Water transport in n-alkane phases through diffusion and emulsion: insights into oil remobilization from a pore-scale perspective

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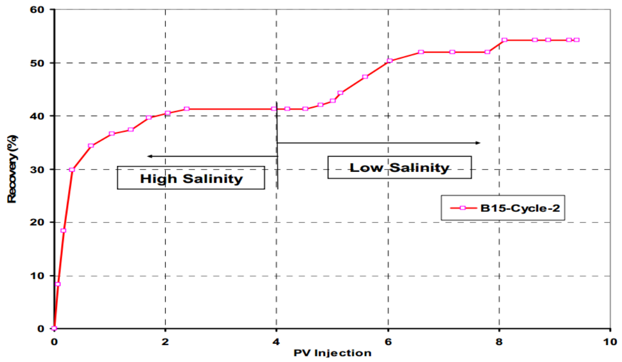
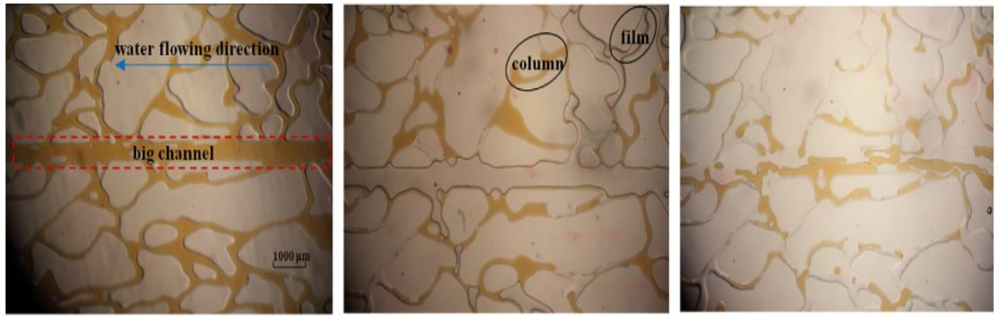
Introduction

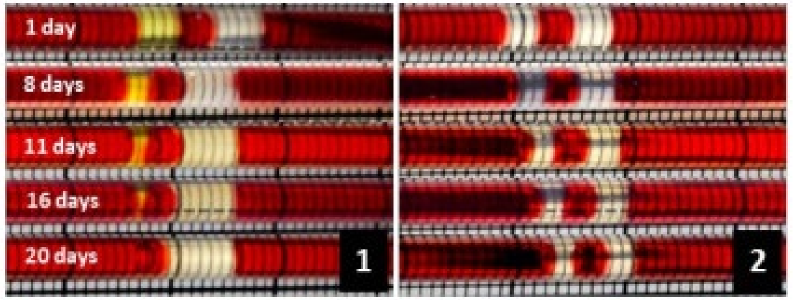
Low salinity waterflooding on EOR



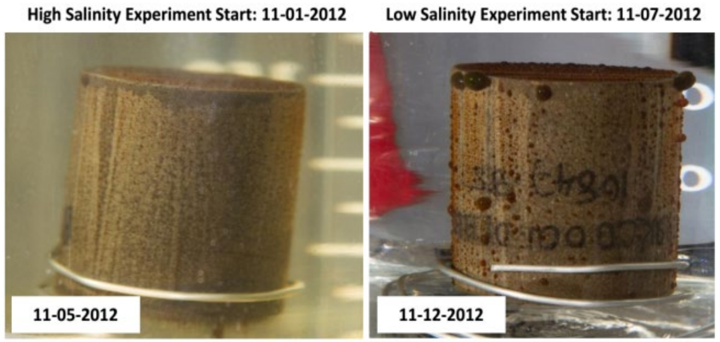
Austad et al., 2010



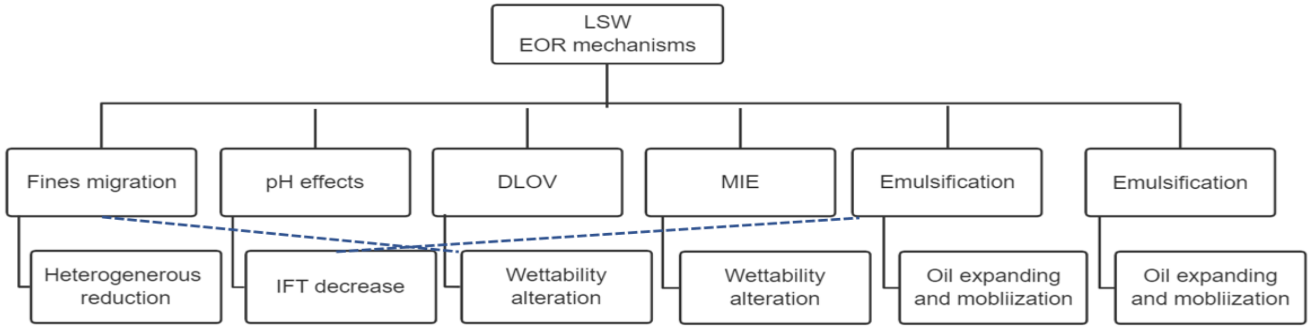
Zhao et al, 2016



Fredriksen (2020)



Fakcharoenphol, Perapon, et al., 2014



Laboratory tests have confirmed that enhanced oil recovery can be obtained from sandstone and carbonate reservoirs by performing a tertiary low salinity waterflooding, but there is no consensus on a single mechanism delineating this effect.

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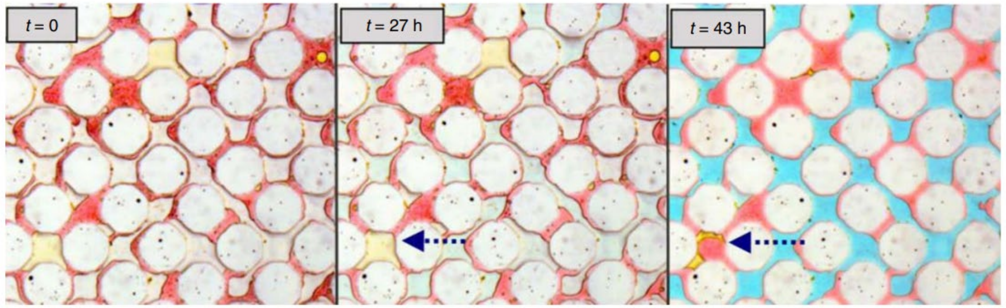
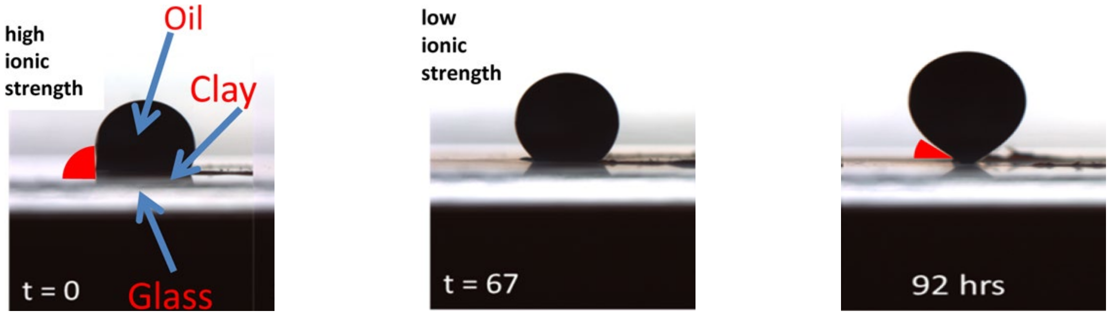
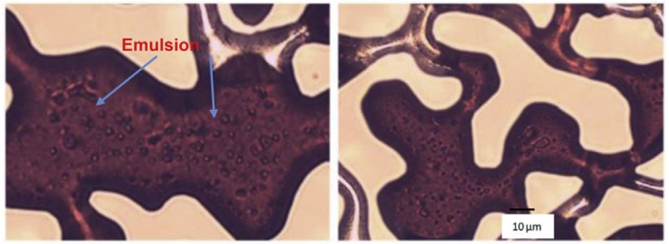
Salinity contrast effects observed in experiments



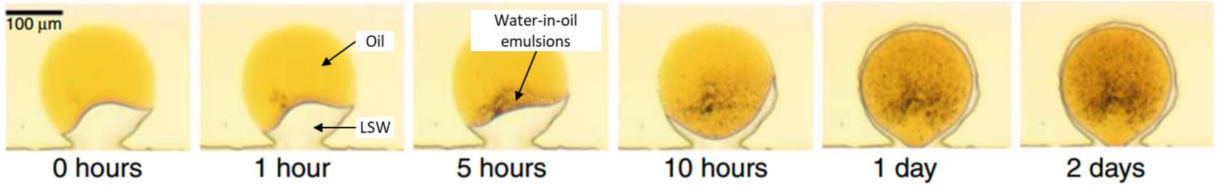
Sandengen et al. (2016)



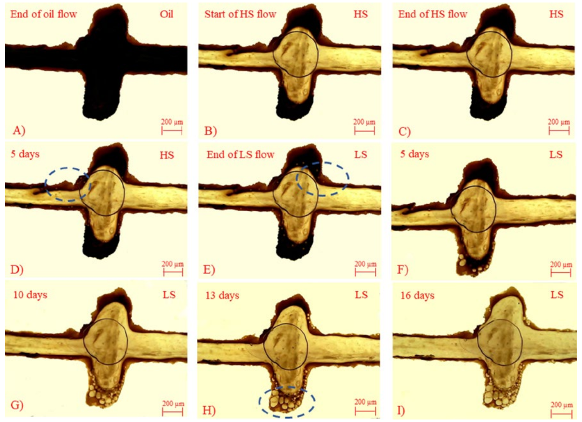
Mahani, Hassan, et al. (2015)

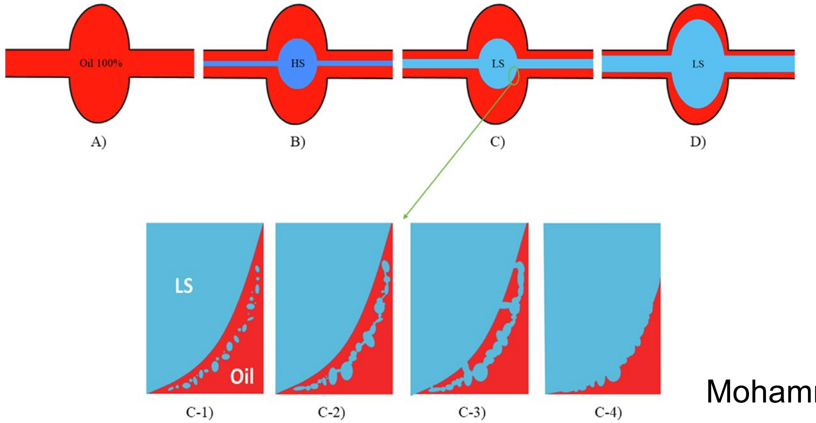


Aldousary, S., & Kovscek, A. R. (2019)



Du, et al.,(2019)

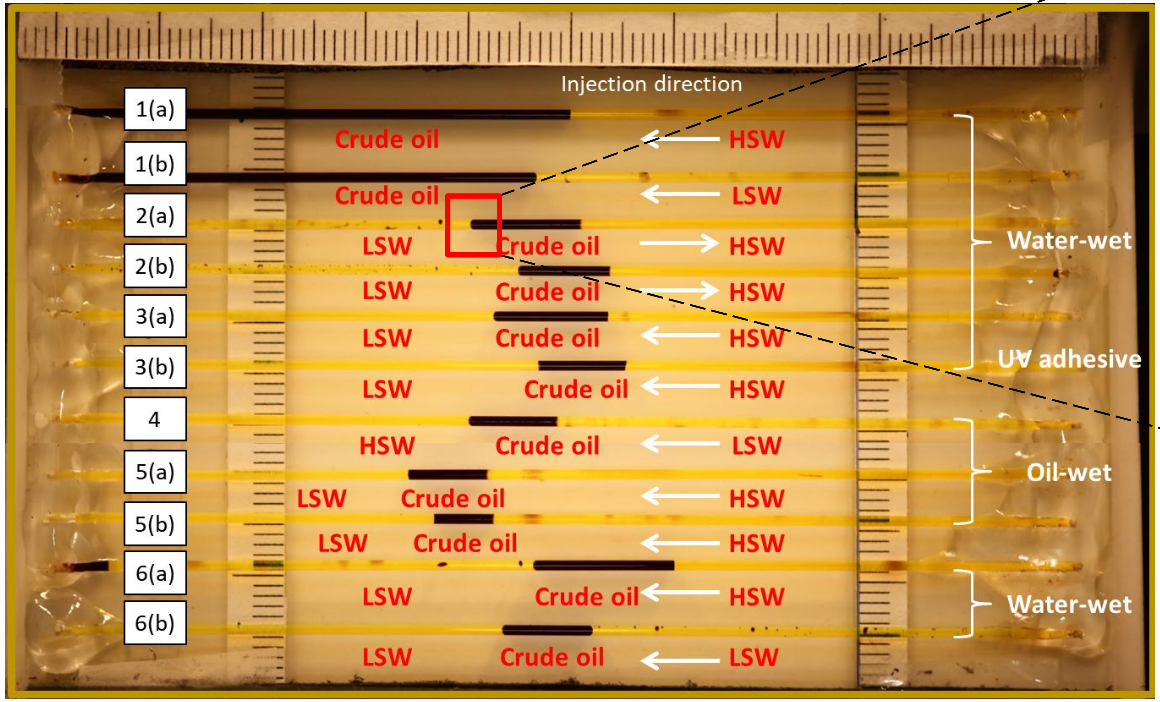


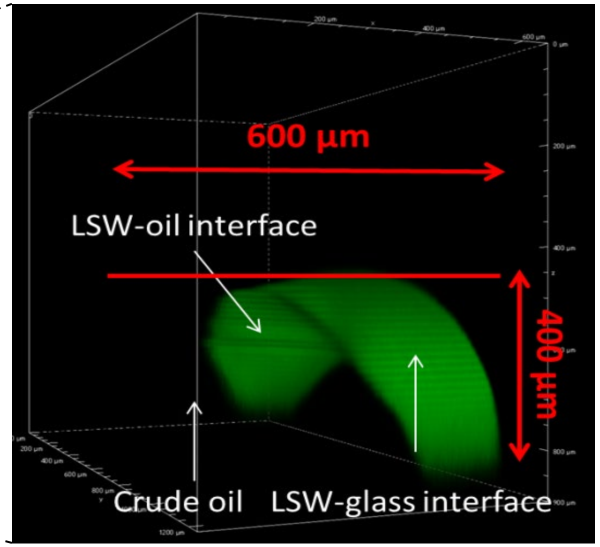


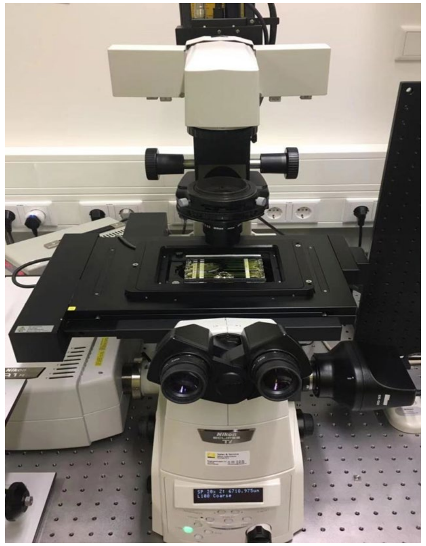
Mohammadi, M., & Mahani, H. (2020)

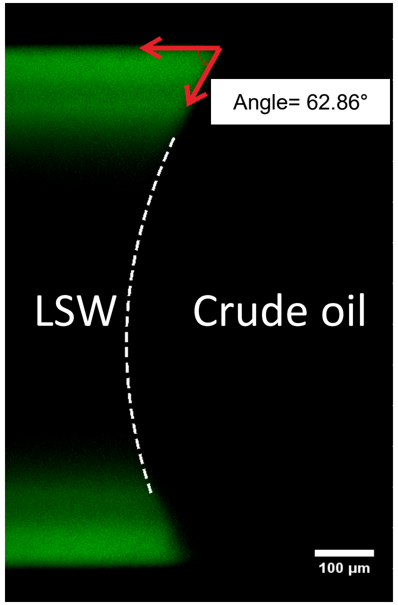
Introduction

Our previous works and findings

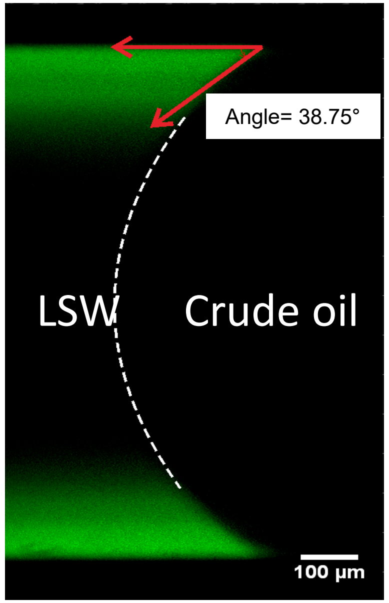




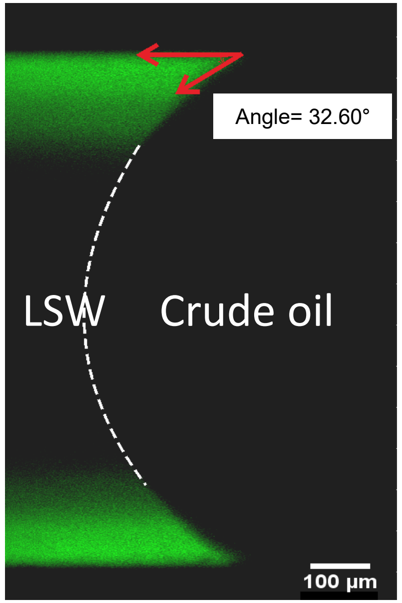




After 1 day



After 15 day



After 40 day

Monitoring oil globules for 40 days!

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Yan, L., et al., 2020. Fuel, 274, p.120798.

Research questions

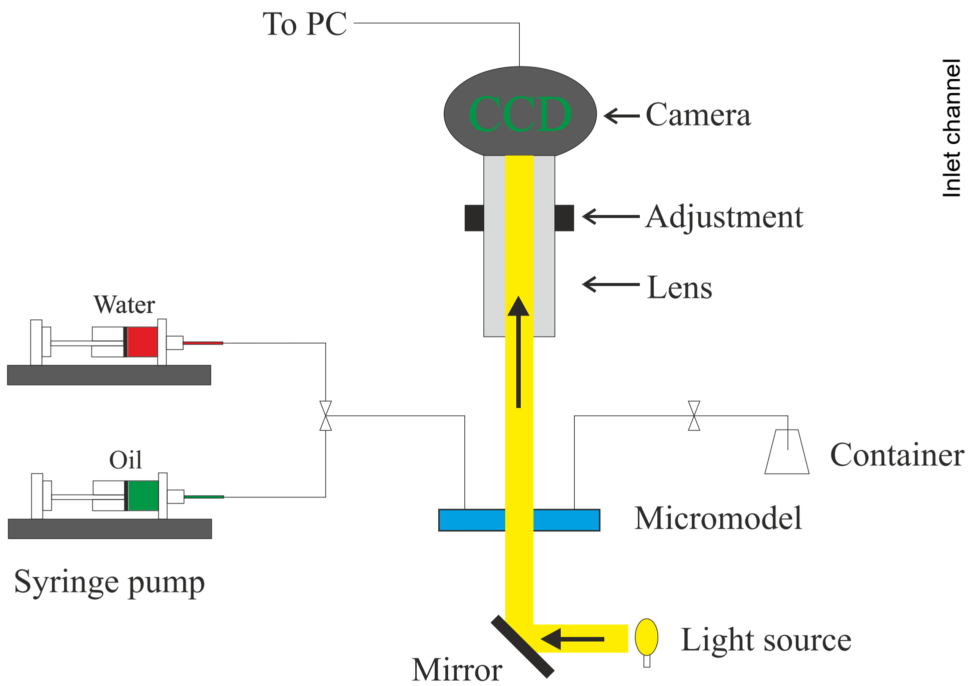
How the osmosis and emulsification work on oil remobilization?

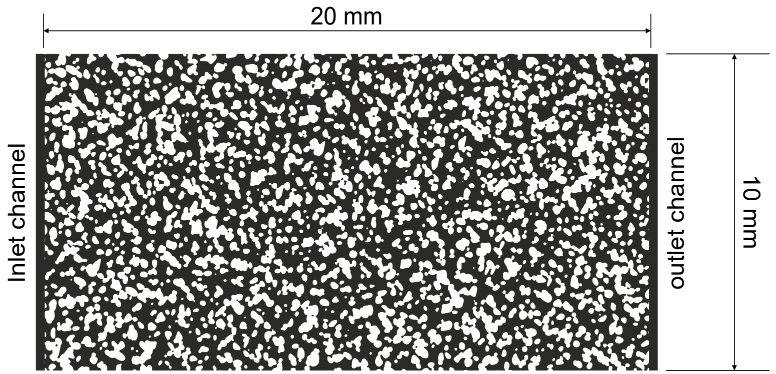
1. For a system of LSW/pure oil/HSW (without surfactant)
   - How to quantify the osmosis effect (water diffusion in oil phase) on oil remobilization?

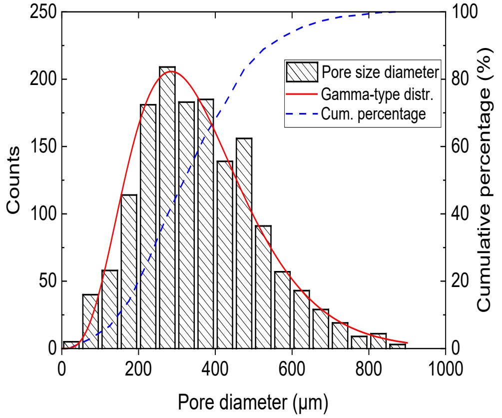
2. For a system of LSW/oil+surfactant/HSW
   - What is the contribution of emulsification on the water transport?
   - What is the driving force for the emulsion transport?

Pore-scale laboratory works

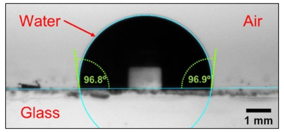
Microfluidic experiments

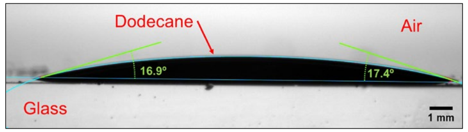






- White spaces are grains.
- 20 μm thick pore spaces
- 0.56 porosity
- 2.5 Darcy permeability

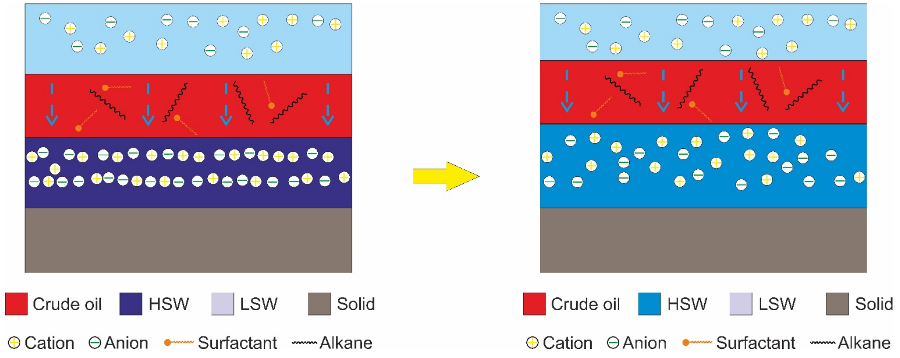


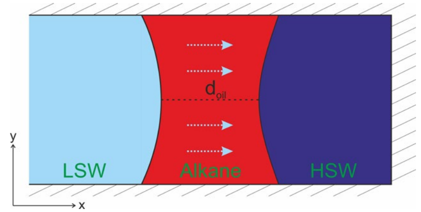


Flooding processes:

- Oil-wet chips modification
- High salinity water saturation
- Oil flooding
- Low salinity water flooding
- Sealing chips and monitoring area of interest

Expected fluid contacts we want to create in microfluidics:





Experiments in microfluidics

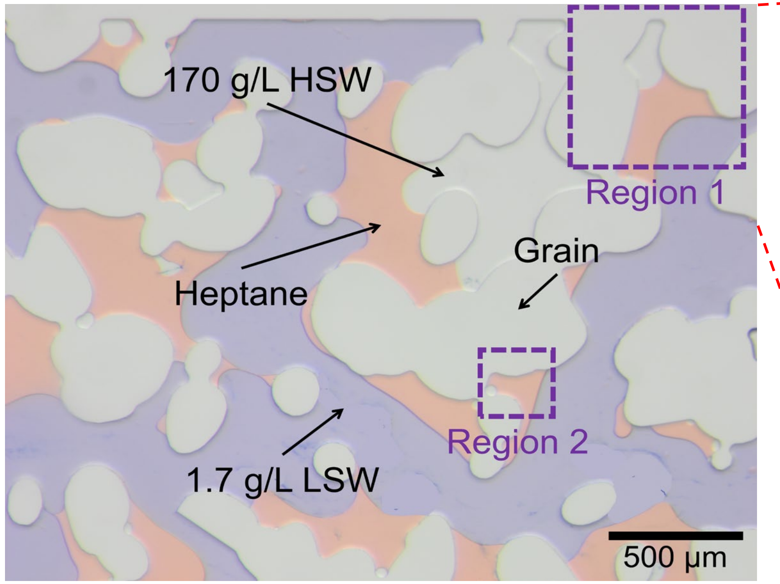
Type of experiments

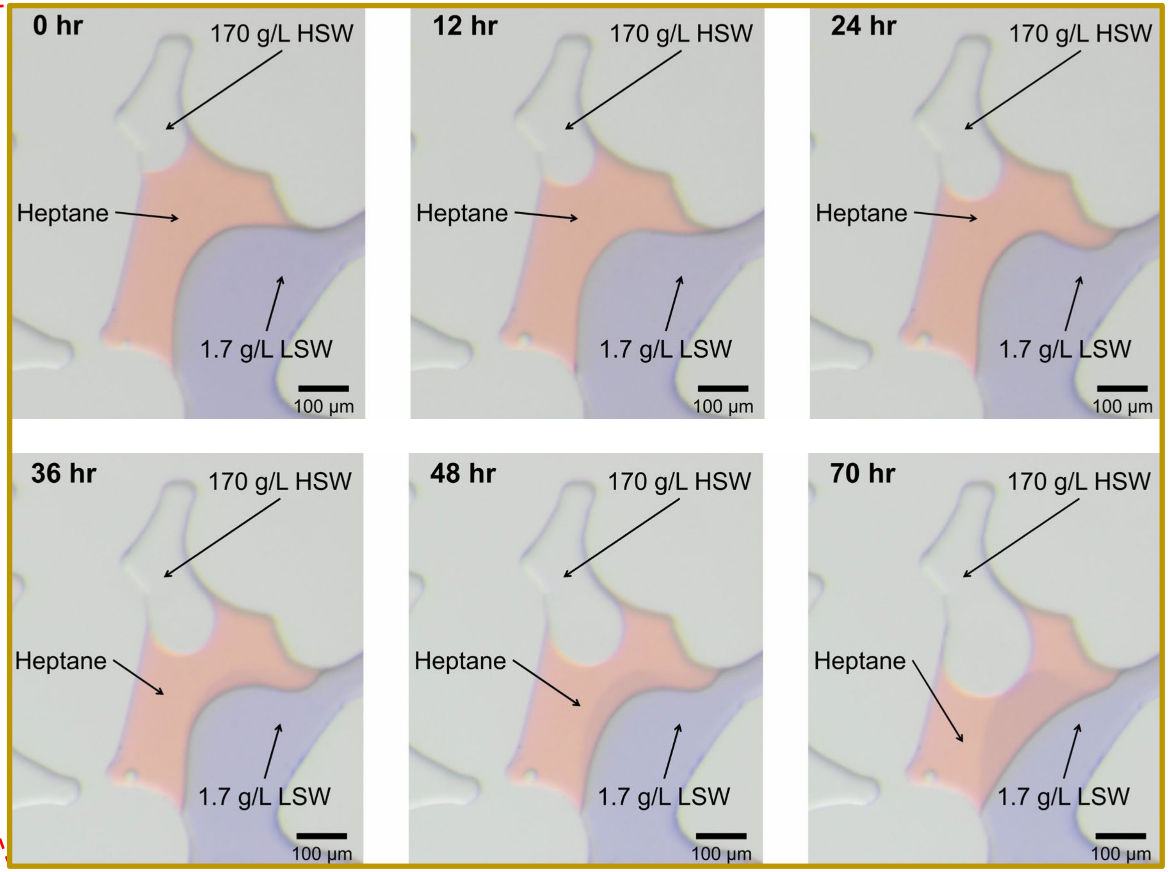
Exp. No	Series	Oil type	Trapped brine (% w/w)	Flooding water (% w/w)	Info.
1	Without surfactant	n-heptane	HSW (20%)	LSW (0.2%)	
2		n-heptane	HSW (20%)	LSW (5%)	
3		n-dodecane	HSW (20%)	LSW (0.2%)	
4		*n-dodecane*	*LSW (0.2%)*	*LSW (0.2%)*	*reference*
5		*n-heptane*	*LSW (0.2%)*	*LSW (0.2%)*	*reference*
6	With surfactant	n-heptane+1% SPAN80	HSW (20%)	LSW (5%)	
7		n-heptane+2% SPAN80	HSW (20%)	LSW (5%)	
8		n-heptane+2% SPAN80	HSW (20%)	LSW (0.2%)	
9		n-dodecane+2% SPAN80	HSW (20%)	LSW (0.2%)	
10		n-dodecane+2% SPAN80	HSW (20%)	LSW (5%)	
11		n-dodecane+1% SPAN80	HSW (20%)	LSW (0.2%)	
12		*n-dodecane+1% SPAN80*	*LSW (0.2%)*	*LSW (0.2%)*	*reference*
13		*n-heptane+1% SPAN80*	*LSW (0.2%)*	*LSW (0.2%)*	*reference*

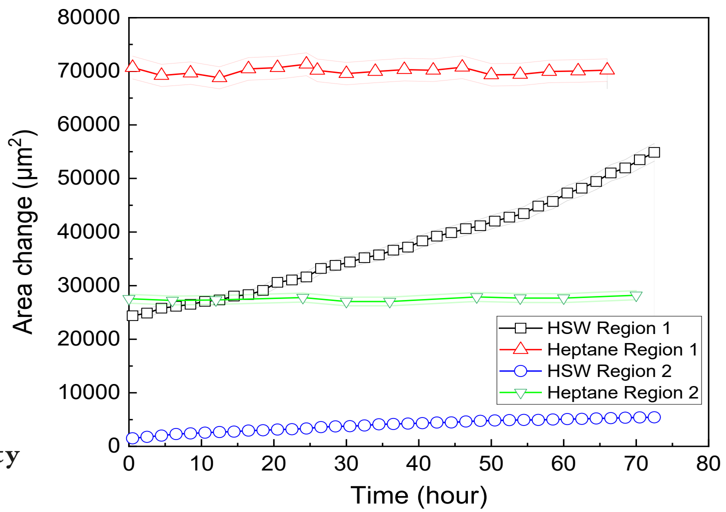
Note: HSW, NaCl, $CaCl_2 \cdot 2H_2O$, $MgCl_2 \cdot 6H_2O$; LSW is obtained from the HSW dilution; SPAN80 is an oil-soluble surfactant. CMC in dodecane is 8.14 mg/L. 1% SPAN80 is around 7,500 mg/L.

Microfluidic experiments

Experiment No.1: Heptane-1.7-170 g/L



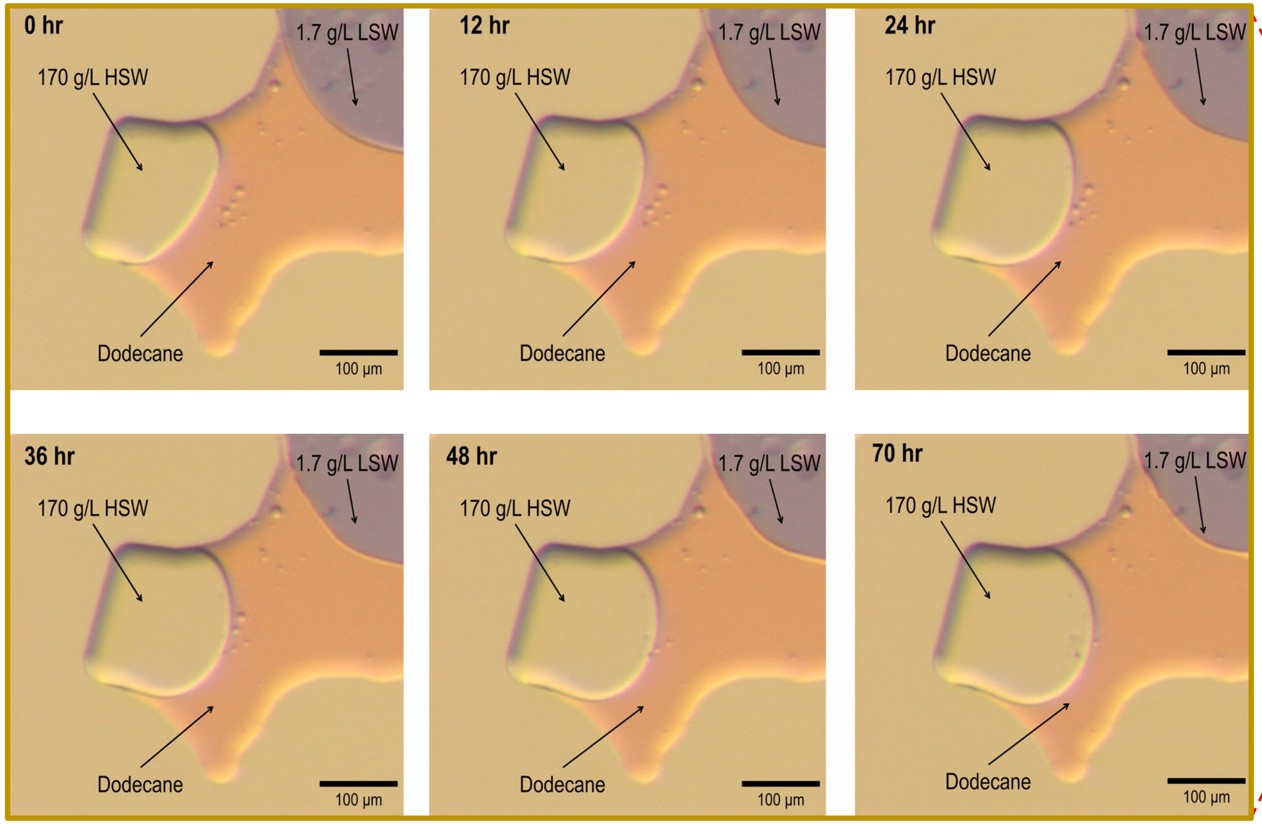


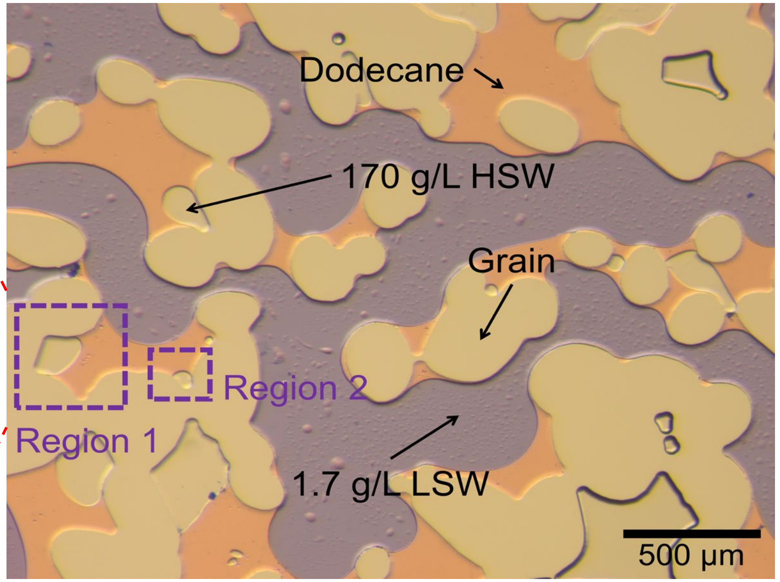


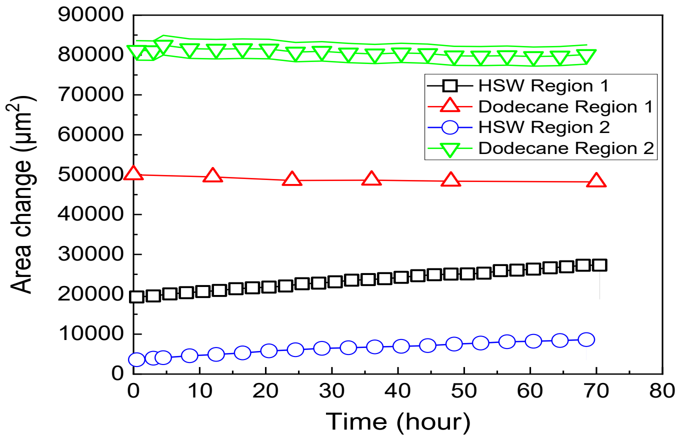
HSW areas of two regions grew by **119.4%** and **261.3%**, respectively, while the heptane areas almost had no change.

Microfluidic experiments

Experiment No.3: Dodecane-1.7-170 g/L



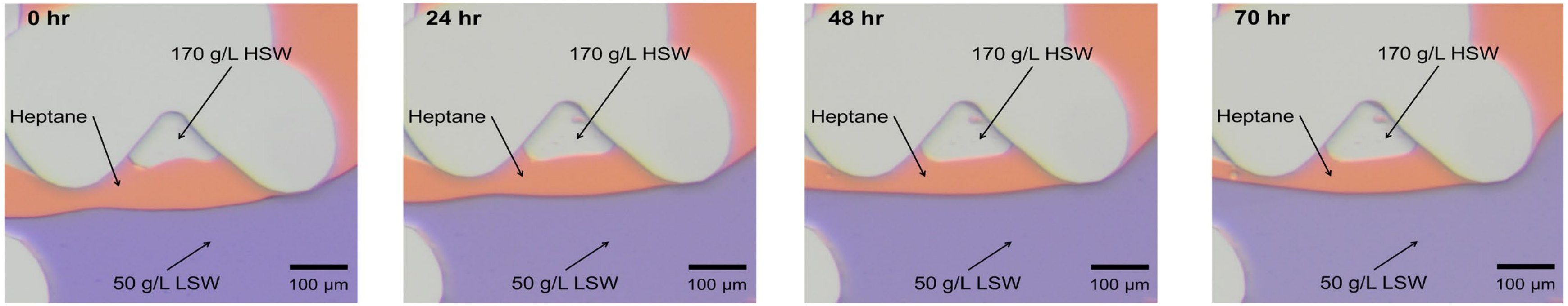




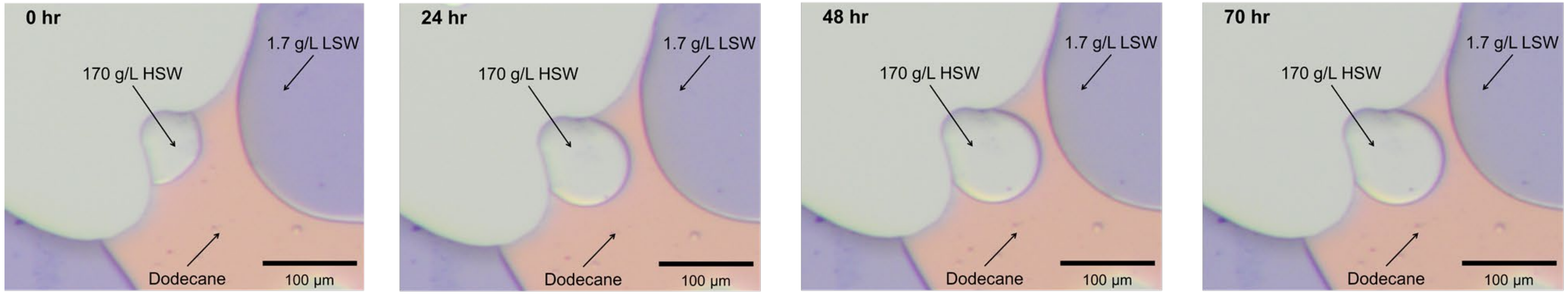
The high-salinity brine got expanded by **41.21**% over 70 hours of monitoring.

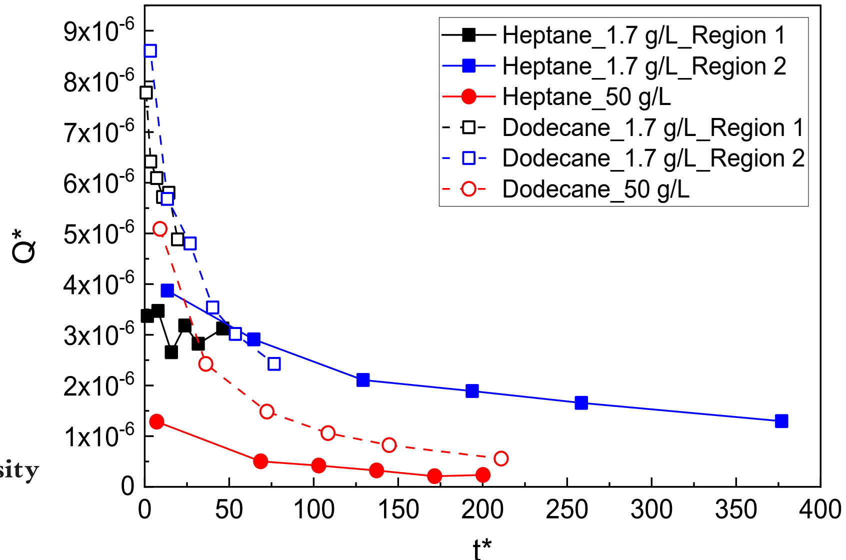
Microfluidic experiments

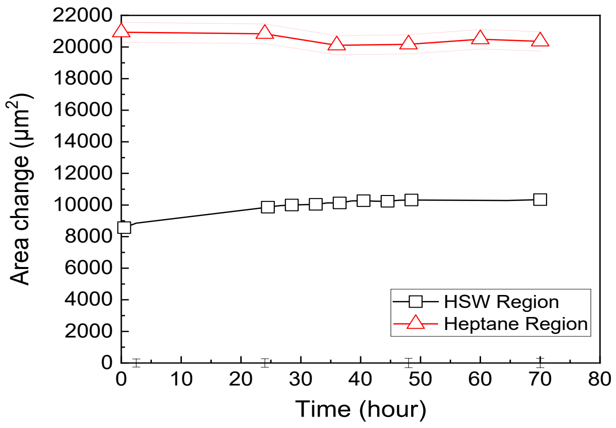
Heptane, salt contrast: 50-170 g/L

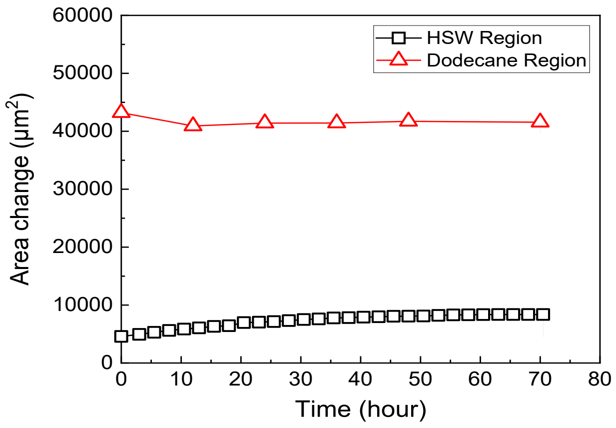


Dodecane, salt contrast: 50-170 g/L



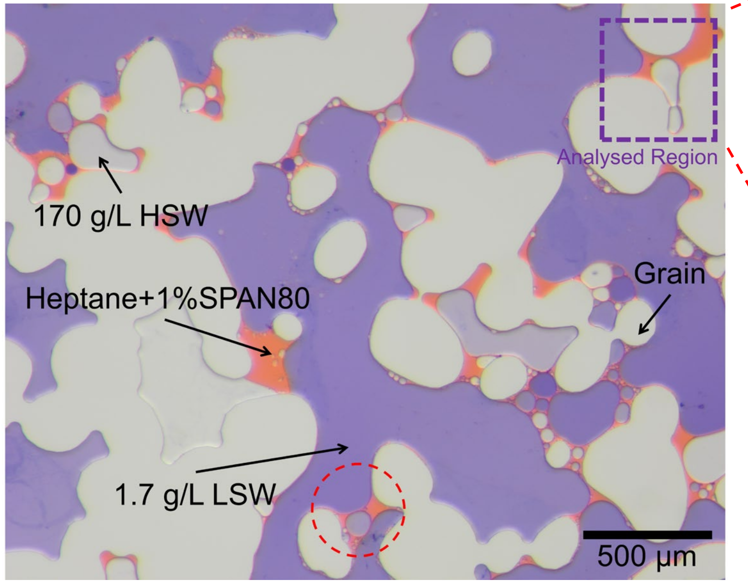


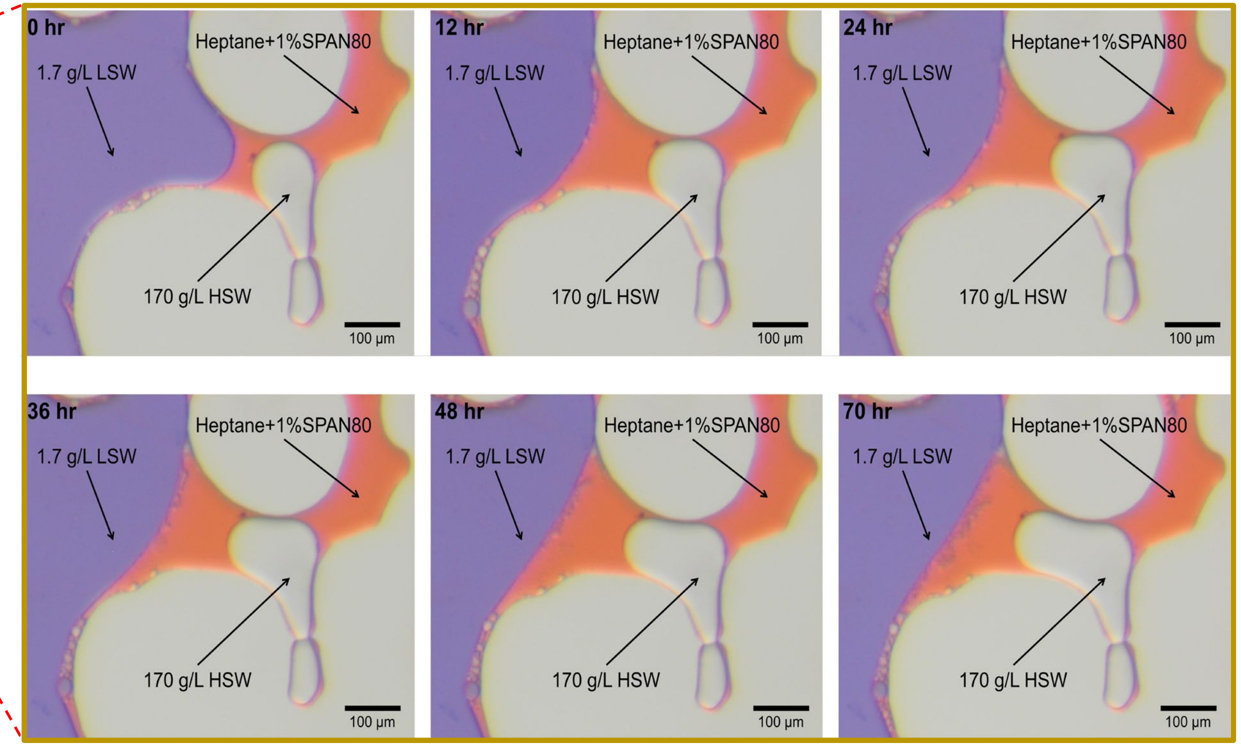


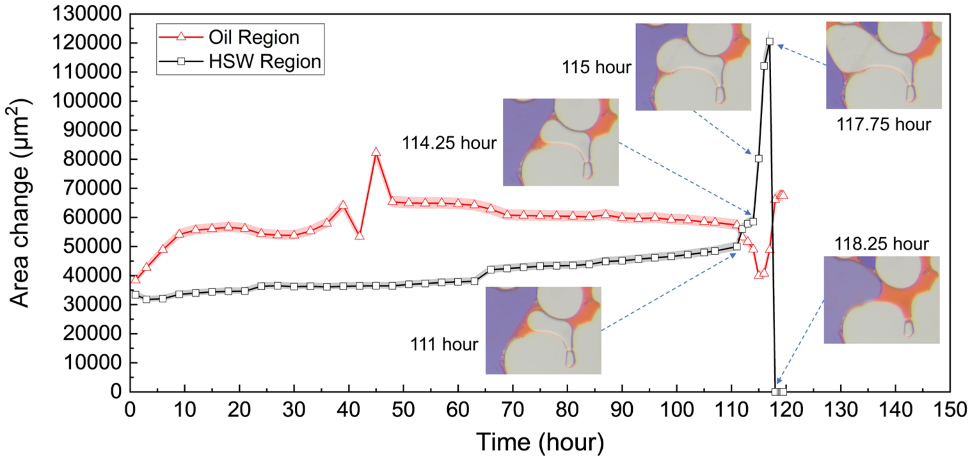


Microfluidic experiments

Surfactant added experiments (Heptane + 1% SPAN80)







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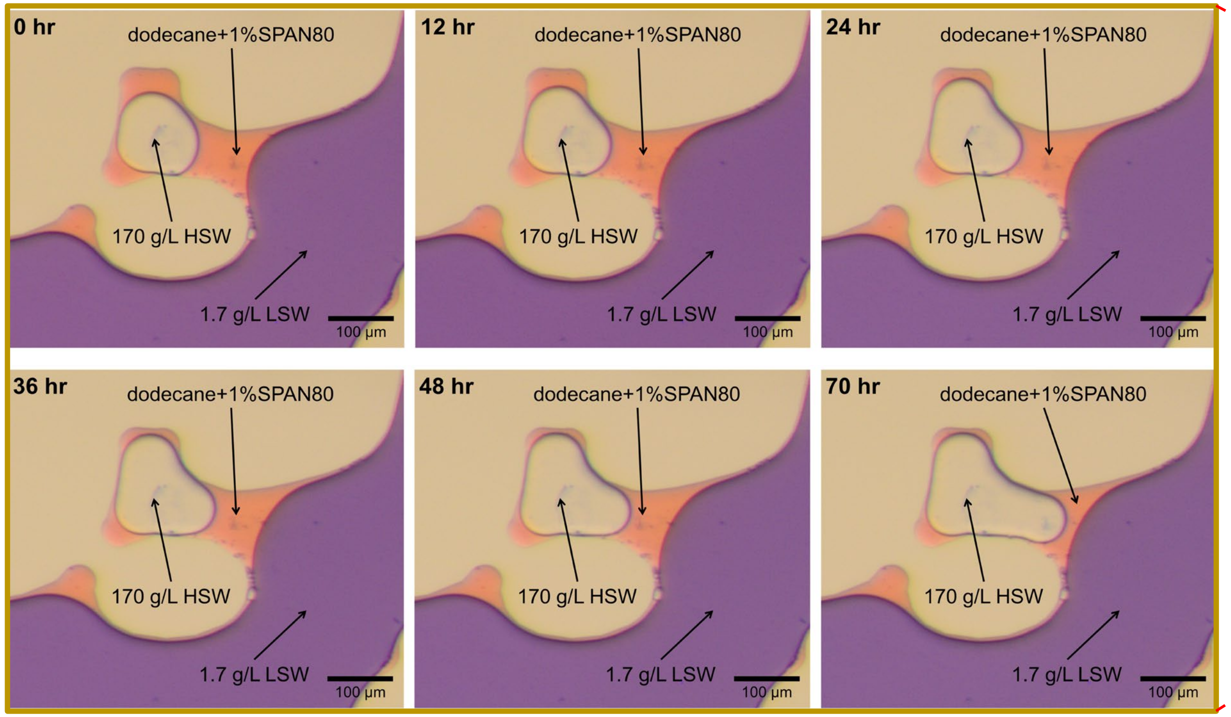
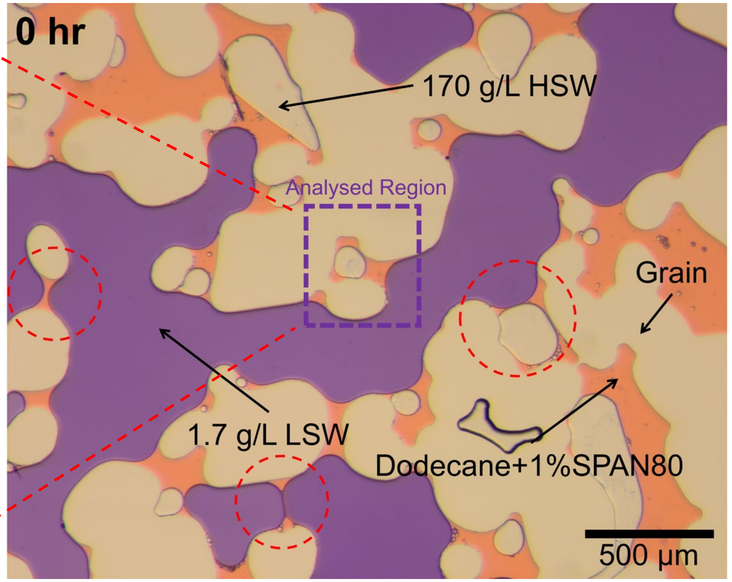
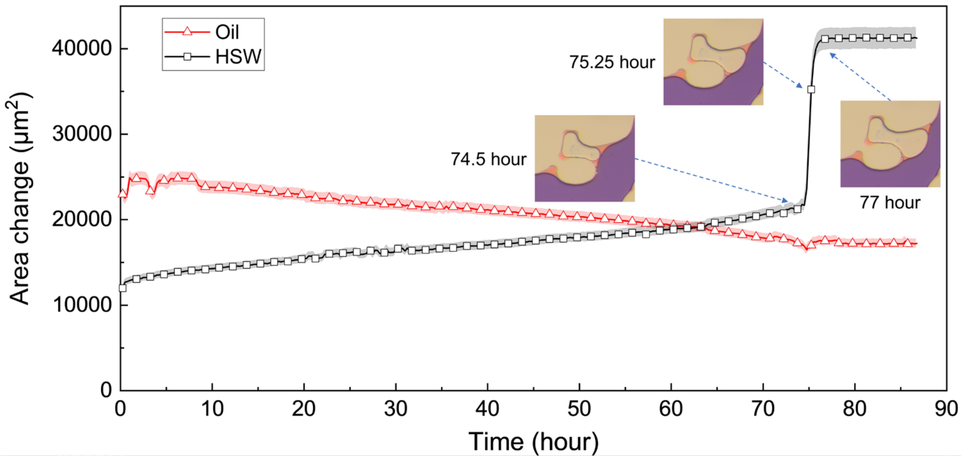
The high-salinity brine got expanded by **76.31**% over 70 hours of monitoring.

Microfluidic experiments

Surfactant added experiments (Dodecane + 1% SPAN80)





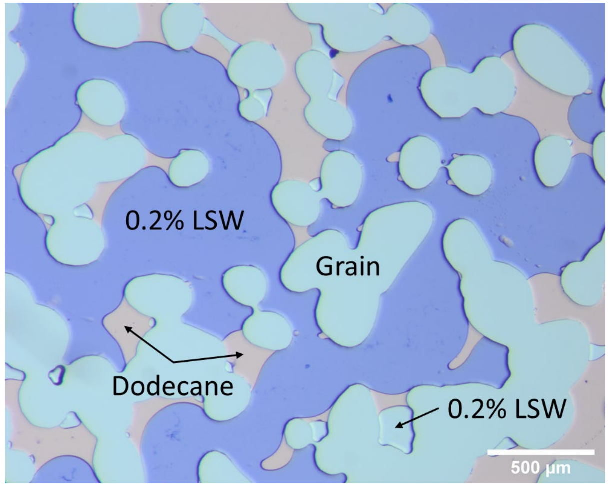


The high-salinity brine got expanded by **<u>71.9</u>**% over 70 hours of monitoring.

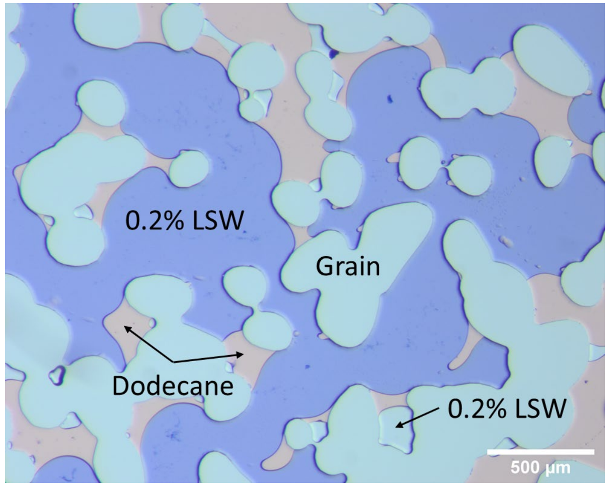
Microfluidic experiments

Reference experiments (LSW/Alkane/LSW)

Without surfactant

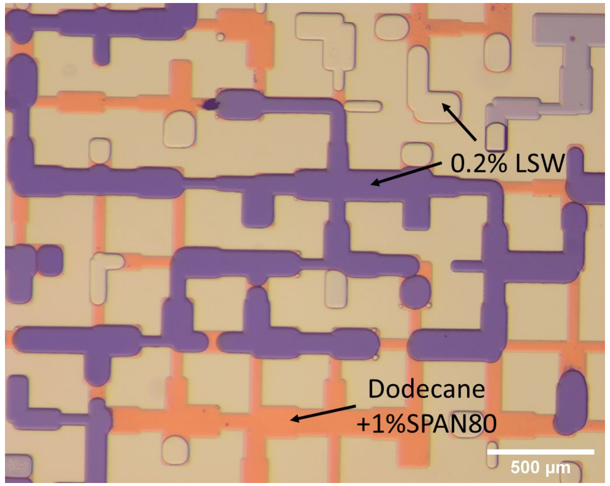


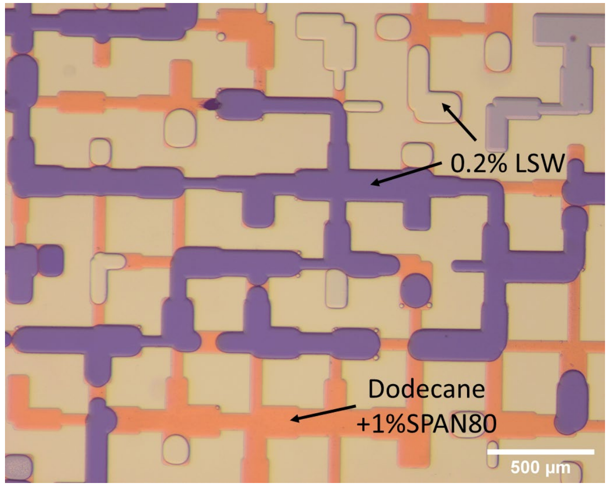
After 1 hour



After 24 hours

With surfactant

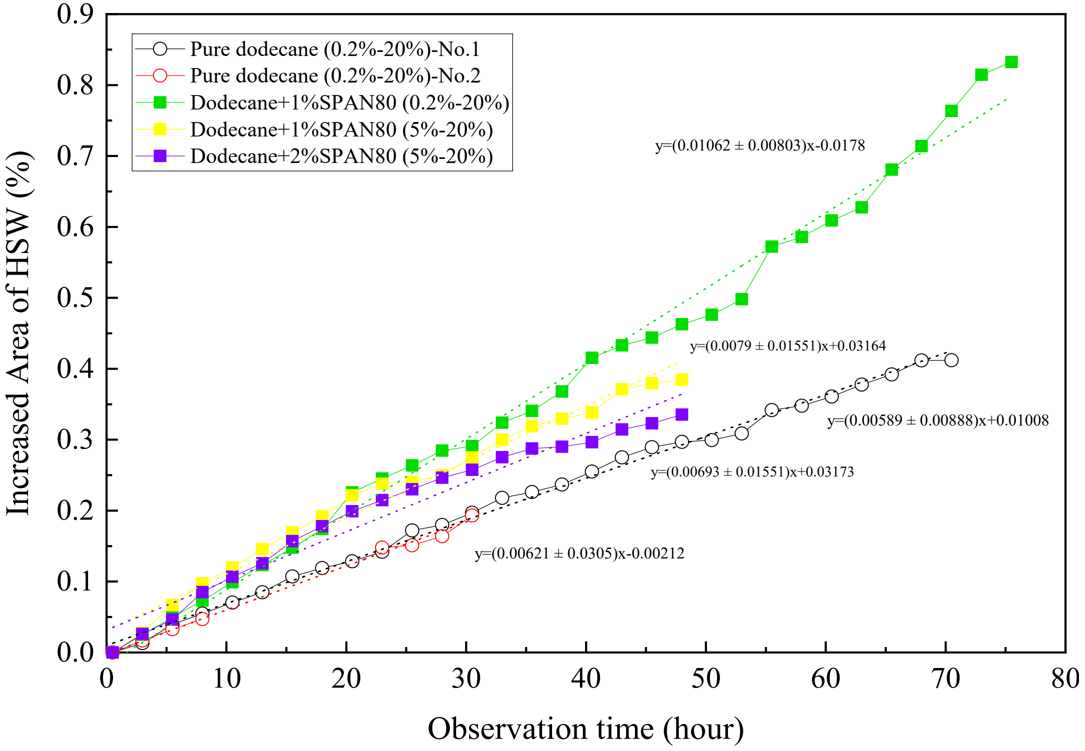


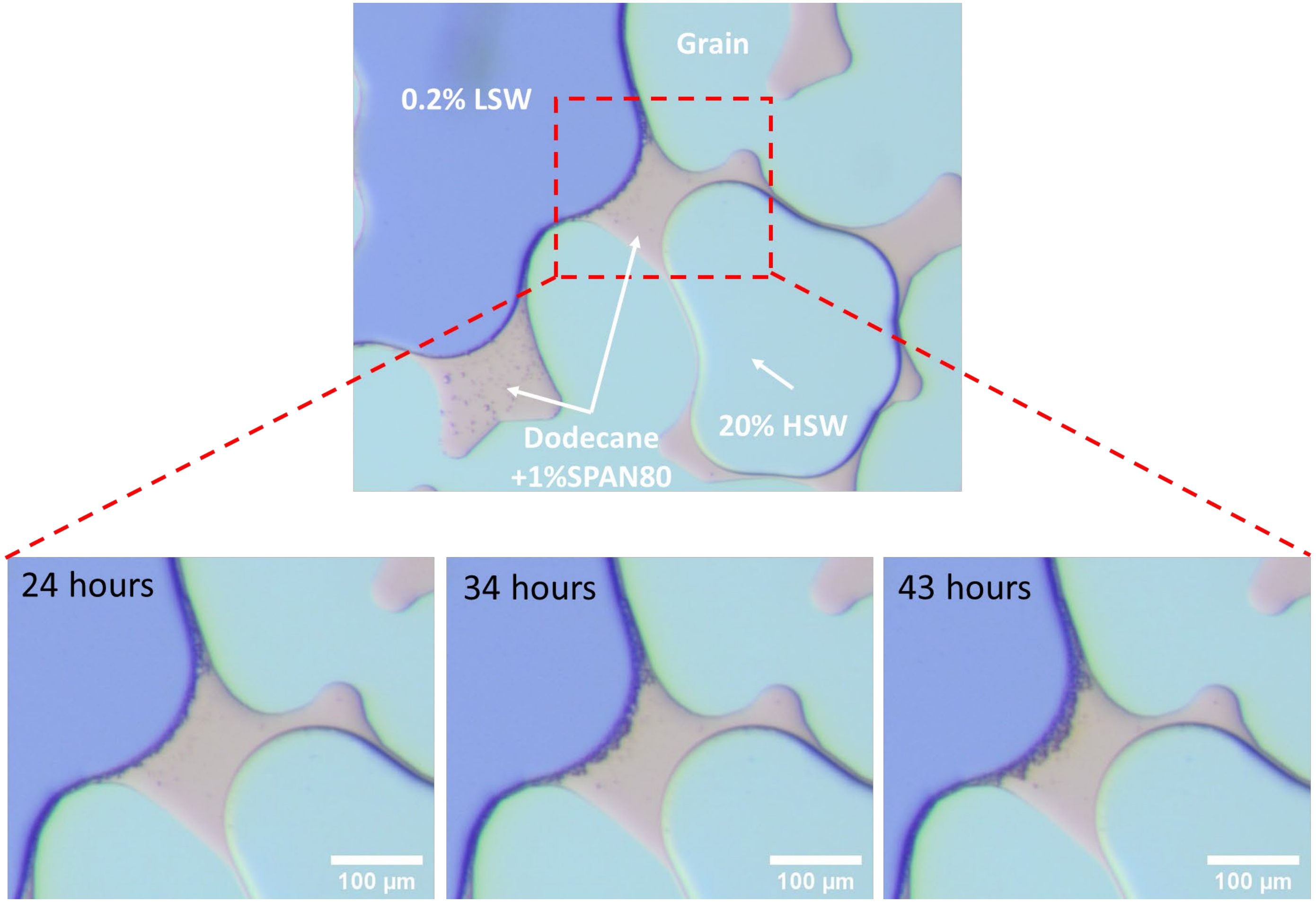


No expansion of HSW during observation in both types of experiment.

Microfluidic experiments

Visualization of spontaneous emulsification (Dodecane + SPAN80)

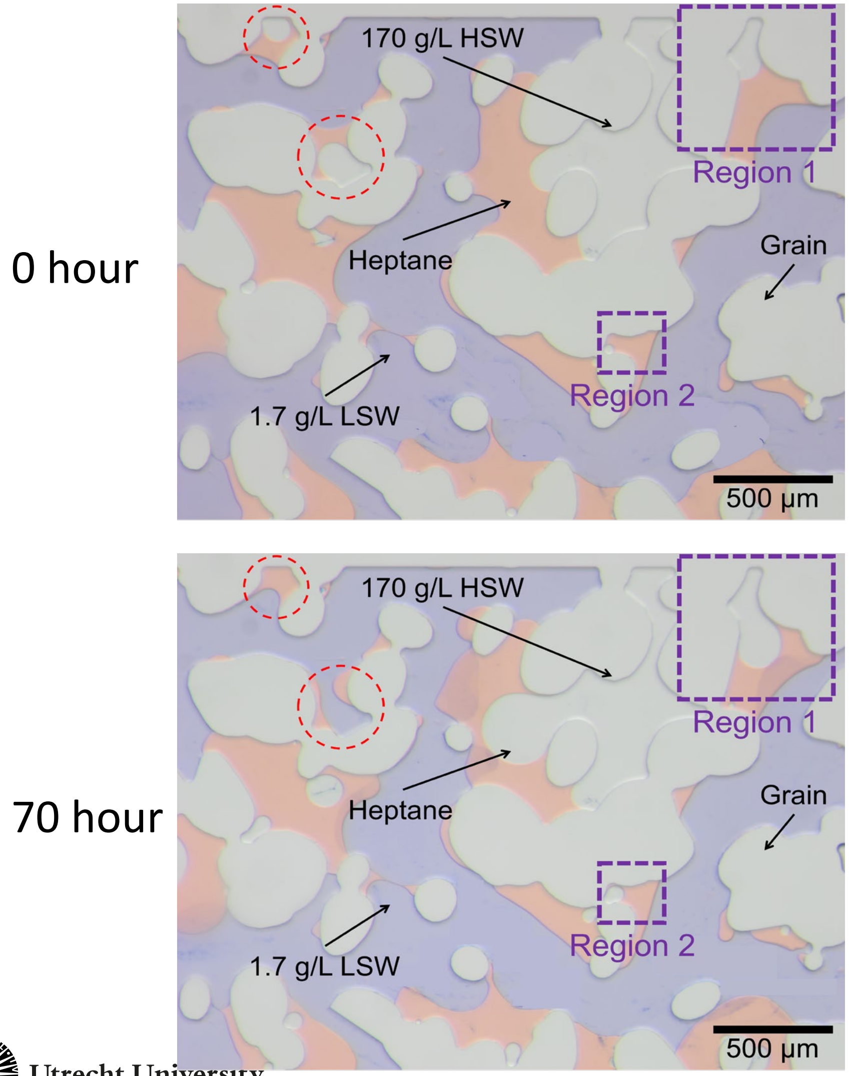


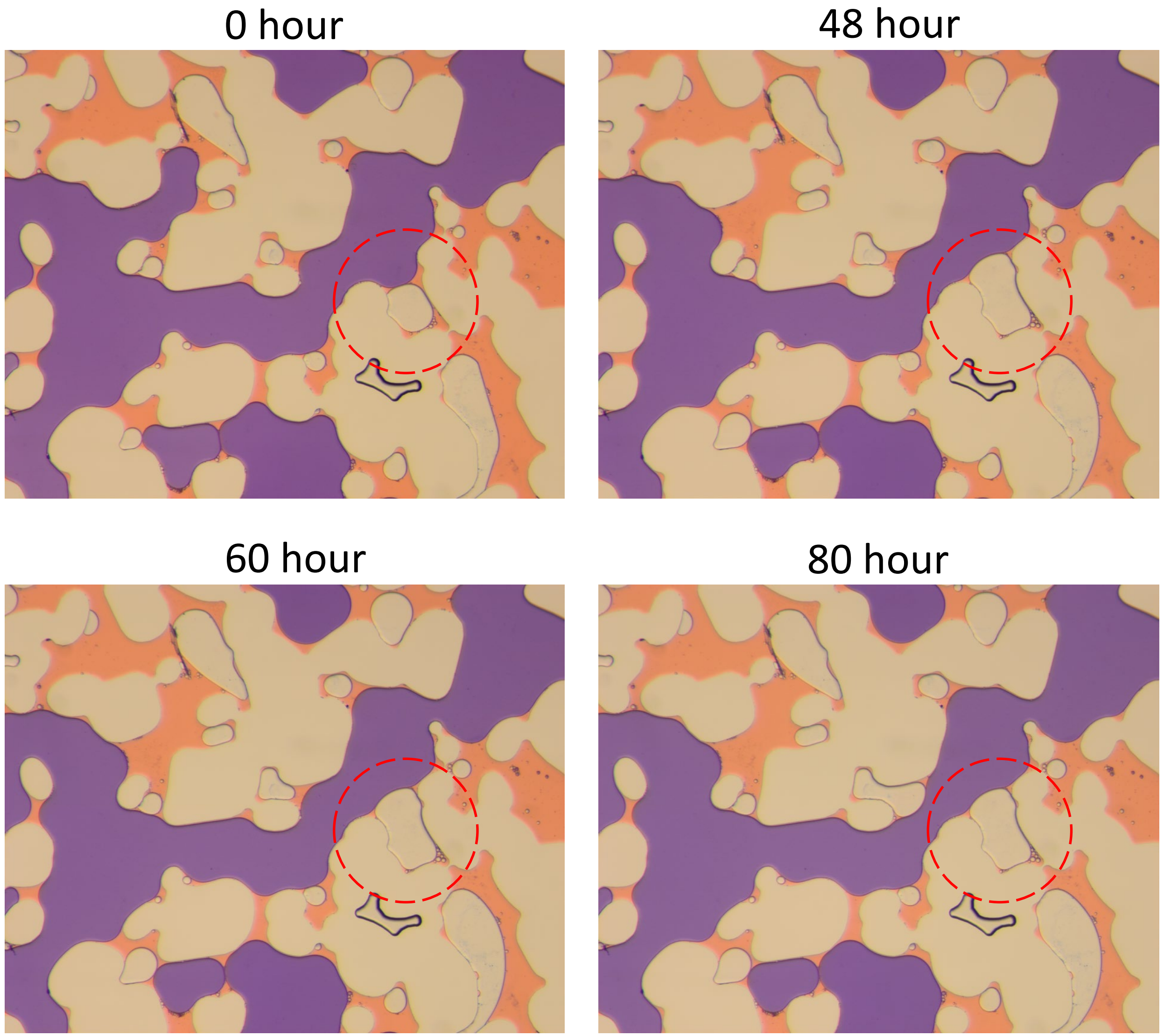


Clearly see the emulsion aggregation at the LSW-Oil interface, but not at HSW-oil side!

Microfluidic experiments

Visualization of HSW bubble burst





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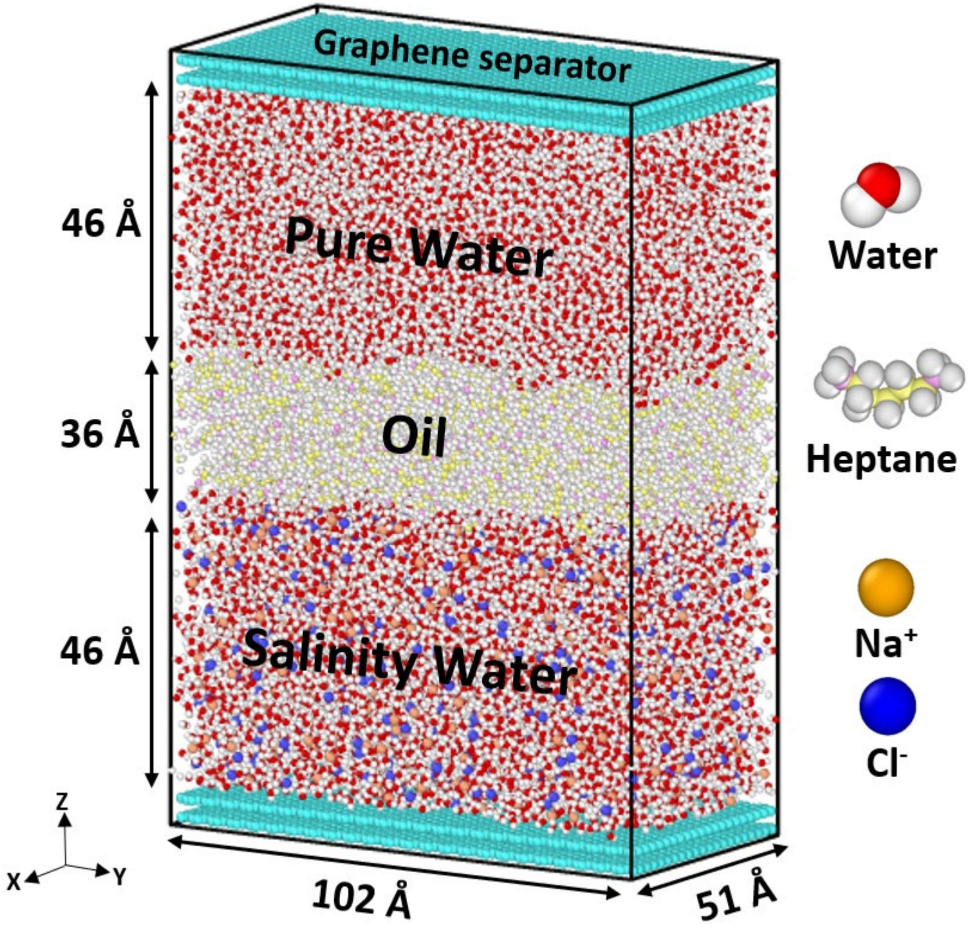
Molecular Dynamic Simulation



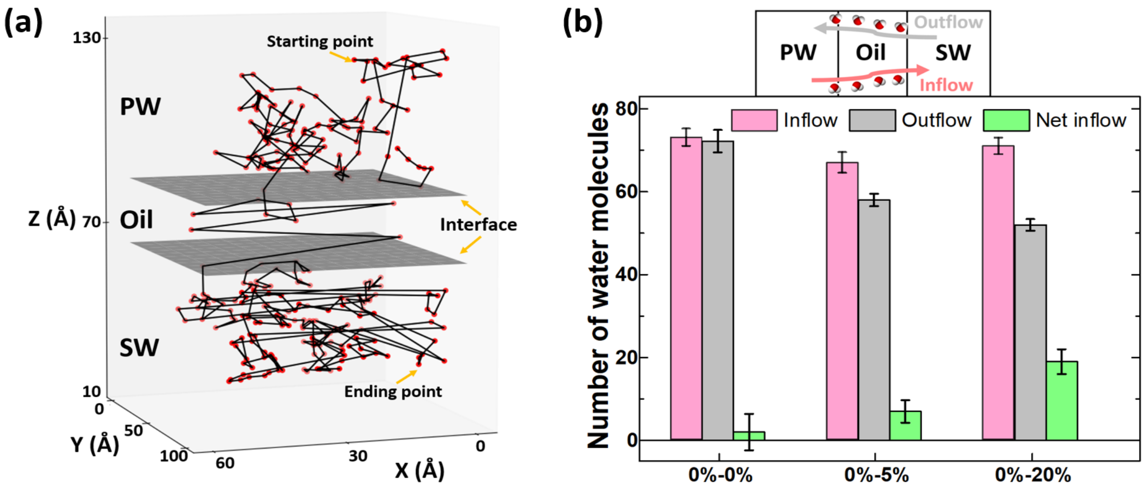
MD simulation domain

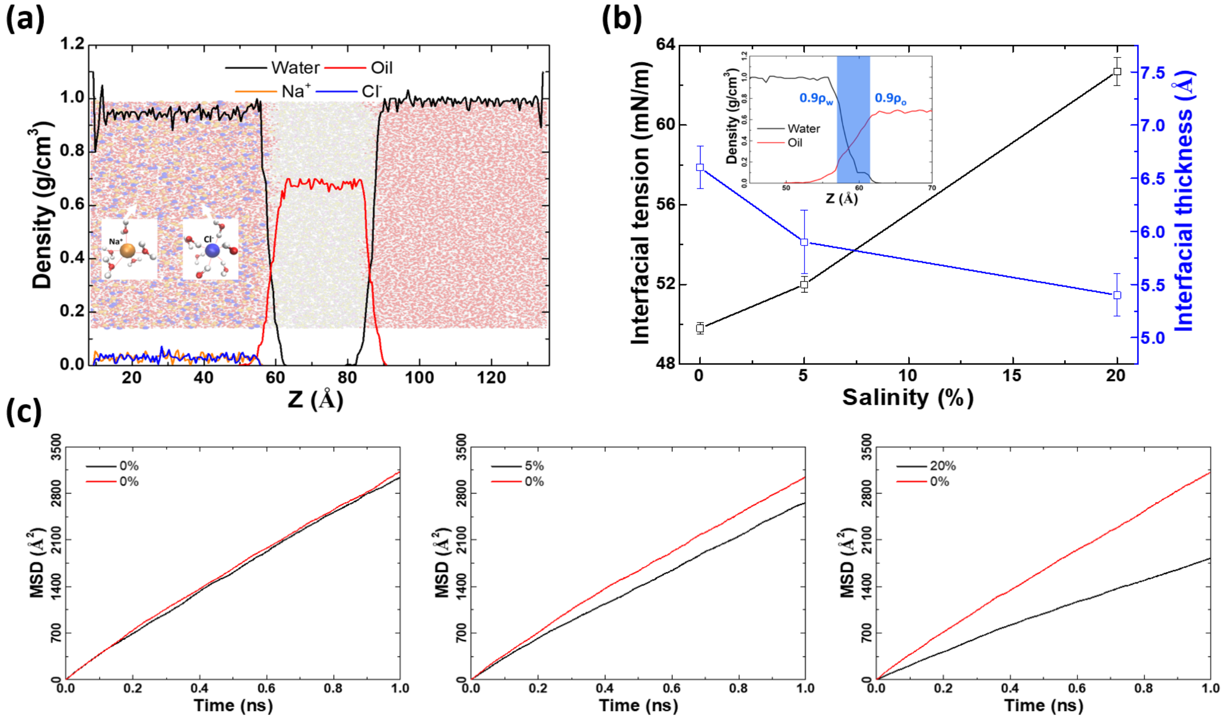
- The system contained 705 heptane molecules and 16374 water molecules (half on each side).
- Three types of systems with ion concentration differences between two water-solution layers of 0%-0%, 0%-5%, and 0%-20% were modelled
- LAMMPS Molecular Dynamics Simulator, Temperature (90^{o}C), Simulation time (50ns)

Molecular Dynamic Simulation

Water diffusion across the oil phase and net inflow in the systems.

(a) A typical migration trajectory of a water molecule across the oil phase (the abrupt steps of trajectory in the oil phase resulted from the periodic boundary condition of the simulation box.);
(b) Comparison of net inflow of water molecules into the SW phase in the three model systems.





Molecular scale water dynamics.

(a) Density profiles of the major components in the 0%-20% system;
(b) Interfacial tension and thickness monitored in the three model systems with different salinity;
(c) The MSD of water molecules in the water and solution phases in the three model systems.

Conclusions

- We have confirmed that water diffusion and emulsification give their individual contributions on trapped oil remobilization and have quantitatively evaluated their effects.
- With the presence of surfactant, the water transport in oil gets accelerated to a large extent.
- High salinity and low concentration of hydrocarbon soluble SPAN 80 both inhibit the generation of water-in-oil emulsion, inducing slower remobilization of the constrained oil.
- Molecular dynamic simulation is conducted and verifies that the salinity has the effect on the water molecule diffusion in pure alkanes.