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Direct pore-scale observation of salinity differential on oil remobilization induced by water transport through oil phases

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Introduction

Low-salinity water flooding (LSWF) has become one of popular strategies for enhanced oil recovery. Osmosis and water-in-oil emulsification have been proposed to explain the trapped oil remobilization as two mechanisms. However, our knowledge of these processes is limited, and their associated time scales are not well understood.

Our goals are to figure out two main questions:

- Which theory is reasonable for explaining the high-salinity water (HSW) expansion? Osmotic water transport or the water diffusion induced by the solubility difference at the two oil-brine interfaces?
- How the micro-emulsions affect the water transport process? Through the electric force among the emulsions or the aggregation and growth of emulsions?

To verify their roles, we conducted a series of microfluidic experiments to build up sandwich-like systems of LSW/Oil/HSW. By continuously observing the system at least 70 hours, the emulsification and osmosis effects are quantitively evaluated. We also investigated the size change of water-in-oil emulsions in nano-scale and pore-scale.

Hypothesis of emulsification and water diffusion in the oil phase

The crude oil phase is considered to have been in equilibrium with brine. Water not only diffuses molecularly in oil but also exists as reverse micelles.

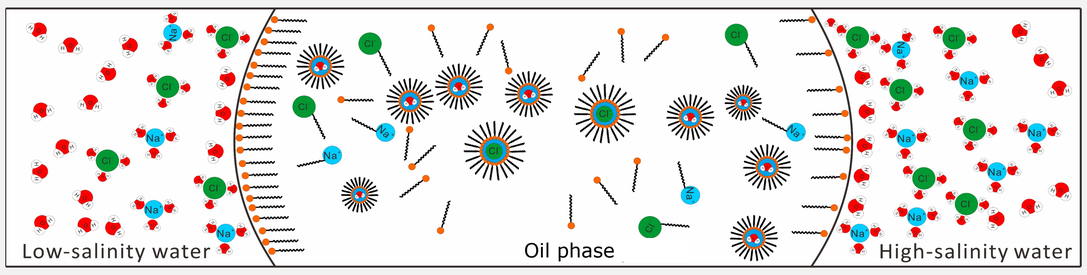

Figure 1: The schematic diagram of interactions among LSW, Oil, and HSW phases

For the case with pure alkane, the water diffusion in oil leads the expansion of HSW. For the case with presence of surfactant, the electrostatic driving of micelles may cause a water transport that could easily exceed that of molecular diffusion.

Micro-fluidic experiments

We prepared three types of brine and four types of alkane: 0.2%, 5%, 20% brines, pure dodecane, dodecane+1%~2% SPAN 80, pure heptane, and heptane+1%~2% SPAN 80. To verify water transport in oil, we built up a brine-oil system inside the microchip where some of the oil phases are constrained by the LSW and HSW.

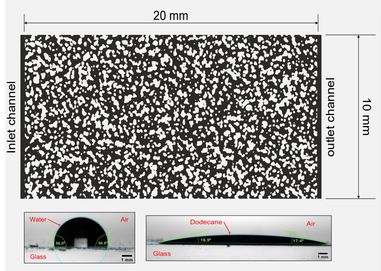

Figure 2. Schematic of micro-chip and wettability modification

Table 1.Types of micro-fluidic experiments at ambient conditions

No	Series	Oil type	Trapped brine	Flooding water	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+ SPAN80	HSW (20%)	LSW (5%)	
7		n-heptane+ SPAN80	HSW (20%)	LSW (5%)	
8		n-dodecane+ SPAN80	HSW (20%)	LSW (0.2%)	
9		n-dodecane+ SPAN80	HSW (20%)	LSW (5%)	
10		*n-dodecane+ SPAN80*	*LSW (0.2%)*	*LSW (0.2%)*	*reference*
11		*n-heptane+ SPAN80*	*LSW (0.2%)*	*LSW (0.2%)*	*reference*

Results

- Experiments with pure dodecane. The high-salinity brine region increased by about 41.21% over 70 hours observation.
- Experiments with 1% SPAN 80+Dodecane. The high-salinity brine region increased by about 76.31% over 70 hours observation.

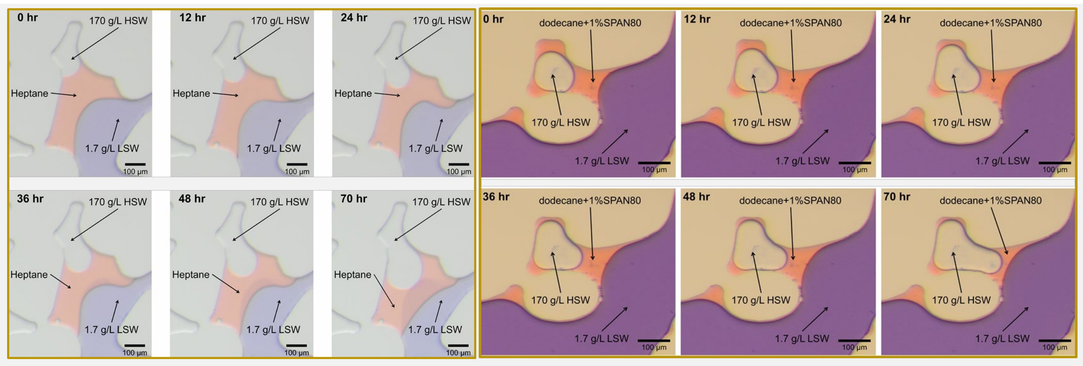

Figure 4. Images of HSW expansion during 70 hours in the experiments with and without adding surfactant.

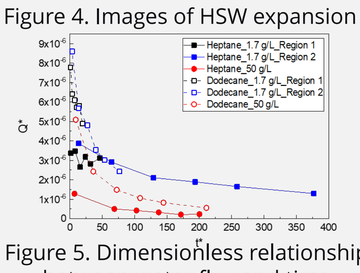

Figure 5. Dimensionless relationship between water flux and time

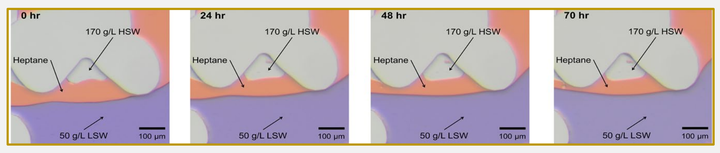

Figure 6. Images of HSW expansion for the experiments with 50-170 g/L salinity contrast

- Visualization of spontaneous emulsification

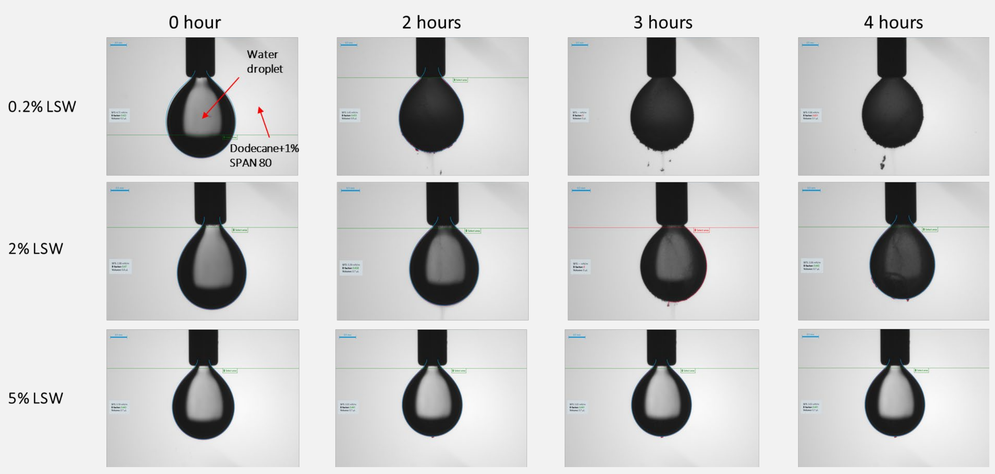

Figure 7. Images of spontaneous emulsification after 4 hours observation of the pendant brine droplets in surfactant-added dodecane.

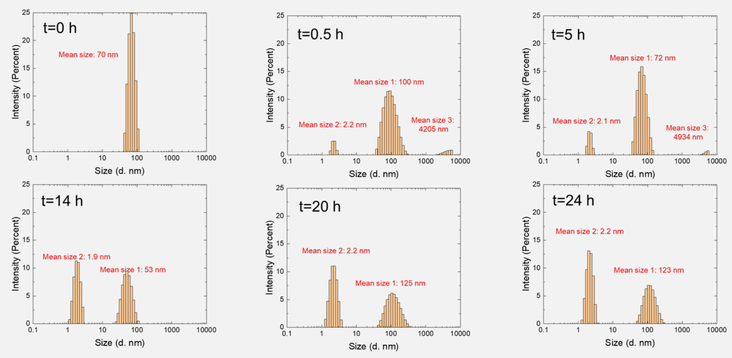

Figure 8. Size change of emulsions for 24 hours contact between 0.2% brine and 1% SPAN 80+dodecane.

Conclusions

- We have confirmed that water diffusion and emulsification give their individual contributions on trapper 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.

References

1. Yan, Lifei, et al. "Impact of water salinity differential on a crude oil droplet constrained in a capillary: Pore-scale mechanisms." Fuel 274 (2020): 117798.
2. Yan, Lifei, et al. "A Quantitative Study of Oil Displacement Induced by Water Diffusion in N-Alkane Phases: From Pore-Scale Experiments to Molecular Dynamic Simulation."

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