single-peak histogram
Spotty segmentation

- Noise
- Pores

?
Cleaning using 3D cluster search
Reconstructed 3D pore space

- The 1.8 micron resolution captures the main features of the pore space geometry.
- A submicron resolution is required to study the microporosity of the sample.
MIS-calculations: Capillary pressure curve

- Consistent results for different samples
- High entry capillary pressure
- No plateau on the curve
- The non-wetting phase gets disconnected below 50% water saturation (sandstone: ~70%)
MIS-calculations: fluid distribution

S = 0.15
MIS-calculation: fluid distribution

\[ S = 0.24 \]
MIS-calculations: fluid distribution

\[ S = 0.33 \]
MIS-calculations: fluid distribution

\[ S = 0.39 \]
MIS-calculations: fluid distribution

S = 0.48
MIS-calculation: fluid distribution

S = 0.62
MIS-calculations: fluid distribution

S = 0.7
MIS-calculations: fluid distribution

\[ S = 0.84 \]
MIS-calculations: fluid distribution

S = 0.94
Future plans

• FIB imaging:
  – Microporosity of tight sand
  – Pore space geometry of shale

• Pore-scale modeling:
  – Incorporation of microporosity in the capillary pressure and relative permeability estimates
  – Klinkenberg effect: a slip condition for the gas flow

• Retrograde condensation model:
  – Pore-scale impact of condensate on the permeability
  – Macro-scale model of a matrix-fracture interface

• Depositional model
  – Mimic tight sand pore space geometry
Issues/problems

• No major problems thus far

• More focus on tight sand than shale
  – More tight sand samples than shale samples available at the moment
  – Still working on microporosity
Summary and conclusions

• Active participation of the industrial partners is greatly appreciated

• Accomplishments thus far:
  – X-ray CT scans of shale and tight-sand cores
  – ALS scans of the samples
  – Modeling, code development, simulations started
  – Proposals to schedule FIB work submitted