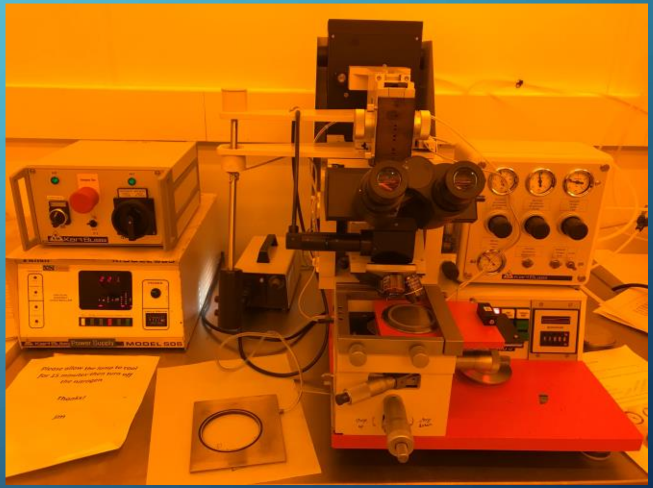
Microfluidic Study of Waterflooding in Fractured Porous Media

The aim of the research is to study how to improve the residual oil production by increasing the RF from fractured porous media in the case of water injection as EOR.

Design Of The Micromodel

- The design of the porous media is based on Voronoi tessellation by using MATLAB and CAD software.
- The path was converted to CAD files, and then printed on photomasks (CAD Services Inc). The Photo-lithography technique was used to etch the patterns on silicon wafers.

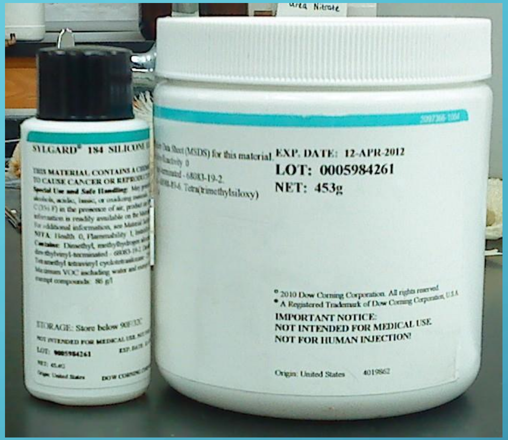


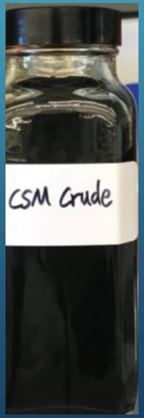
The final dimensions of the system are respectively:

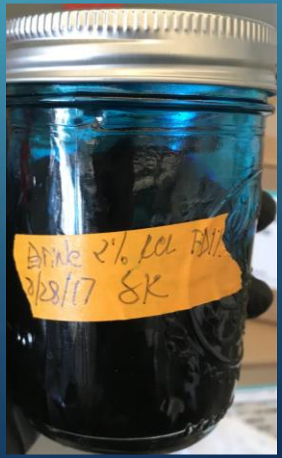
- 4800 μm × 1200 μm.
- Channels width 10 μm , the inlet / outlet
- Channels are 25 μm deep
- ϕ =15% which reflect the average values for high-permeability sandstone formations.

MATERIALS USED

- PDMS (184 Sylgard Elastomer) and curing agent (184 Sylgard Curing Agent
- NOA81(Norland Optical Adhesive 81)
- Silicon wafer
- Haliburton Oil (at 20C ρ= 0.811[g/cm3], μ= 4.525 [cP]
- Brine (2%KCL,DI water) (at 20C ρ= 1.0111[g/cm3], μ= 0.999 [cP]
- Micro tubes
- Glue (Epoxy 5 min)
- screws







Material and Methods

PDMS PREPARATION

- Poly (dimethylsiloxane) polymer (PDMS) is used as an intermediate mold to transfer an etched pattern from the silicon wafer to NOA81. PDMS solution was prepared using 10:1 ratio of a base elastomer (184 Sylgard Elastomer) and curing agent (184 Sylgard Curing Agent).

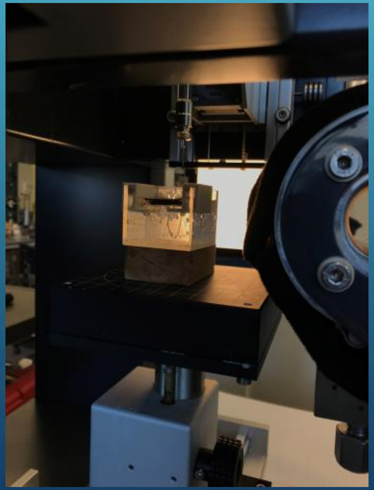
- Then, PDMS master was molded from the silicon wafer and cured in the oven for four hours–one day at 80°C. After development, PDMS master was peeled off from the silicon wafer.

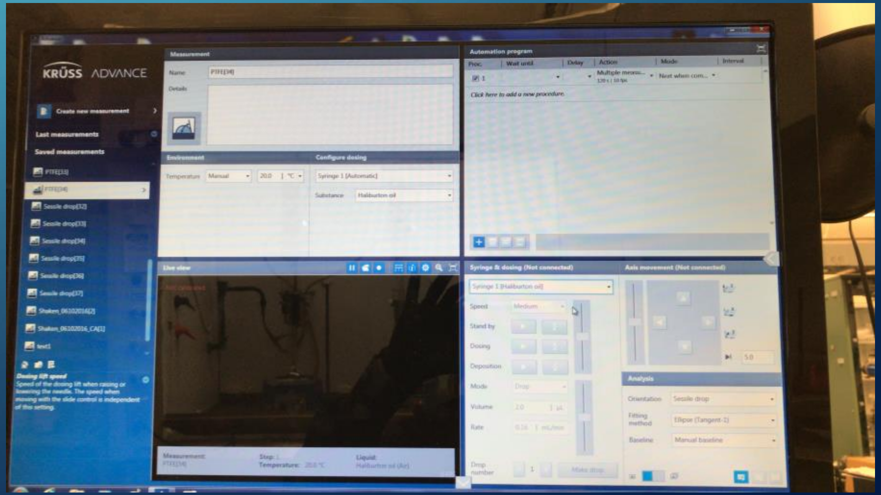
NOA81

- In the preparation of microchips, we use NOA81 as our based material and some microtubes.
- First of all we punch 4 holes on the PDMS master and we add 4 tubes, and we cover our system with NOA81.
- The porous medium pattern is transferred from the PDMS master to NOA81 by UV-light exposure.
- The flat NOA81 is cured only 1 min each side and it leaves the surface sticky for further bonding. Then, the patterned NOA81 substrate is pressed gently against the flat NOA81 substrate on the glass slide.
- At this point our micromodel is ready to run the experiments.

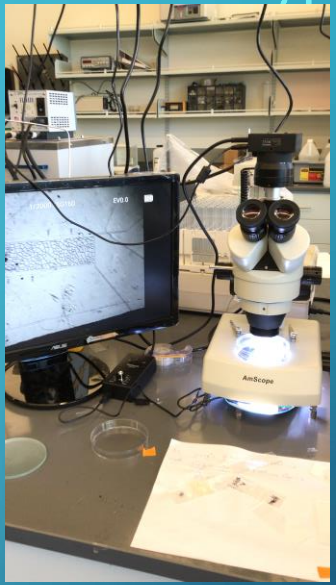
Wettability Measurements

- We decide to measure the wettability properties of our system to demonstrate that the micromodel has a uniform wettability.
- The contact angle IFT measurements and are conducted in water-crude oil environment using a KRÜSS drop shape analyzer DSA-100. The measurement cell of DSA-100 was first filled with brine (DI water and 2% KCl), and then crude oil was injected to generate a buoyant droplet on the NOA81 surface.
- The pendant drop method was then used to determine the contact angle of crude oil on the NOA81 surface surrounded by the brine, and IFT was calculated based on the equilibrium shape of the drop impinging on the tip of the capillary.
- Without any treatment, NOA81 shows an intermediate wettability with a water-oil contact angle of 87° and IFT of 23.3 mN/m.





Experiment Set Up



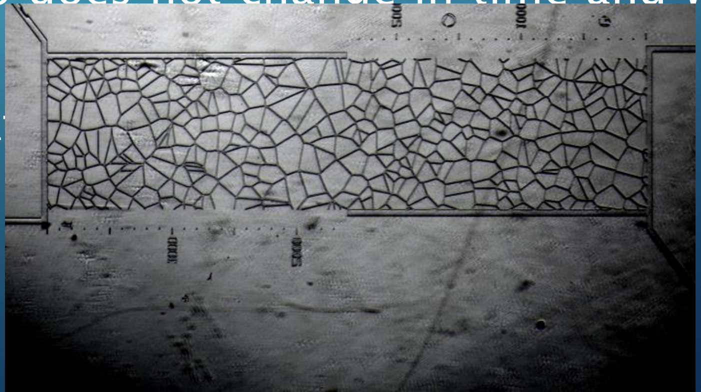
- Oil saturation
- The system is working at ambient condition and the Qo (oil flowrate) is constant.
- We inject 1µl/min of oil (Haliburton oil) in the system to saturate the porous medium and we control the saturation phase on the microscope camera.

1. We start the oil injection from A and we leave open A/D(injectors wells) to make sure that all the air present in the system will be displaced along the channel D. While B/C (production wells) are closed with valves.

2. When all air is displaced and we see a level of oil production from well D, we close it with a valve. We continue the saturation phase by opening B/C.

3. We stop the oil injection, when the So does not change in time and when there is a level of oil in all 4 wells.

4. At this point our porous medium is sa

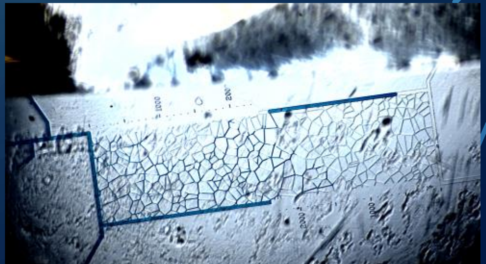


- Water Injection Phase 1
- The system is working at ambient condition and the Qw (water flowrate) is constant.
- We inject 1µl/min of brine (prepared before) in the system to displace the oil porous medium and we control the breakthrough on the microscope camera.

1. We start the water injection from C and we leave open B/C (injectors wells) to make sure that all the air present and the accumulated oil in tubes will be displaced along the channel B. While A/D(production wells) are closed with valves.

2. When all the remained oil is displaced, we can observe a continuous phase of water along the channel C/B and we can close B to avoid additional water production. We continue the waterflooding operation by opening A/D.

3. We stop the water injection, when the breakthrough is continuous phase and it   reaches the producer wells (A/D) and does not change in time.



Reverse Water Injection Phase 2

The system is working at ambient condition and the Qw (water) is constant. We follow the same sequence of the previous steps, with the only difference that we reverse the injectors point with the productions. We inject 1µl/min of brine (??prepared before) in the system to displace the residual oil remained in the porous medium and we control the breakthrough on the microscope camera.

1. We start the water injection from D and we leave open D/A (injectors wells) to make sure that all the air present and the accumulated oil inside the tubes will be displaced along the channel B. While A/D(production wells) are closed with valves.

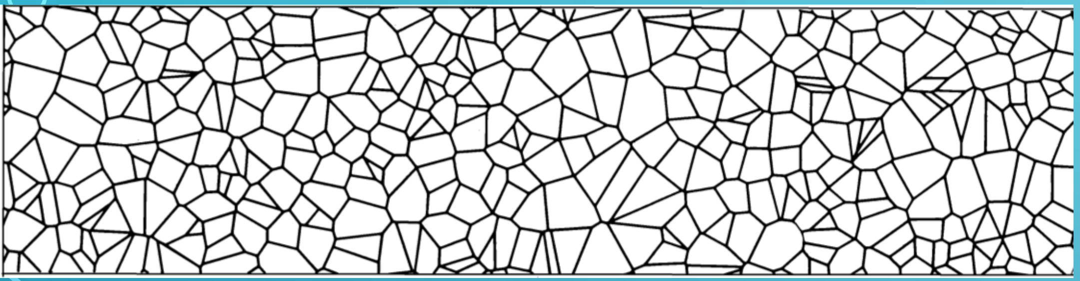
2. When all the produced oil is displaced from the channels (D/A), we can observe a continuous phase of water along the channel D/A and we can close A to avoid additional water production. We continue the waterflooding operation by opening B/C.

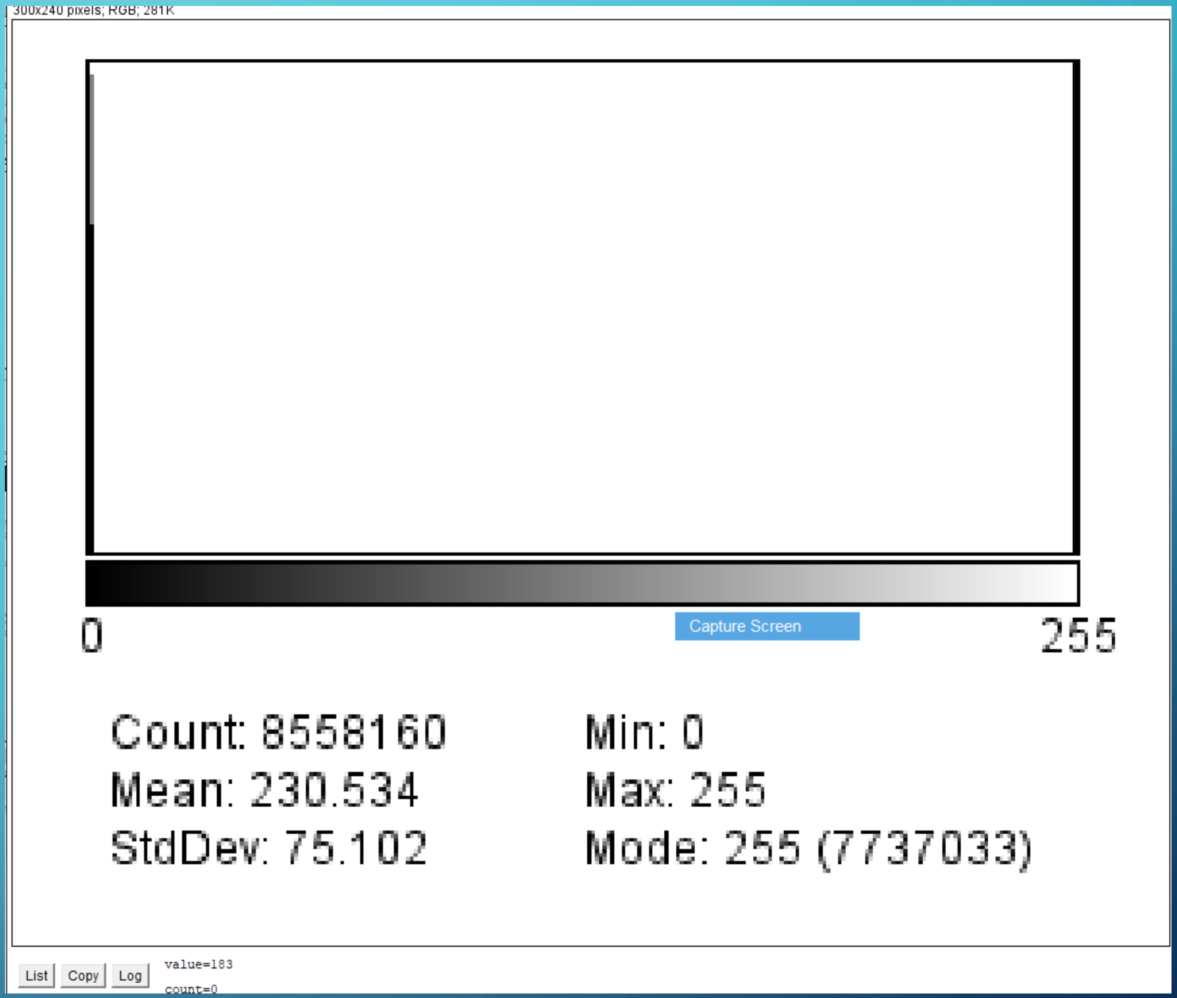
3. We stop the water injection, when the breakthrough is shown as a continuous phase and it reaches the producer wells (B/C) and the saturation does not change in time.

Data Analysis

- The main target of our project is to calculate the RF of the system, based on the experimental saturations.

- We know the exact So, Sw, Sa based on the binary Image analysis, since oil will appear as white, while brine will appear in blue and air will appear in black. So based on the number of pixel we know how is changing the saturation inside the po

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Optimization of the System

Parameters

- The optimization of our system can be made by changing the water injection flow rate and then by comparing the experimental time required for displacement with the theoretical time based on t=Q/v. We
- Parameters calculated with the valid assumption of Darcy Model :
- Vdisplacement, k, Nc, Rh, Sor, Rf

Reservoir Scale Simulations

- This study is performed at microscale in lab , and it cannot be comparable with reservoir scale. For this reason we decide to verify the consistency of our model at microscale with a reservoir model simulator at reservoir simulator: CMG

- We are thinking to define a simple model representative of our reservoir in 2 dimension (i, j), with 40i grids and 10i.

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