Engineered Low Salinity Waterflood in Carbonate Reservoirs: —Boosting Fluid-Fluid Interaction and Oil Recovery by Cost Effective Additives

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Scaled Solutions

SPE-220744-MS & SPE-221893-MS

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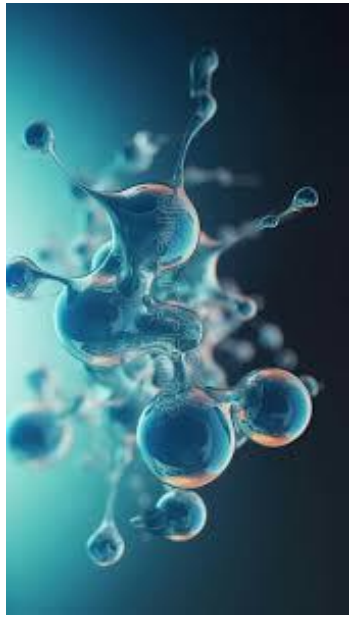
Outline

1) Background/Objective
2) Overall Study Workflow
3) Fluid-fluid Interaction (FFI) Tests
4) EOR Core Flood Tests
5) Hypothesis of FFI Mechanism
6) Conclusions and Way forward



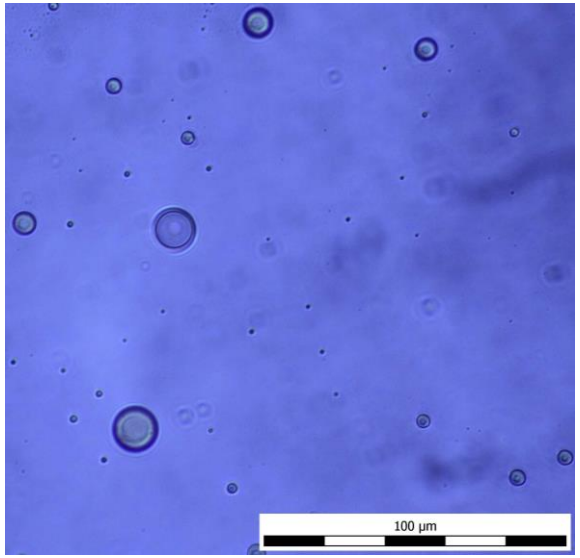
Background: Past LSW Research in Carbonates

- LSW EOR research has been advanced in sandstone reservoirs and more recently research focusing on carbonate reservoirs has been conducted.
- Many reports discussed mechanisms surrounding rock-fluid interactions in carbonates, such as wettability alteration, ion exchange and/or rock dissolution effects.
- However, a consensus in mechanism and reliable screening process has not been reached.

Objective

Development of LSW EOR boosting Technology:

- New focus on fluid-fluid interaction (FFI), forming micro dispersion as an interfacial reaction of oil-water mixing, as a main driver of the mechanism for improving oil recovery.
- Use FFI testing as a screening for LSW EOR potential - rank crude oils and various LSW additives. Perform core flood tests to further investigate oil recovery.
- Target is an offshore giant carbonate field in the Middle East.
- LSW + additives preferred over e.g. more traditional spiking of divalent ions (incl. SO_4^{2-}), which may bring scaling and/or souring risks. Surfactant/polymer LSW considered but potentially less cost effective.



Overall Study Workflow

SPE-220744-MS – Low Salinity Water Basis

(1) Screening LSW-reactive Oil by Fluid-fluid Interaction (FFI) Tests

- Obtain micro-dispersion ratio (MDR) in contact with LSW
- Select most positive oil for Stage 2 testing.

(2) Exploring LSW EOR Boost Additives

- Evaluate impact of DEK, DMK, and Cu(II) on MDR formation in FFI tests

(3) EOR Core Flood Tests using FFI-screened Oil (CF01 - CF04)

- Secondary SW injection
- Tertiary LSW injection (CF01)
- Tertiary LSW + additives injection (CF02-04)

(4) Mechanism Discussion

- MDR in FFI tests *vs.* Oil recovery increment in CF tests
- Micro-dispersion forming mechanism
- Way forward

SPE-221893-MS – Seawater Basis

(5) Compatibility Testing

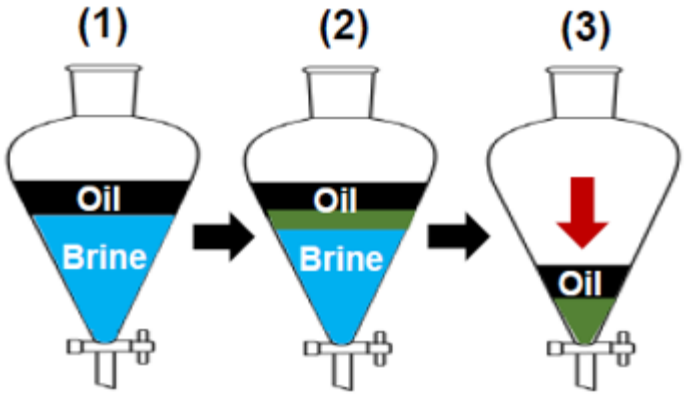
- Compatibility Check: To select DEK additive concentration in SW

(6) EOR Core Flood Test using FFI-screened Oil (CF05)

- Secondary SW injection
- Tertiary SW + DEK additive injection (CF05)

Fluid-fluid Interaction Tests

Fluid-fluid Test Procedure

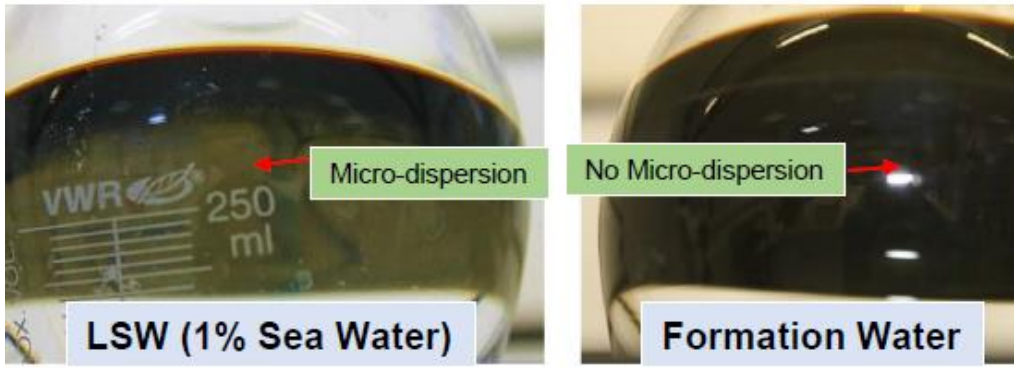


Crude oil was centrifuged to remove free water

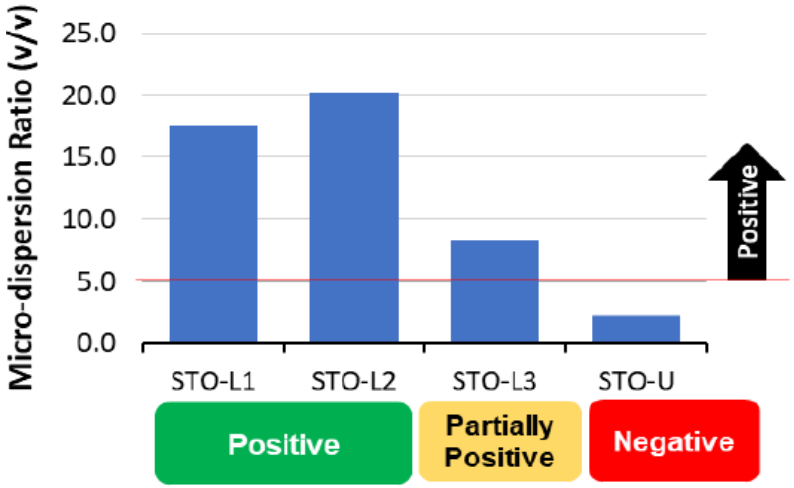
(1) Crude oil and brine carefully placed in separatory funnel.
(2) Placed in oven for 3 days. If positive oil, micro-dispersion (MD) is formed at interface of oil and brine.
(3) After removing aqueous phase, MD phase is taken to measure water content by Karl Fischer Titration.

$$\text{Micro-dispersion Ratio (MDR)} = \frac{\text{Water content of micro-dispersion phase}}{\text{Water content of crude oil before contact with brine}}$$

Photographs of Fluid-fluid Interaction Tests



Positive Oil Screening Results (LSW: 1% SW)



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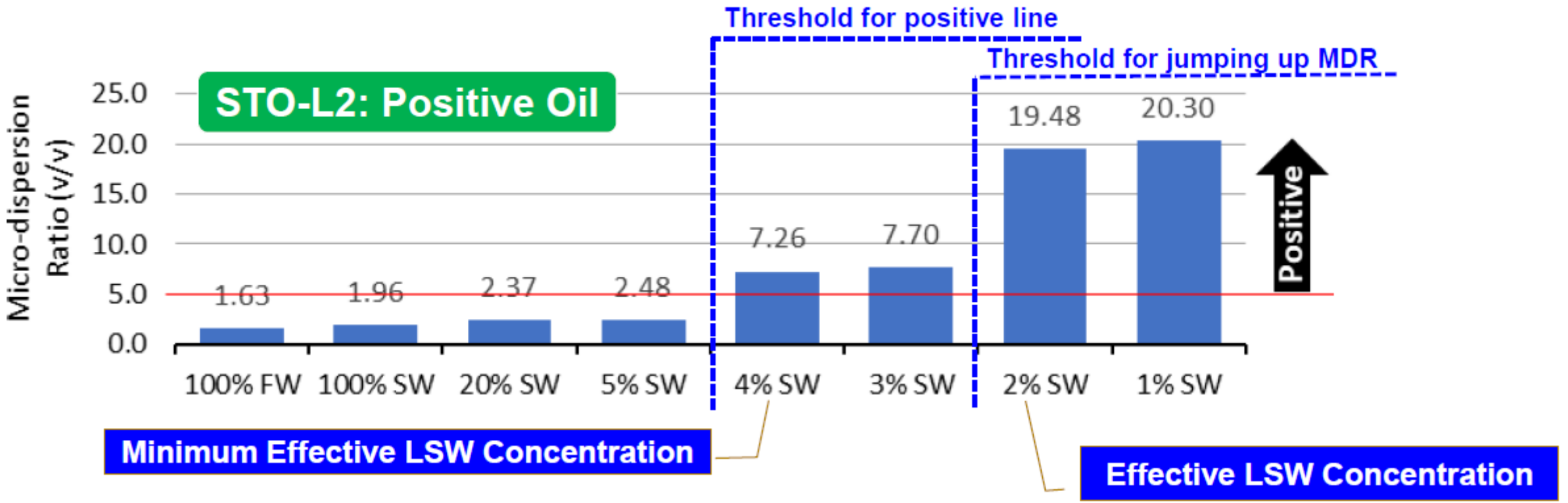
Fluid-fluid Interaction Tests: Effective LSW Concentration Impacts on MDR



$$\text{Micro-dispersion Ratio (MDR)} = \frac{\text{Water content of micro-dispersion phase}}{\text{Water content of crude oil before contact with brine}}$$

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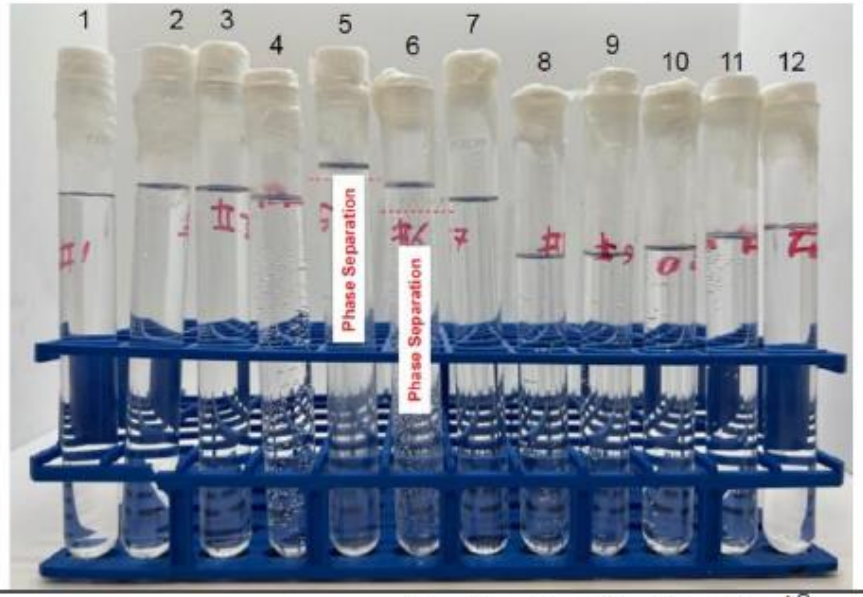
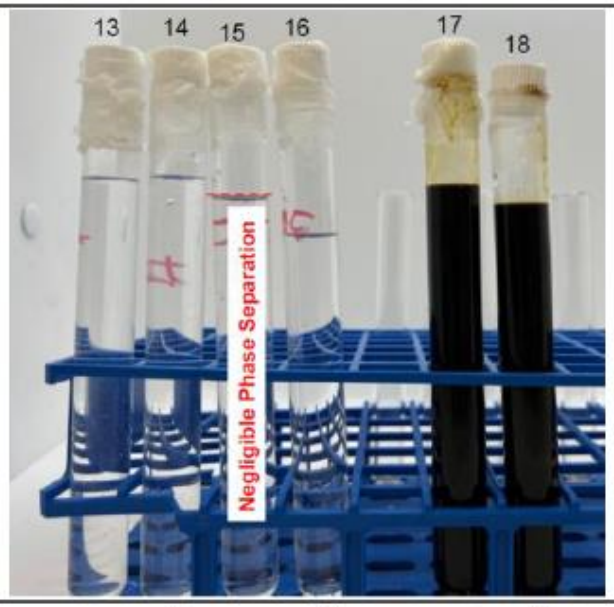
Compatibility Test Results: DEK and DMK vs. 100%SW, 1%SW, 100%FW, and Crude Oil

COMPATIBILITY WITH	100% SW												1% SW		100% FW		Crude Oil	
PHOTOS																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ADDITIVES	DEK 0.1 wt%	DEK 0.2 wt%	DEK 0.5 wt%	DEK 2.0 wt%	DEK 5.0 wt%	DEK 10.0 wt%	DMK 0.1 wt%	DMK 0.2 wt%	DMK 0.5 wt%	DMK 2.0 wt%	DMK 5.0 wt%	DMK 10.0 wt%	DEK 2.0 wt%	DMK 2.0 wt%	DEK 2.0 wt%	DMK 2.0 wt%	DEK 2.0 wt%	DMK 2.0 wt%
RESULTS	☑	☑	☑	☑			☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

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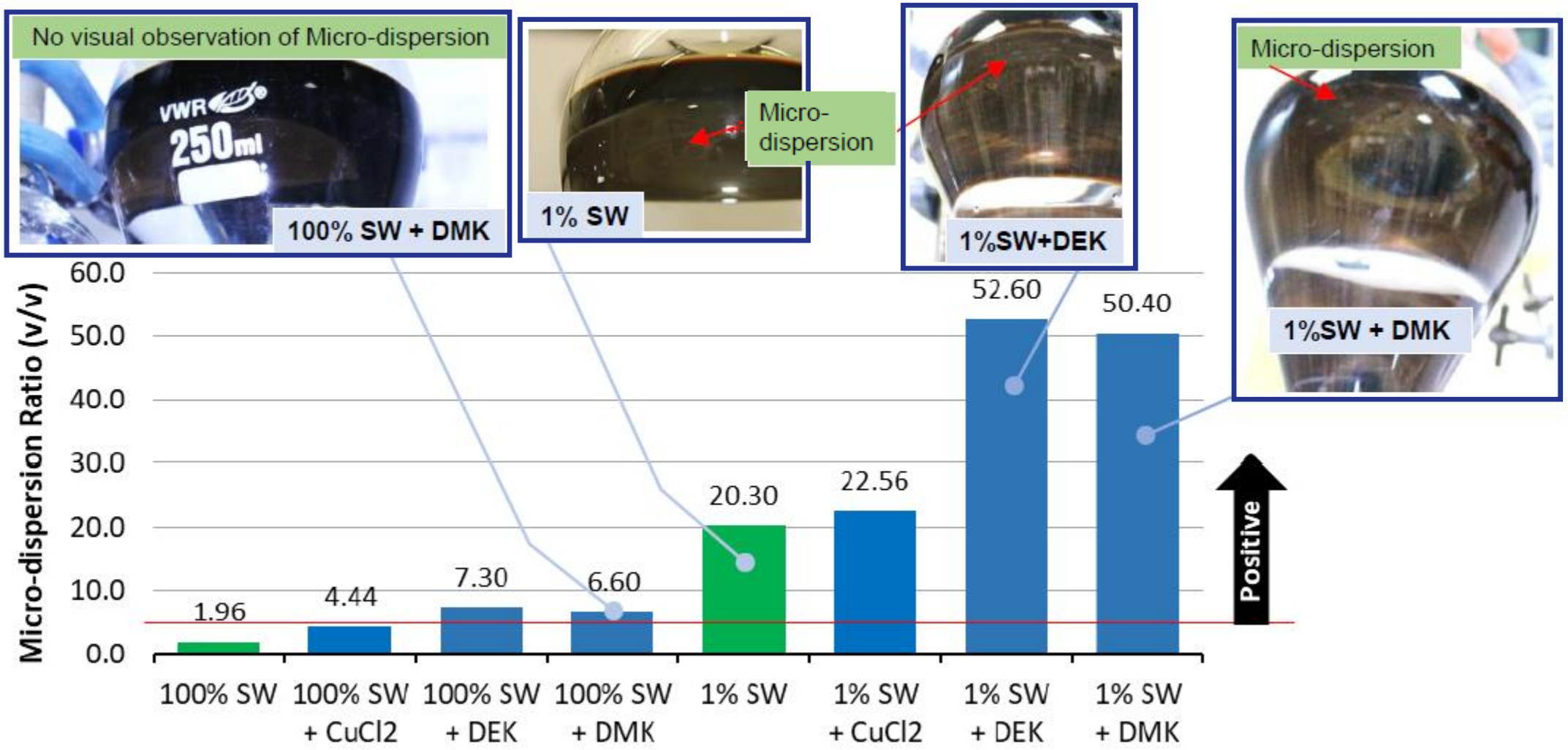
Fluid-fluid Interaction Test Results: Additive Sensitivity using STO L 2



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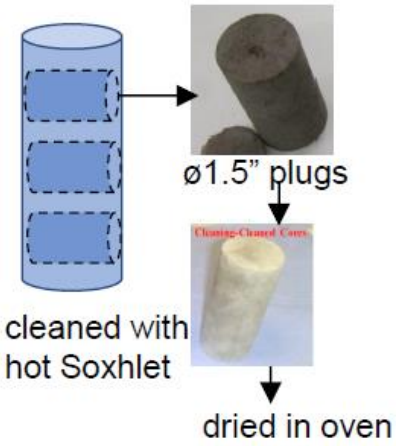
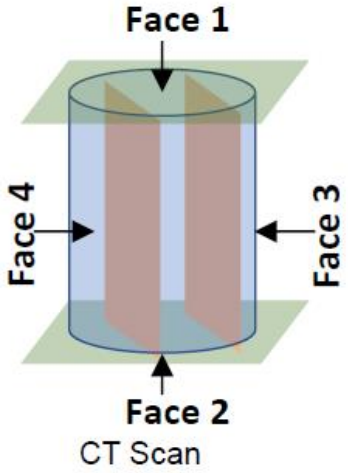
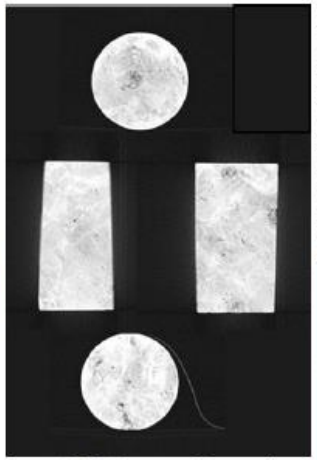
Core Flood Tests

(1) Core Preparation

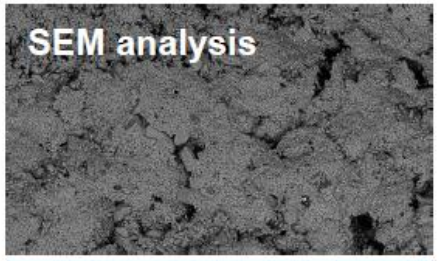


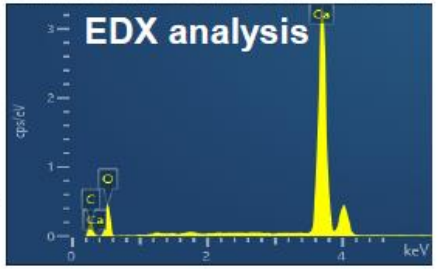
(2) Plug Core Check





CT Scan Results for Plug Core #1.





(3) Composite Cores

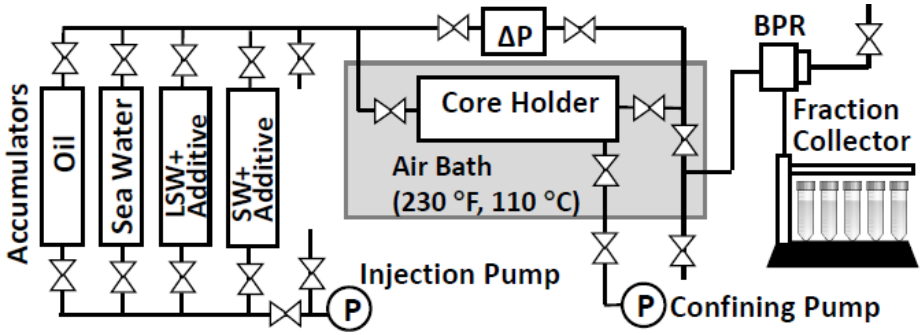
- L24-26 cm x ø3.9cm
- 49.3 mL pore vol.
- 19-20 % porosity
- 12-20 mD permeability
- Mineralogy: calcite

Composite Core-A

Composite Core-B

(4) Aging, Core Flood, and Restoration

- Aging with dead oil (4 weeks)
- Replaced with synthetic live oil
- Secondary injection (SW)
- Tertiary injection (LSW / SW + additive)
- Quaternary injection (LSW + additive)
- Clean cores for restoration



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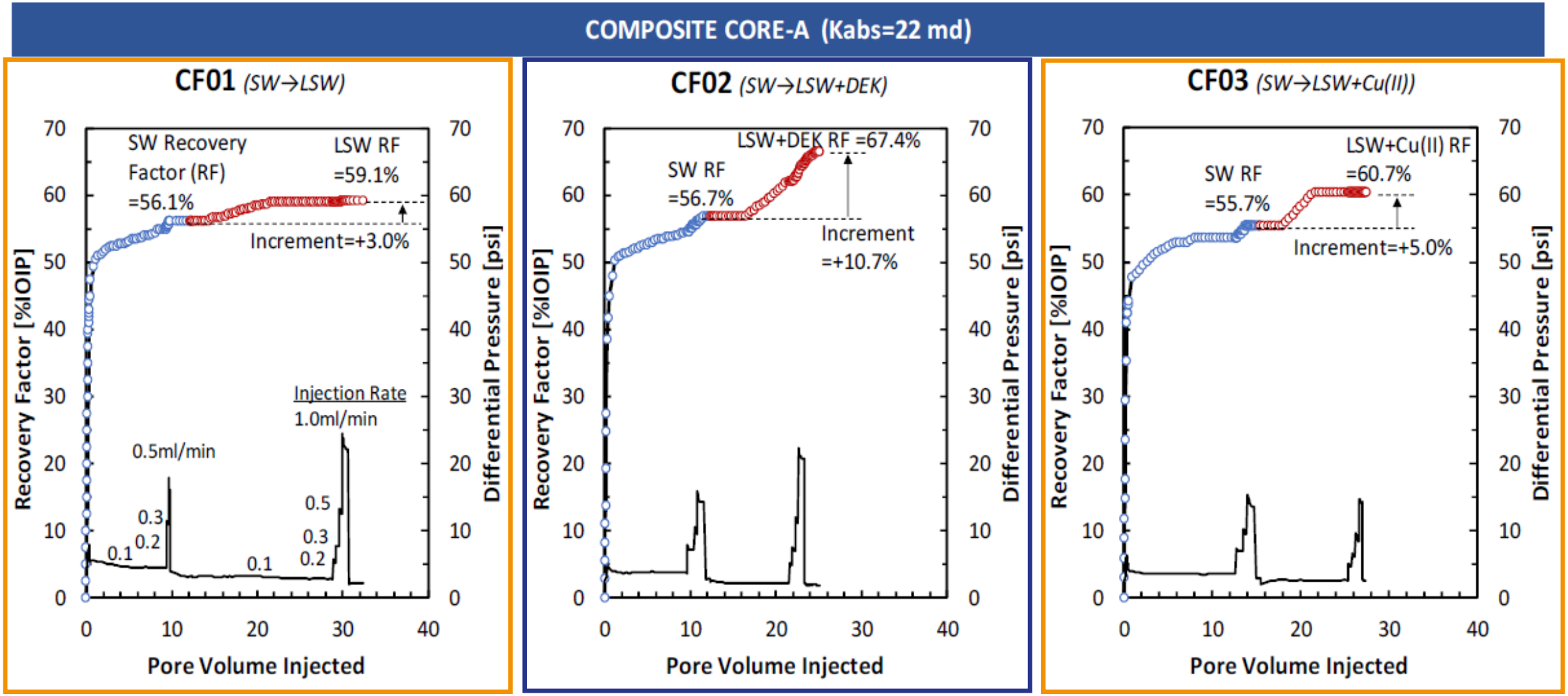
Core Flood Test Results: Pure LSW *versus* LSW + Each Additive



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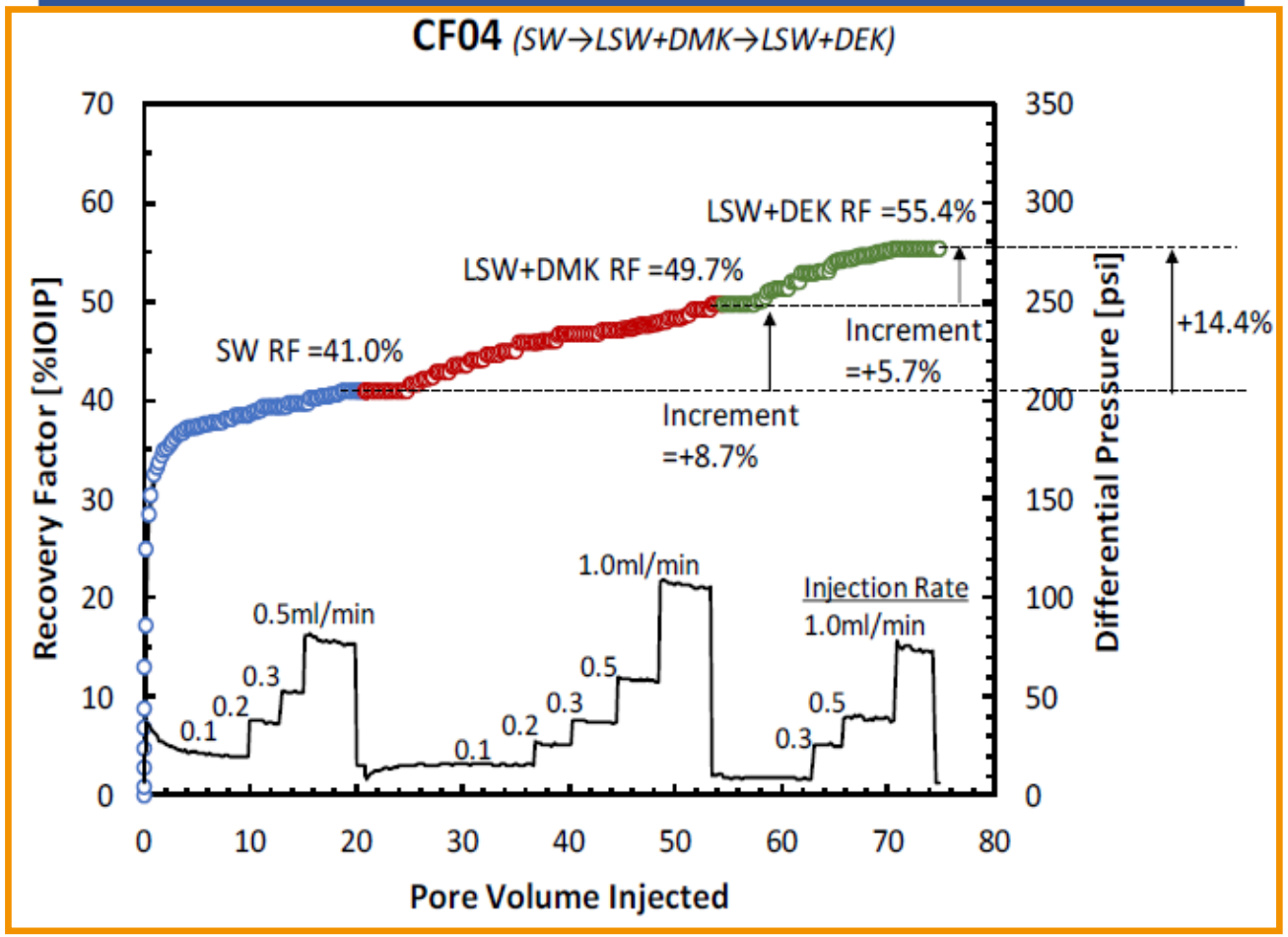
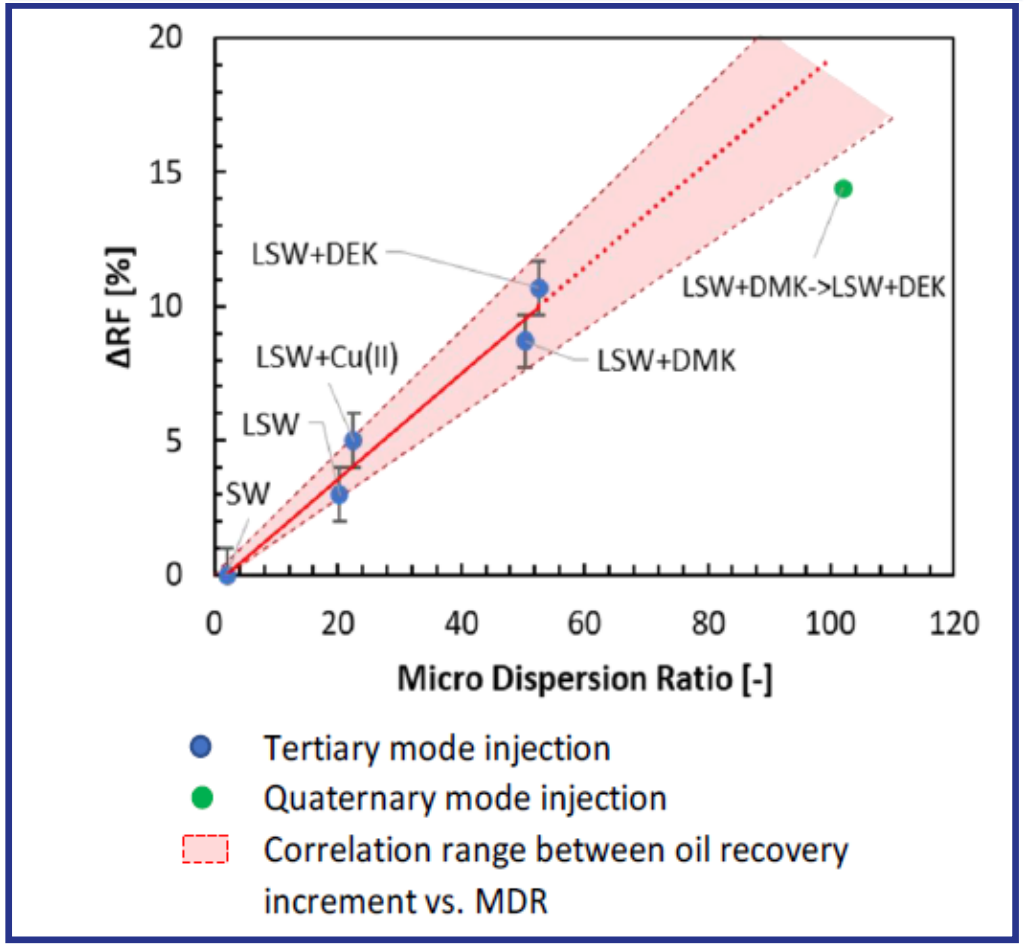
Core Flood Test Results: Pure LSW versus LSW + Each Additive

COMPOSITE CORE-B (Kabs=12 md)



CORRELATION BETWEEN OIL RECOVERY INCREMENT vs. MDR



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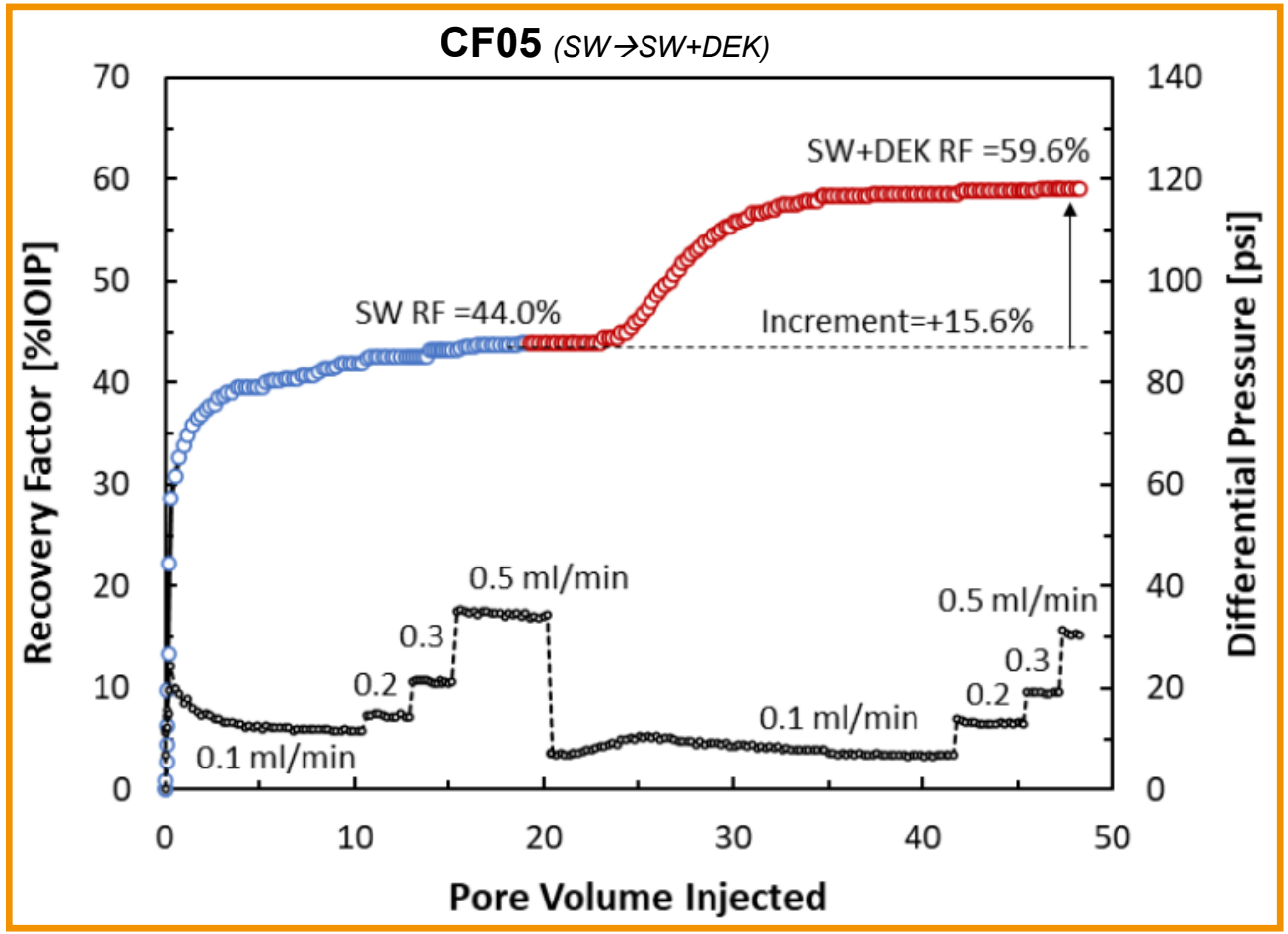
Core Flood Test Results: Comparison between Pure SW *versus* SW + DEK

COMPOSITE CORE-B (Kabs=12 md)



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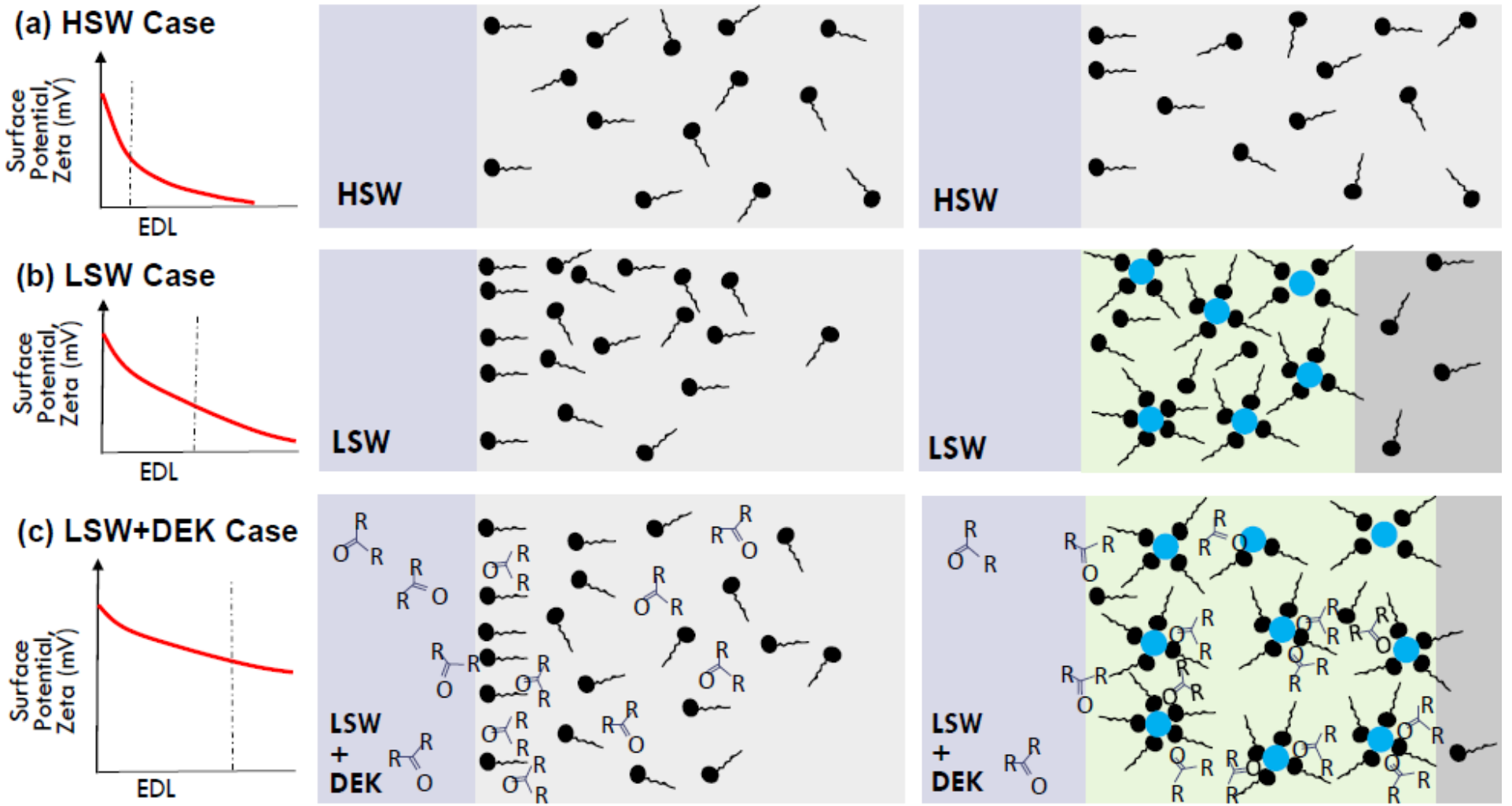
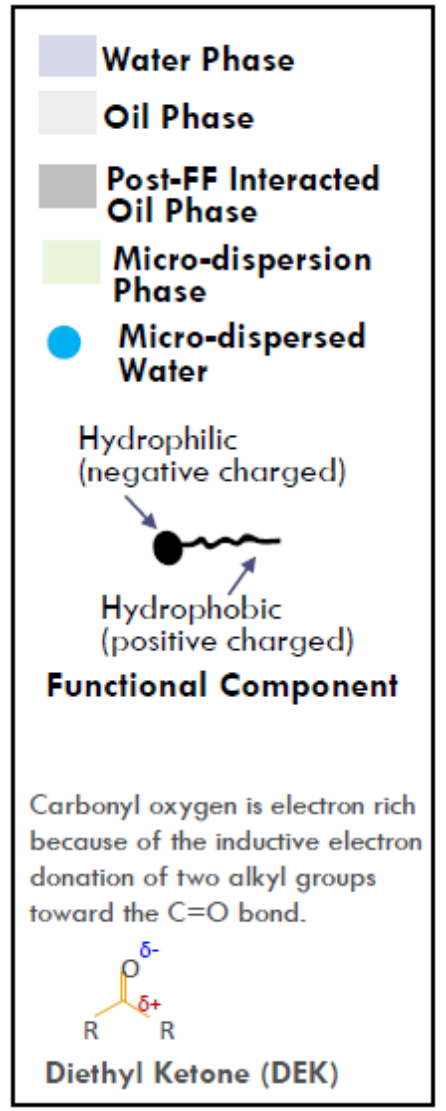
Mechanism - Hypothesis of MD Formation





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Identification of the Functional Component in Positive Oil

SPE-218172 -MS (Yonebayashi et al., 2024)

- Based on micro-dispersion (MD) ratios with 1% SW, a positive crude, a partially positive crude and a negative crude were analysed by FT-ICR MS.
- Samples were taken from the original crudes and, for positive oils, from the MD fluids and post-FFI testing oils. Samples were fractioned prior to analysis.

- Asphaltenes in positive oils consisted of higher double-bond-equivalent (DBE) composition.
- Higher DBE asphaltenes moved to the MD phase, majority of polar resins remained in the oil phase.
- Hypothesis that asphaltenes that were stabilized by being surrounded with resins, destabilized as polar resins were detached by the interaction between LSW and asphaltenes' surface-active components.
- The subject oil field has a clear asphaltene gradient and future work will explore oil taken from target areas.

Conclusions

- ❑ **Fluid-fluid interaction (FFI) tests highlighted large impact of LSW additives on MDR and oil recovery**
- ✓ MDR could double by adding DEK or DMK in LSW. Cu(II) had a less significant effect.
- ✓ The increment of tertiary oil recovery after secondary SW:
  LSW +3%, LSW-$CuCl_2$ +5%, SW-DMK +9% and LSW-DEK +11% of IOIP
- ✓ A linear correlation between MDR in fluid-fluid testing and increment of oil recovery in core flood tests.

- ❑ **Fluid-fluid interaction and core flood tests showed similarly positive impact for SW-DEK**
- ✓ MDR increased more than 3 times by adding DEK in SW and 15.6% increment in tertiary oil recovery
- ✓ Potentially quicker oil recovery than Hybrid LSW options
- ✓ Would save on need for desalination plant by applying SW basis

Way Forward

- ➢ Further exploring of effective additives and exploring the potential to optimize dosages
- ➢ Exploring more FFI reactive (richer polar-heavier-ends) field oils

Acknowledgement

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Thank you

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