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Salinity effects on oil droplet re-mobilization in constrained capillary tubes: pore-scale mechanisms

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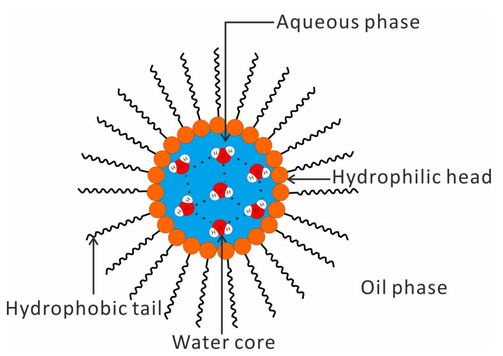
Motivation

Numerous controlling mechanisms have been proposed to explain the oil re-mobilization due to low-salinity effects. are among these mechanisms. However, our knowledge of the contributions of osmosis and water-in-oil emulsification is limited, and their associated time scales are not well understood. In this paper, 11 capillary tubes with an inner diameter of 800 µm are used to inject a sequence of low-salinity water, crude oil, and high-salinity water phases and to observe the evolution of the system.

1. Introduction

When the crude oil is in contact with water, the polar components in the crude oil, such as naphthenic acids, resins and asphaltenes, are adsorbed at the phase interface which could bond with water molecules and produce water-in-oil emulsions [1,2]. It is indeed known that, in a low-salinity water environment, when the salinity is less than a threshold value, there is a higher water content in the oil phase [3].



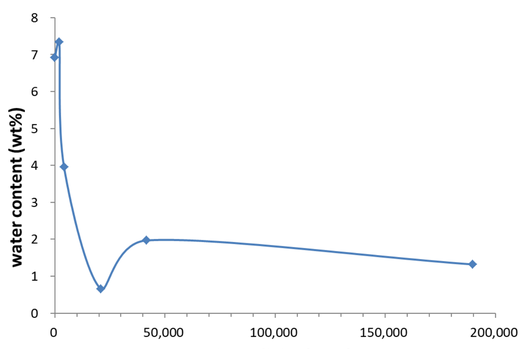
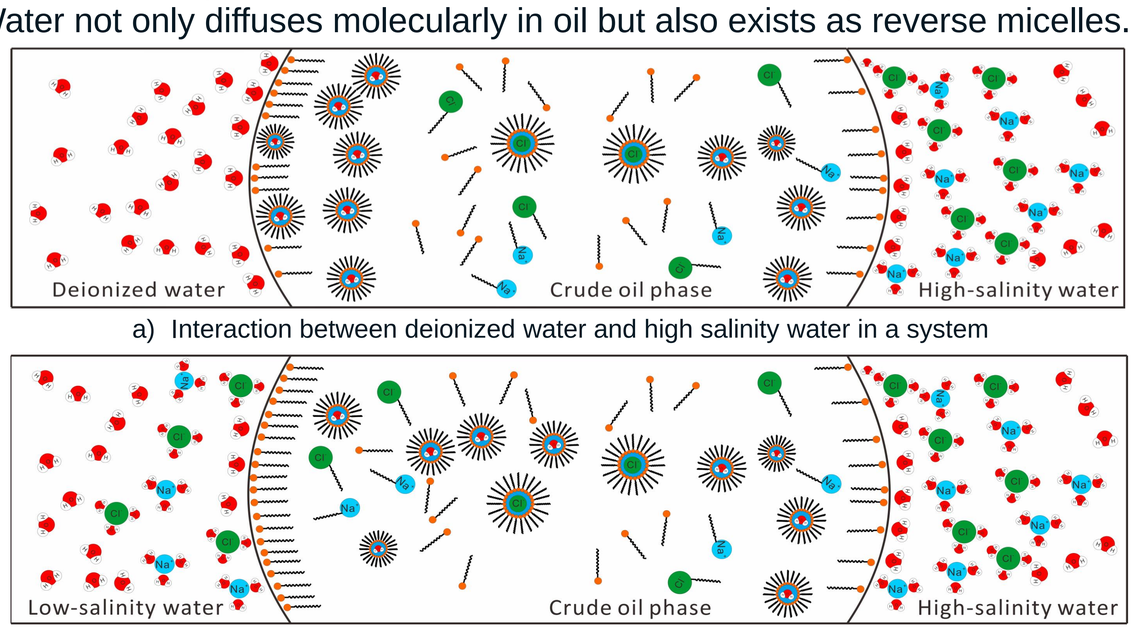


Figure 1: A water-in-oil reverse micelle **Figure 2: Water content in oil versus brine salinity**

2. 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.



a) Interaction between deionized water and high salinity water in a system

b) Interaction between low-salinity water and high salinity water in a system

Figure 3: The schematic diagram of interactions between crude oil and DIW, LSW, and HSW phases. When deionized water (Figure 3a left part) is brought into contact with equilibrated crude oil, the surfactants attract water molecules and aggregate them into reverse micelles, reducing the surface tension. In the case of LSW environment (Figure 3b left part), the salt ions cause the polarization of interface, which can adsorb more polar compounds on the oil-water interface. In the case of HSW environment (right parts of Figure 3a) and 3b)), the surface free energy increases due to the shorter Debye length.

The diffusion of reverse micelles can be described by the Fick's equation:

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$$

For typical situations, the estimated time for a reverse micelle to pass through the oil phase would be about 18 days.

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3. Experimental Methods

We monitored and measured oil globule movement, contact angle change, pressure change in mini-capillaries within 40 days using 2 observation set-ups and microscopic pressure sensors.

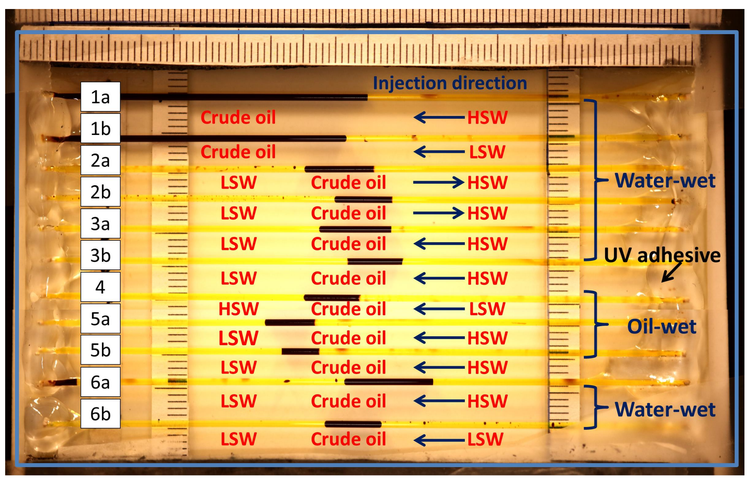


Figure 4: Sets of capillaries with different processing situations

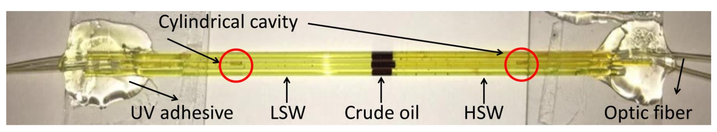
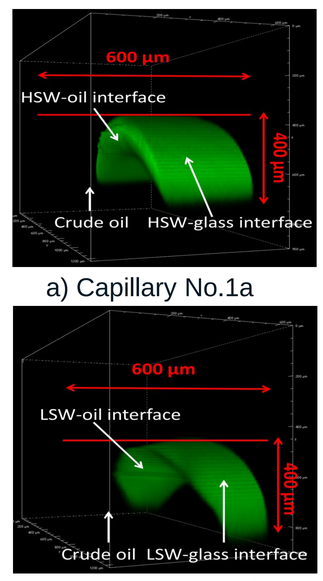


Figure 6: Two fiber optic micro-transducers used as pressure sensors in the capillary.



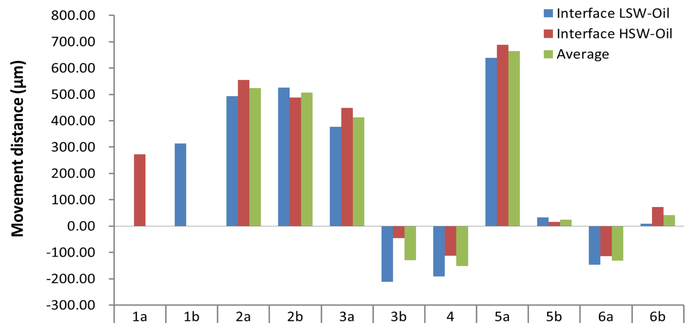
a) Capillary No.1a

b) Capillary No.1b

Figure 5: Confocal microscope 3D scanned parts of water-oil-glass interfaces in capillaries

4. Results

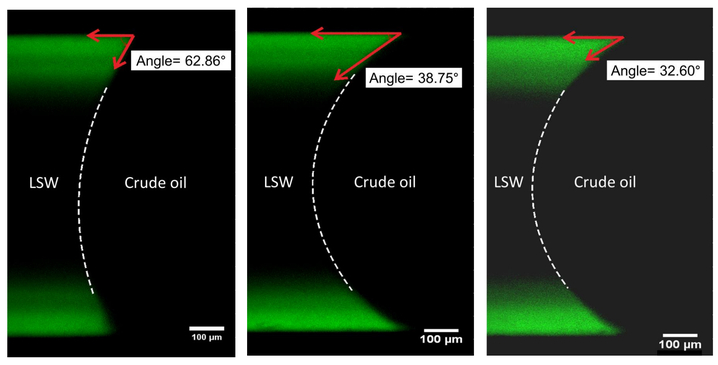
Oil droplet movement



	1a	1b	2a	2b	3a	3b	4	5a	5b	6a	6b
Interface LSW-Oil		313.61	492.80	525.72	376.89	-212.62	-192.04	639.23	32.93	-147.41	9.70
Interface HSW-Oil	272.13		554.87	488.10	449.59	-46.55	-113.17	688.61	15.17	-114.26	73.05
Average			523.83	506.91	413.24	-129.58	-152.61	663.92	24.05	-130.84	41.38

Figure 7: The movement of oil droplet. The positive values indicate that the oil droplet moved from the side with HSW to the side with LSW. The negative value means oil moved in the opposite direction.

Contact angle changes



(a) After 1 day b) After 15 days c) After 40 days

Figure 8: 2D confocal images of contact angle changes of LSW side in the capillary No.2a

Pressure changes

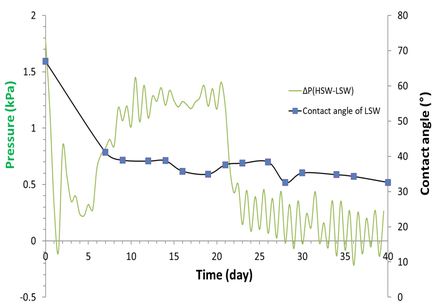


Figure 9: Graphs of monitored pressure difference in HSW and LSW phase in capillary No.2a.

5. Conclusions

- In the water-wet capillaries the oil droplet moved a distance of about 524 µm.
- The contact angles of LSW/HSW with crude oil gradually decreased by 34.32° and 18.23°, respectively, during the first 15 days.
- The pressure difference between HSW and LSW phases reached a plateau with a maximum value of 1.65kPa during a period of 24 days.

Acknowledgment

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Reference

[1] J. G. Speight, The chemistry and technology of petroleum. CRC press, 2014.
[2] G. Sørbø, "Polar Components in Crude Oils and Their Correlation to Physiochemical Properties," The University of Bergen, 2016.
[3] S. Aldousary and A. R. Kovscek, "The diffusion of water through oil contributes to spontaneous emulsification during low salinity waterflooding," Journal of Petroleum Science and Engineering, vol. 179, pp. 606-614, 2019.