Primary Drainage and Waterflood Capillary Pressures and Fluid Displacement in a Microporous Reservoir Carbonate

Guanglei Zhang, Martin Blunt and Branko Bijeljic
Objectives

The objective of this experiment is to use a Differential Imaging Porous Plate (DIPP) method to:

a) characterize primary drainage and waterflood capillary pressures and fluid displacement in a microporuous reservoir carbonate, and

b) provide measurements for validation and calibration of our generalized network model (GNM)
Sample and experimental protocol for primary drainage, imbibition and waterflooding experiments

1) Confining pressure: 1500 kPa; Back pressure: 500 kPa

2) Dry scan and 30%KI brine scan

3) Primary drainage: Inject decane at 8 capillary pressures from ~10 to ~1000 kPa with a water-wet porous plate

4) Dynamic ageing with crude oil for 3 weeks

5) Imbibition: put the bottom end into 30%KI brine for one week

6) Waterflooding: Inject 30%KI brine at 8 capillary pressures from ~ -25 to ~ -1000 kPa with an oil-wet porous plate

CT imaging

Three high resolution scans (3.58 µm) for top 14.2 mm of the sample

- He Porosity: 0.190 ± 0.003
- Measured permeability: 88 ± 2 mD

Sample size:
6.1 mm × 21.5 mm

Metal end piece
Porous plate
Rock sample
PeeK spacer
Metal end piece

X-ray Enclosure
Brine pump
Pressure transducer
Confining pump
Coreholder
Back pressure pump
Flow direction
Scanning length

He Porosity: 0.190 ± 0.003
Measured permeability: 88 ± 2 mD
Greyscale-based differential imaging to compute porosity

Differential imaging → fewer parameters → lower uncertainty

\[ \overline{CT} = CT_{\text{rock}}(1 - \phi) + CT_{\text{air}} \phi \]

\[ \phi = \frac{(\overline{CT} - CT_{\text{rock}})}{(CT_{\text{air}} - CT_{\text{rock}})} \]

\[ \text{Differential imaging} \quad \text{dry} - \text{brine} \]

\[ CT_{\text{rock}} = 0 \quad \rightarrow \quad \phi = \frac{\overline{CT}}{CT_{\text{air}}} \]

Differential imaging → fewer parameters → lower uncertainty
Greyscale-based differential imaging to compute saturation

\[ \overline{CT} = CT_{\text{rock}}(1-\phi) + CT_o\phi S_o + CT_w\phi(1-S_o) \]

\[ S_o = \frac{\overline{CT}-CT_{\text{rock}}(1-\phi)-CT_w\phi}{(CT_o-CT_w)\phi} \]

Differential imaging → fewer parameters → lower uncertainty
Watershed segmentation for grain, macropore and sub-resolution pores

- Total porosity: $0.188 \pm 0.010$
- Macropore: $0.073 \pm 0.005$
- Sub-resolution pores: $0.115 \pm 0.005$
- Helium Porosity: $0.190 \pm 0.003$

Grain: grey
Sub-resolution pores: blue
Macropores: red
Greyscale images for primary drainage experiments
Total brine saturation during primary drainage

Flow direction

Brine saturation

Length (mm)
Brine saturation in microporosity during primary drainage
Brine saturation in macropores during primary drainage
Capillary pressures vs $S_w$ during primary drainage

![Graphs showing capillary pressures vs. water saturation ($S_w$) during primary drainage.](image)
Greyscale images for waterflooding experiments

After Ageing

After Imbibition

-25 kPa

-42 kPa

-67 kPa

-115 kPa

-180 kPa

-349 kPa

-660 kPa

-1024 kPa
Total brine saturation during waterflooding

Flow direction

Inlet

Outlet

Brine saturation

Length (mm)

AfterAgeing

AfterImbibition

-25 kPa

-42 kPa

-67 kPa

-115 kPa

-180 kPa

-349 kPa

-660 kPa

-1024 kPa
Brine saturation in sub-resolution pores during waterflooding

![Graph showing brine saturation as a function of length and pressure]
Brine saturation in macropores during waterflooding
Capillary pressures vs $S_w$ for waterflooding

$P_c$ (kPa)

$S_w$

- Total
- Microporosity
- Macropore
Capillary pressures vs $S_w$ for drainage and waterflooding
Capillary pressures vs $S_w$ in sub-resolution pores for drainage and waterflooding.
Capillary pressures vs $S_w$ in macropores for drainage and waterflooding
Conclusions

• Developed an experimental methodology to measure capillary pressure during primary drainage and subsequent waterflooding using a porous-plate technique.

• Can accurately impose capillary pressure and a homogeneous equilibrium saturation distribution.

• Applied the method to a micro-porous carbonate.

• Can distinguish capillary pressure in resolvable macropores and micro-porosity.

• Benchmark experiments for multiscale pore-scale modelling.
Any questions?

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