The Role of Smart Water in Oil Recovery

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Primary CNF Tools Used: CRC hot press, CorSolutions Microfluidic Probe Station

MECHANICAL DEVICES

Abstract:

Global oil demand and consumption continues to increase yearly, but current oil recovery techniques lack the efficiency needed to extract most of the oil in reservoirs. The use of nanoparticles as sensors for the available quantity of oil to extract has been demonstrated in experimental laboratory evaluations with core samples. This report will discuss how microfluidic devices were used to provide a controlled environment for studying how particles partitioned between oil and flooding fluids. Smart water was injected into the devices at various flow conditions in order to determine favorable circumstances for particles to enter the pockets of the channels. Solutions that contained less than 50% water to ethanol minimized particle clogging at the inlets and T-intersections of the devices. At 2.5 µL/min, the contact line between the oil and smart water remained stable and boluses did not appear. The hydrophobicity of the walls of the inlets negatively affected the flow of particles in smart water solutions. These flow conditions will ultimately allow for the particle concentration at the inlet and outlet of microfluidic devices to be measured, which will inform the effectiveness of particles as sensors for oil in a reservoir.

Summary of Research:

With the rapid depletion of known oil reserves, detecting properties of oil reservoirs and optimizing oil extraction is critical. Global oil demand and production continues to increase every year, with the rate of oil consumption in 2018 having grown to an above average 1.4 million barrels per day [1]. Nanoparticles can serve as sensors for the interiors of oil reservoirs by partitioning into oil or releasing nanoreporters upon contact with oil [2]. Microfluidic devices can provide a micro-scale environment to analyze singular effects in pores by modeling partially saturated rock with crude oil [3]. Laminar flow in the microchannels of the devices allows for experiments that can be reliably repeated and observed over a pore network [3].

The microfluidic device that is utilized to mimic subsurface conditions is fabricated from two layers of polypropylene in the Cornell NanoScale Facility. To manufacture a mold for forming the channels, a Si wafer is patterned with SPR-220-7 using standard photolithography techniques and deep reactive ion etching. The mold is used to emboss a polypropylene square on a CRC Hot Press at 166.6°C at 200 lbf (pound-force) for 2.5 minutes, after which the embossed piece is bonded to blank polypropylene square with a thickness between 0.17 mm and 0.24 mm at 149.5°C at 9 lbf above the baseline force for six minutes. As seen in Figure 1, the design features 16 parallel, bifurcating channels that allow for uniform, low flow rates for the given syringe pump range. The depth and width of the main channels was approximately 20 µm, and the pockets were rounded with a side width of 13 µm and placed apart from each other every 13 µm.

Figure 1: Silicon wafer patterned with 16 channel design.

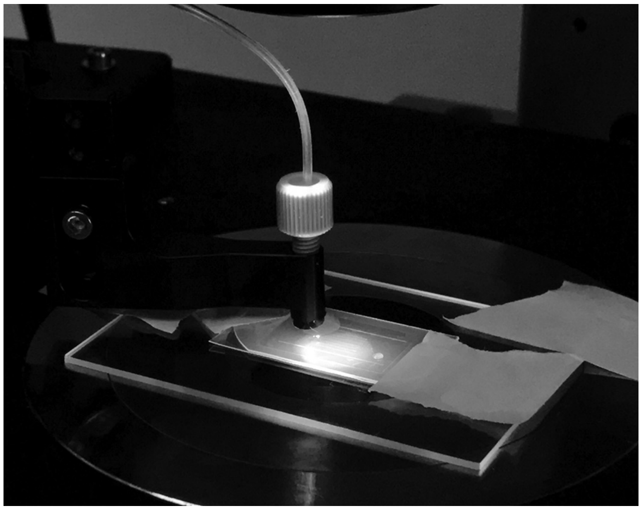
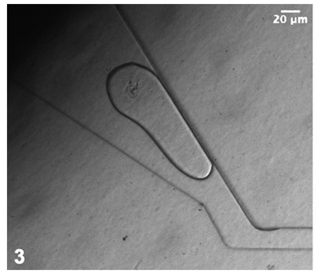


Figure 2: Experimental setup close-up of CorSolutions arm connector.



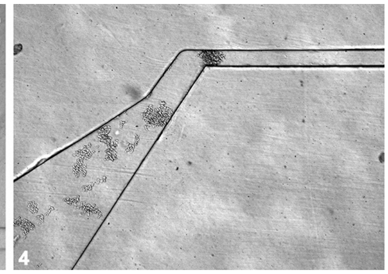


Figure 3, left: *Oil bolus attached to wall of inlet of microfluidic device.*
Figure 4, right: *Particles clustered at the narrowing of the inlet for 25% water: 75% ethanol solution.*

The formation of oil boluses in the inlet of the microfluidic devices after water-ethanol solutions were injected was investigated. Boluses that formed at any point in the device would lead to particles dispersing at an uneven rate and would lead to clogs in the channels of the device. Undecane, oil, and water-ethanol were sequentially injected into a device using a Tygon® tube as shown in Figure 2 (CorSolutions). Boluses at the inlet were qualified as a distinct second phase that appeared to fill the center of the inlet or as singular bubbles of oil that remained attached to the inlet wall for the duration of the trial as seen in Figure 3.

For every flow rate, 25% water: 75% ethanol had inlets free of boluses. The contact line between oil and the injected solution was most stable for 2.5 µL/min, as it took the longest amount of time for the oil to be displaced from the pockets compared to 5 and 10 µL/min. The 25% water: 75% ethanol solution containing microparticles was injected in a new device at 10 µL/min. 2 µm particles clumped together immediately at the inlet and the first T-intersection for all three trials as shown in Figure 4, but there was no evidence of boluses in the inlet.

Conclusions and Future Steps:

Because the devices were primed with oil, it was expected that the particles would partition from the injected solution to the oil in the pockets. As the particles had a tendency to attach to the walls of the inlet and to each other at T-intersections, no particles were able to flow into the channels of the devices at a variety of water-ethanol solutions and flow rates. Qualitative data presented in this report suggests that smart water consisting of 25% de-ionized water and 75% ethanol prevents boluses from forming in the inlet of the device. However, the hydrophobicity of the solution and the surface of the channels causes particles to cluster at the inlet and clog flow into the channels.

Future work will focus on changing the composition of the smart water with a surfactant that allows particles to partition into the oil in the pockets, and ultimately serve as a sensor for oil.

References:

[1] British Petroleum. (2019). BP Statistical Review of World Energy 2019. (Report No. 68).

[2] Sireesha, M., Babu, V. J., Kiran, S. K., and Ramakrishna, S. (2018). A Review on Nanomaterial Revolution in Oil and Gas Industry for Enhanced Oil Recovery Methods. Res Dev Material Sci. 4 (1).

[3] Gogoi, S., and Gogoi, S. B. (2019) Review on microfluidic studies for EOR application. Journal of Petroleum Exploration and Production Technology.

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