Fluid Topology in Drainage and Imbibition: Pore Scale Imaging by Synchrotron Tomography

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Introduction

In two-phase flow in porous media, a fluid phase is normally composed of a large connected cluster (connected pathway) and numerous disconnected smaller clusters (ganglia). A flooding experiment including drainage and imbibition was performed on a water-wet Berea sandstone. 3D pore scale changes of fluid configuration were captured under flow using synchrotron X-ray tomography. The connectivity (Euler characteristic) was calculated separately for ganglia and for connected pathways of the wetting and nonwetting phases to give more insight of their impact on topology of the water and oil phases.

Definition

Following the recent papers (ref. in the article) on the subject, Euler characteristic (χ) is used to describe the connectivity of a fluid phase, where χ is defined as:

$$\chi = N - L + O$$

In this equation, *N* is the number of isolated clusters of a fluid phase, *L* is the number of redundant connections within all clusters, and *O* is the number of cavities. A negative value of χ indicates higher connectivity while a positive value indicates fragmented fluid.

Method

Cylindrical core sample (D=4mm, L=10mm) was a water wet Berea sandstone (k≈200–300mD & Ø ≈ 15%).
Core flooding and synchrotron imaging was conducted in the *TOMCAT beamline* at the *Swiss Light Source* with spatial resolution of 3.25 micron.
The images were filtered, segmented and binarized using ImageJ. Water and oil binary data sets were used to calculate χ, volume etc.

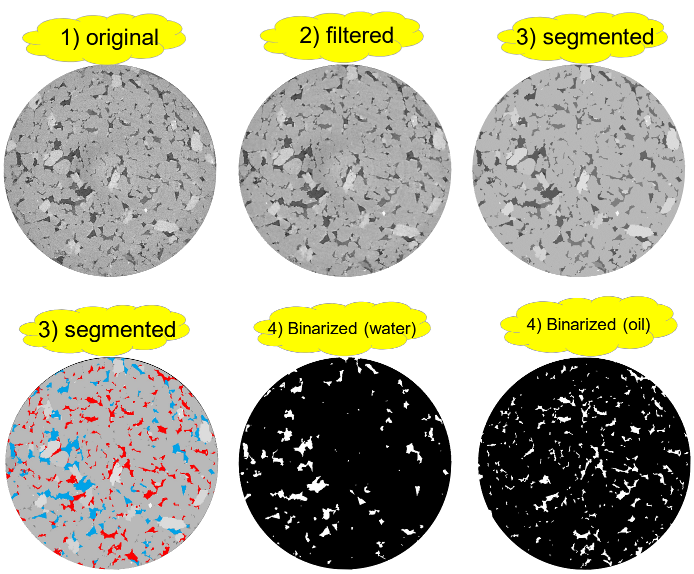
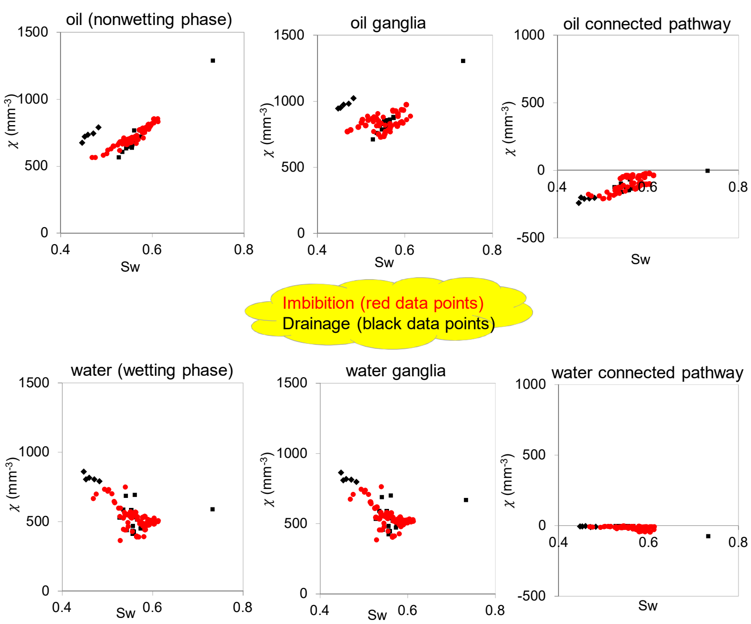


Diagram shows major steps of image processing.

Results

1. The connectivity of the nonwetting phase mainly depended on the connectivity of the nonwetting ganglia and was less sensitive to connectivity of the nonwetting connected pathway (See below figure). The wetting phase had also the same behavior.



Figures show Euler characteristic (χ) versus water saturation (S_w). A negative value of χ indicates higher connectivity while a positive value indicates fragmented fluid.

2. The ganglia and the whole phase (ganglia plus connected pathway) showed hysteresis in the topology in imbibition and drainage for both wetting and nonwetting phases (See above figure). The connected pathways however had insignificant hysteresis in imbibition and drainage, i.e. the hysteresis in topology of a phase was likely to be caused by the ganglia.

Details of the presented results and the discussions on the possible wetting change can be found in the paper.
Comprehensive results and discussions are under review in a journal.

Summary

Results revealed that topology of a fluid mainly depended on topology of the corresponding ganglia and was less sensitive to topology of the corresponding connected pathway. A fluid phase and its ganglia had hysteresis in the topology during imbibition and drainage. However the connected pathway had insignificant hysteresis, i.e. the hysteresis in topology of the phase was caused by the ganglia.

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