Engineered Water for Improvement of Oil Recovery from Fractured Reservoirs

Project # 12842957

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U.S. Department of Energy
National Energy Technology Laboratory
April 2-4, 2024

Project Overview

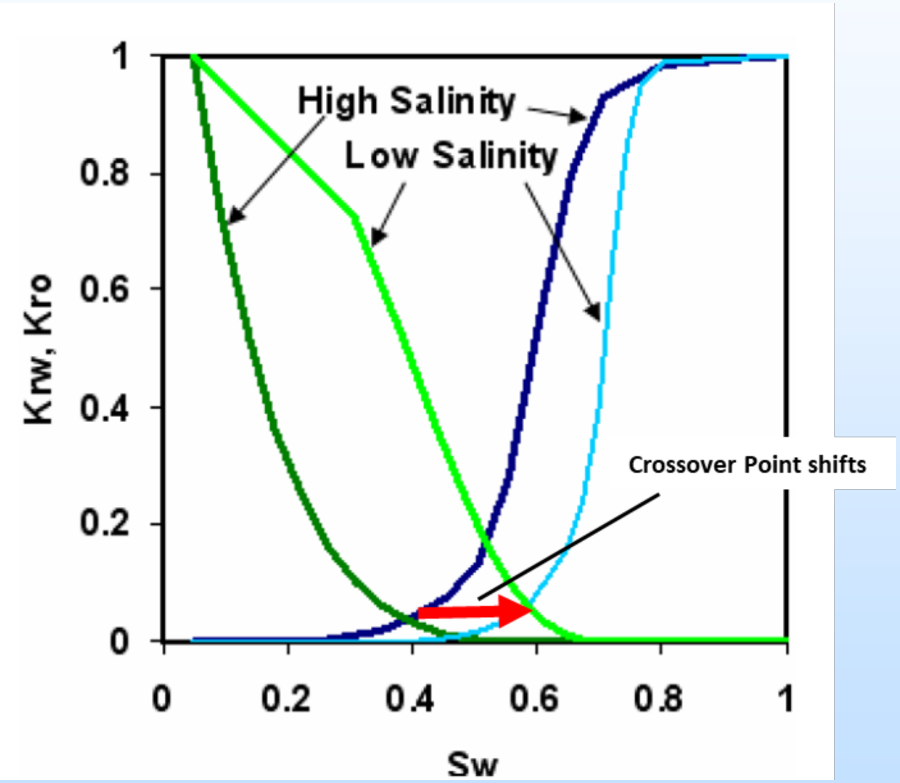
- Funding
  - DOE: $7,919,227
  - Cost Share: $1,979, 808
- Overall Project Performance Dates
  - October, 2019-August, 2024
- Project Participants
  - The University of Texas: K. Mohanty, W. Song, M. Pyrcz
  - Kinder Morgan: M. Panda, R. Valdez

Project Objectives

– Identify wettability altering agents (using ions, surfactants and/or nanoparticles) to enhance oil recovery in a fractured carbonate reservoir (Goldsmith Field GLSAU) in West Texas
– Conduct field tests using the wettability agents
– Evaluate field tests
– Develop criteria to apply these chemical processes economically in carbonate reservoirs (Yates & SACROC)

Background

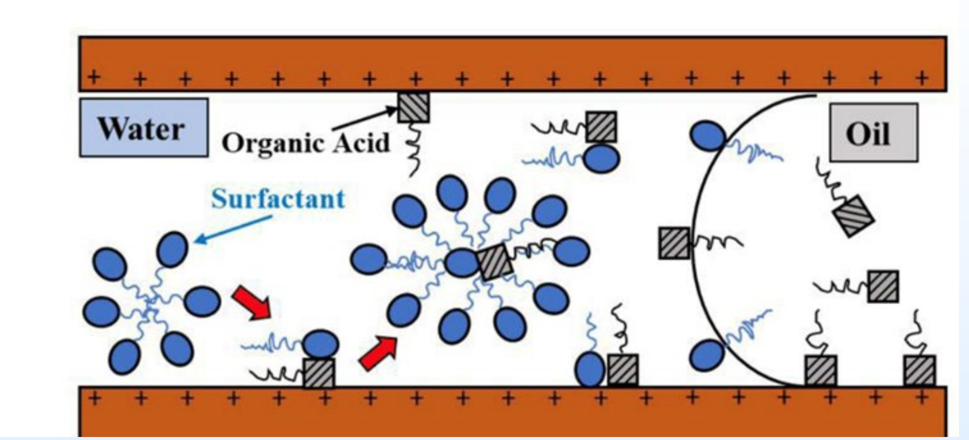
- Many carbonate reservoirs are heterogeneous and oil-wet.
  - ✓ Low oil relative permeability leading to low oil cut
  - ✓ High water cut
  - ✓ High water recycling
  - ✓ Low oil recovery
- Objective - Improve oil recovery by wettability alteration using engineered waterflood
- Test fields are in the Permian Basin.
- Several operators have injected water and CO2 in this field for decades

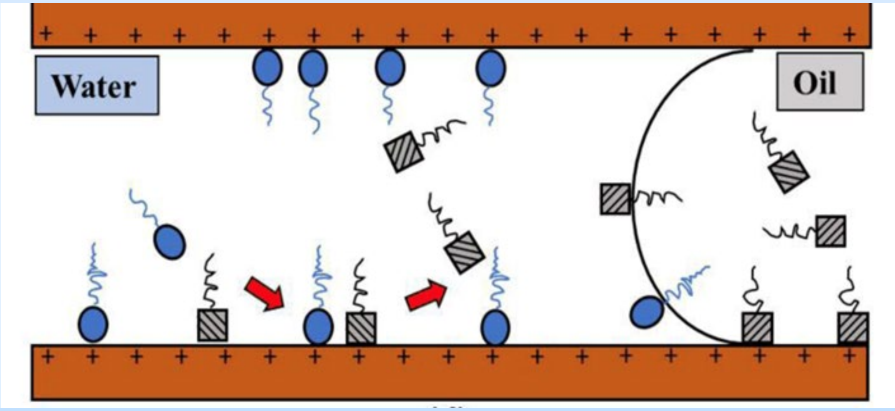


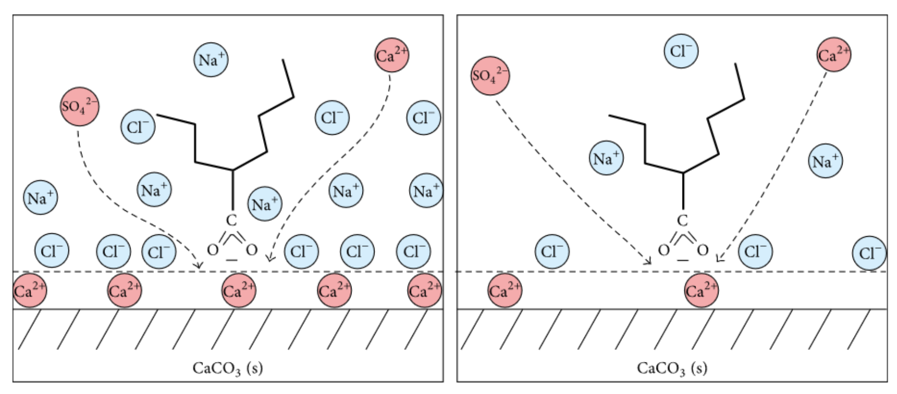
Background

- Carbonates have a positively charged rock surface. Oil has negatively charged acidic and/or asphaltic components that tend to attach to the surface and result in oil-wetness

- Cationic surfactants can remove thick oil films through IFT reduction and alter wettability by forming ion pairs with the attached organic acids.

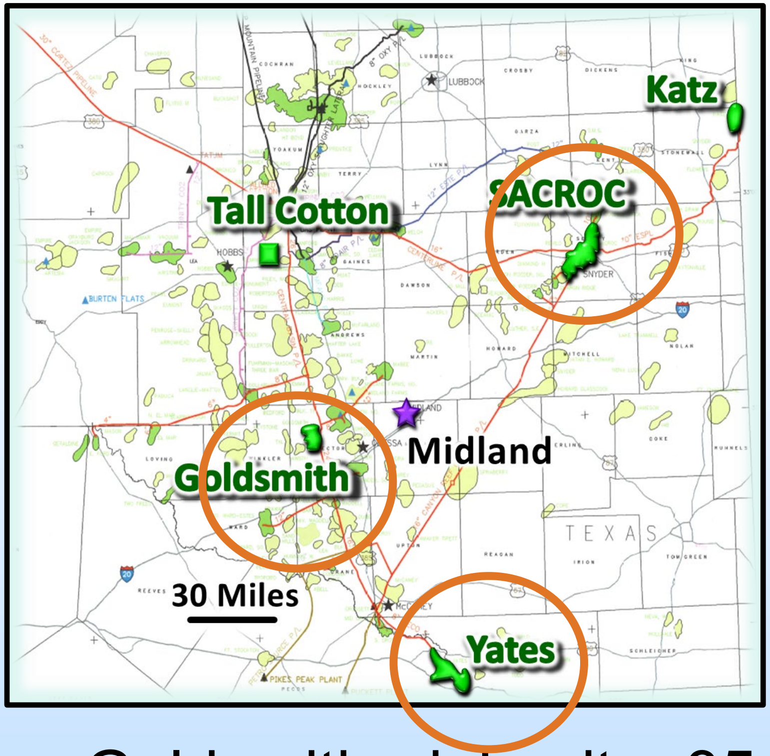






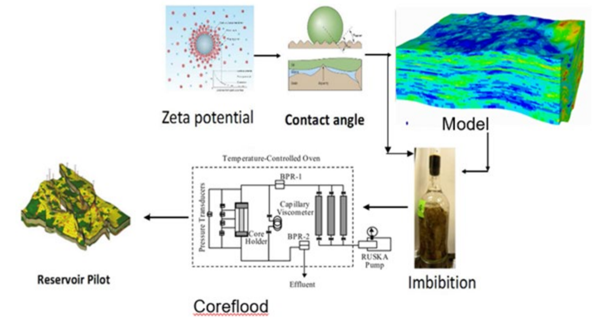
Background

- Goldsmith cumulative oil recovery < 20%
- Oil is bypassed due to
  - -heterogeneity
  - -oil-wettability
- Improve oil recovery by imbibing water into the bypassed regions
- Improve water-wettability by
  - -ions
  - -surfactants
  - -nanoparticles
  - -weak acids



- Goldsmith: dolomite, 35 ºC
- Yates: dolomite, 30 ºC
- SACROC, Limestone, 60 ºC

Methodology



Zeta & Contact Angle

➢ Screen brine salinity & wettability agent

Imbibition

➢ Confirm wettability agent

Core Flood

➢ Evaluate oil recovery at lab scale

Single-Well Test

➢ Evaluate oil recovery in ISP tests

Multi-Well Test

➢ Evaluate oil recovery in multi-well tests

Engineered Waterflood Design

- **39 Surfactants Tested**

	Surfactant name	Catagory	Provider
1 2	Surfactant name	Catagory	Provider
3	Domiphen Bromide	Cationic	Fisher Sci.
4	STEPANQUAT 3712W	Cationic	Stepan
5	CTAC	Cationic	Fisher Sci.
6	DTAB	Cationic	Fisher Sci.
7	Aspiro 6420	Cationic	BASF
8	Soloterra 938	Anionic	Sasol
9	Soloterra 939	Anionic	Sasol
10	Soloterra 982	Anionic	Sasol
11	Soloterra 983	Anionic	Sasol
12	CalFax 10L-45	Anionic	Pilot
13	Calffax 16L-35	Anionic	Pilot

- **Injection water salinity tested**

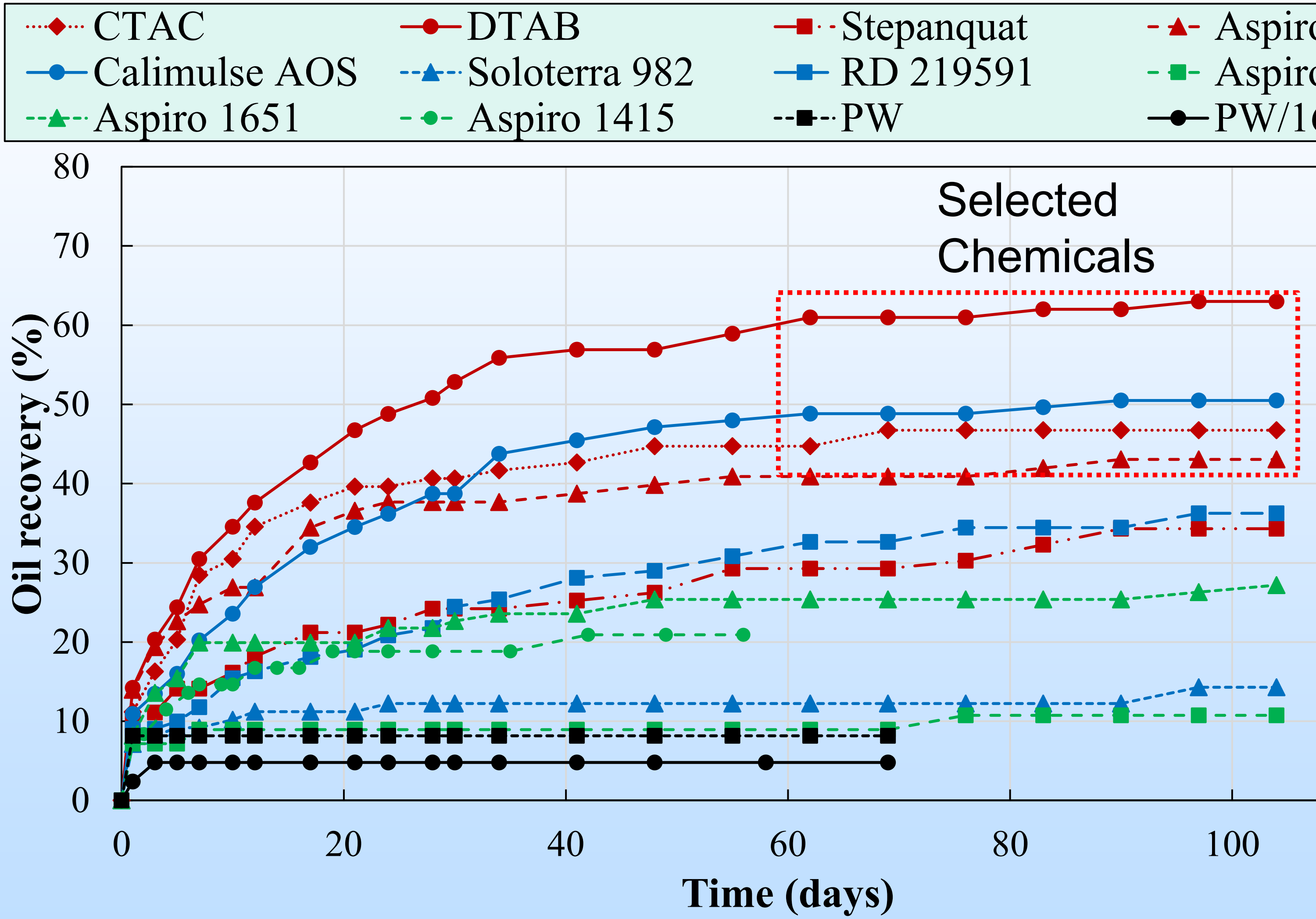
PW	PW/2 (Twice diluted)	PW/5	PW/10	PW/20	PW/40	DI (Deionized water)

- **Salts tested**

Na2SO4	NaHCO3

- **Nano particles tested**

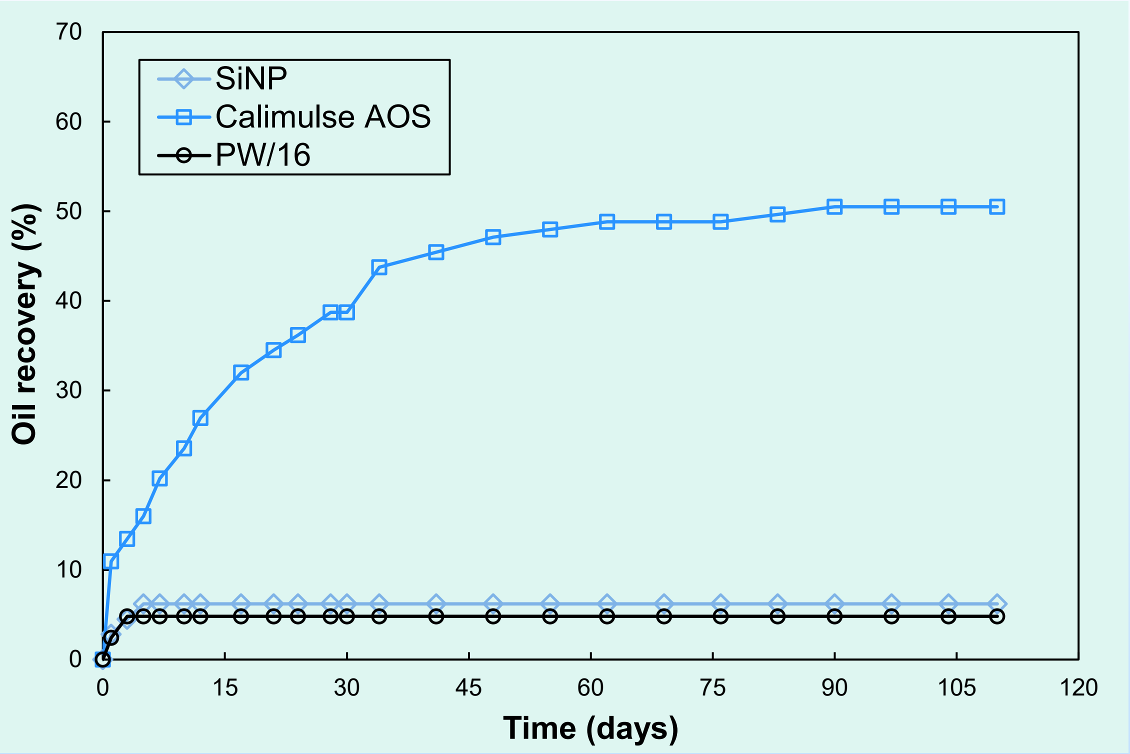
Identified Surfactants & Brine (PW/16) Goldsmith



Tested Nanoparticles for Wettability Alteration

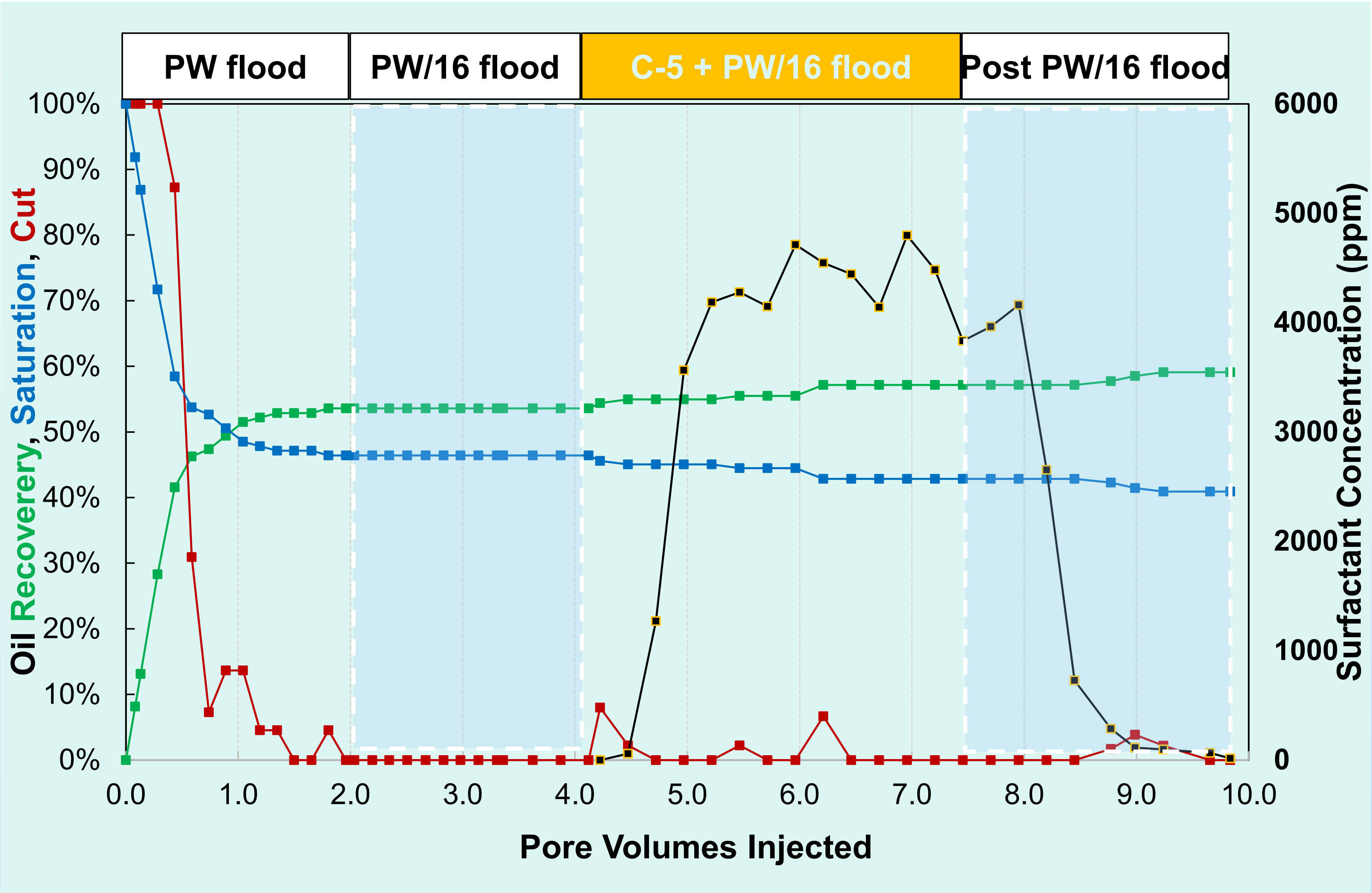
Oil-aged chip in SiNP solution

Imbibition into an oil-wet carbonate core



Nanoparticles do NOT alter wettability, but retain wettability

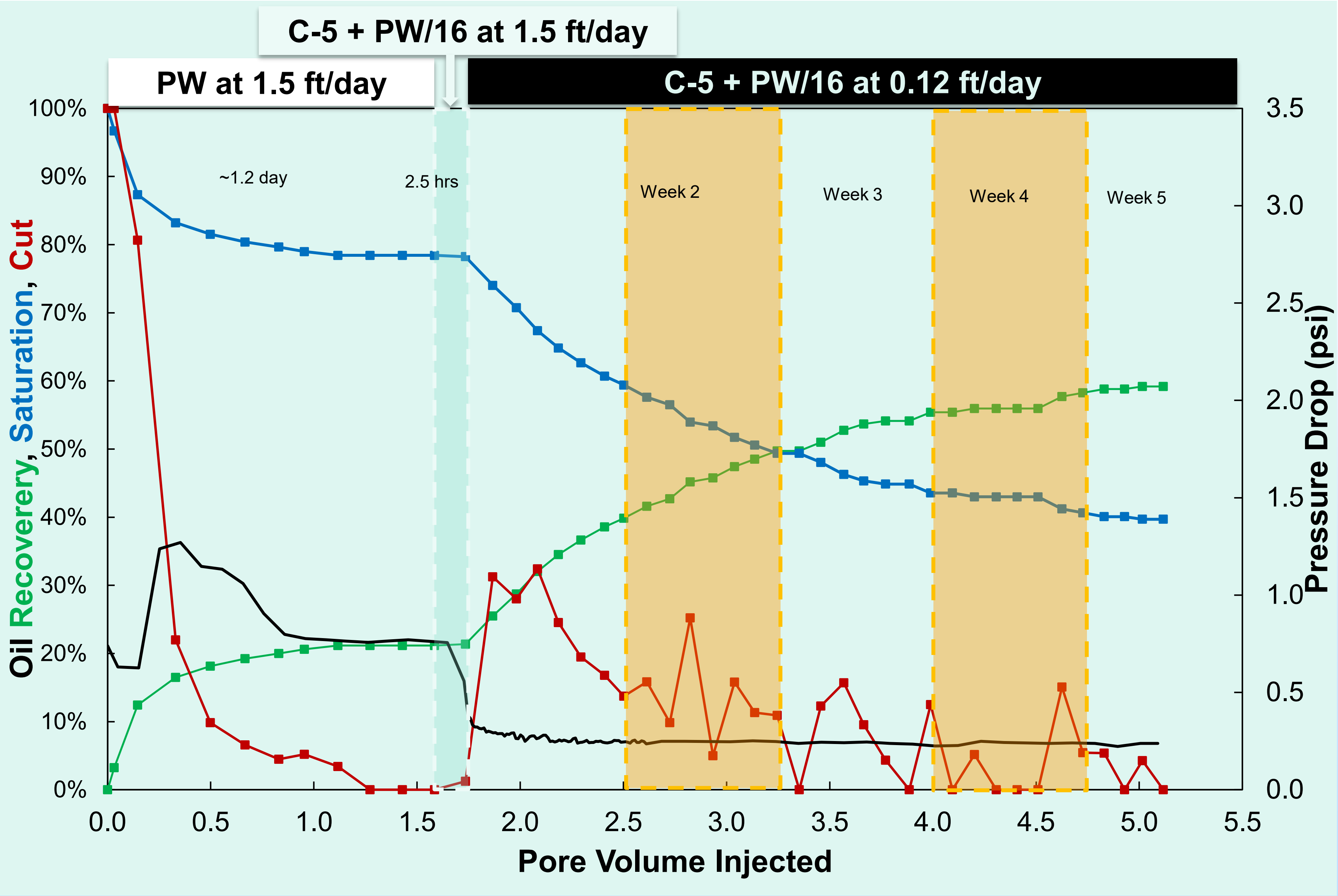
Identified EOR Mechanisms: Long Core Flood



WF: 53.6%

SF: +3.6%

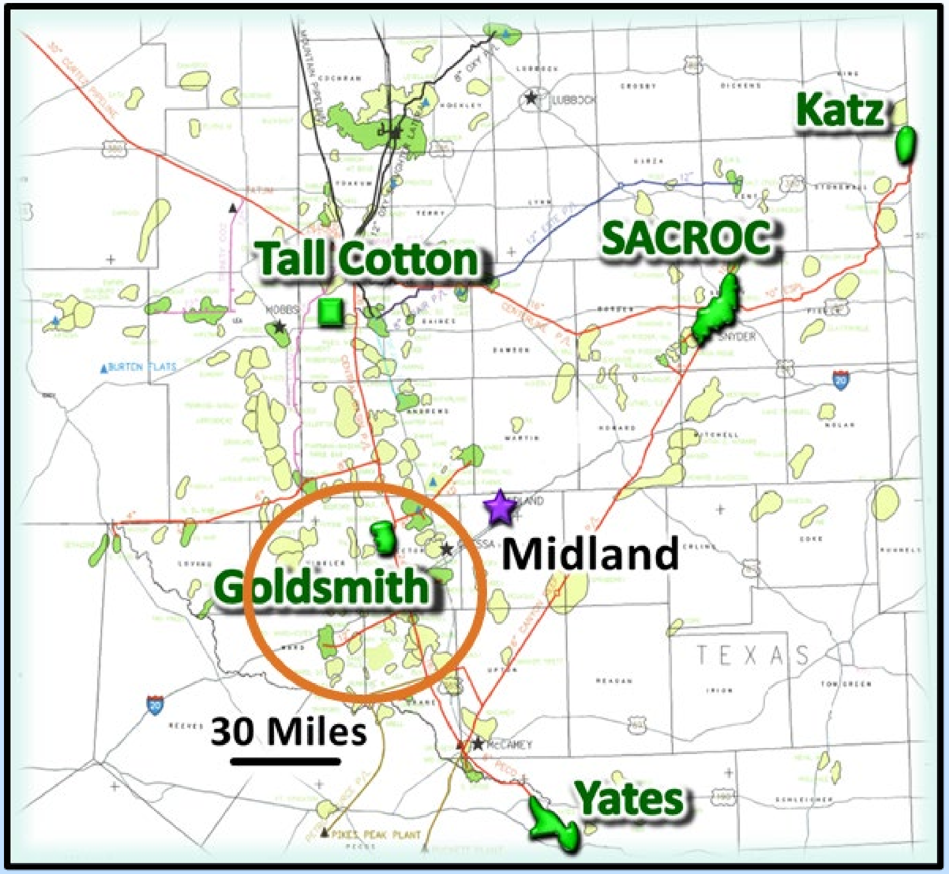
Identified EOR Mechanisms: Heterogeneous Core Flood



WF: 21.2%
SF: +38%

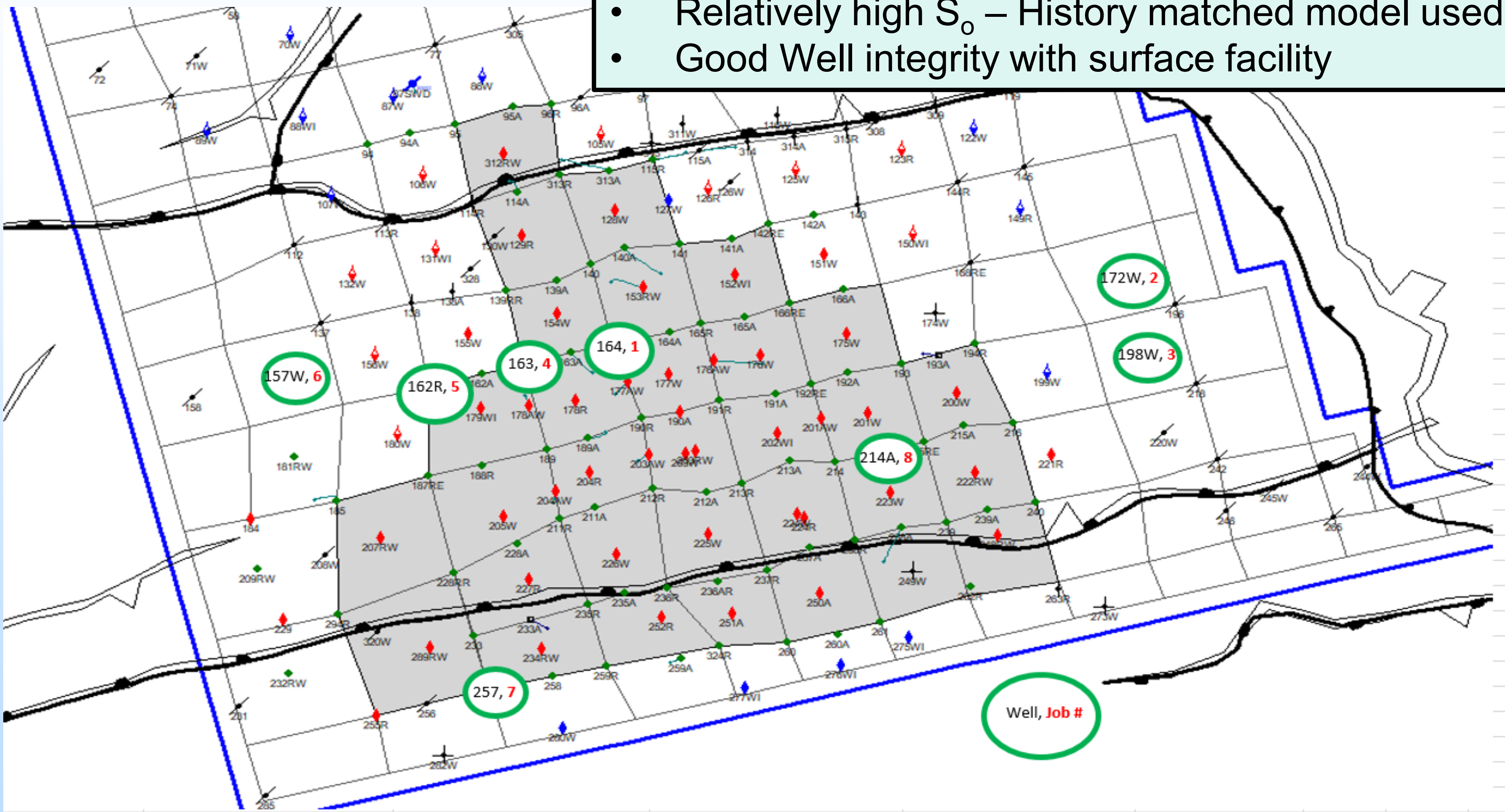
WA recovers oil from the bypassed regions.

Field tests –Goldsmith reservoir



Single Well Tests – Injection Soak Production

- Well with relatively high PI
- Oil rate declined
- Relatively high S_o – History matched model used
- Good Well integrity with surface facility

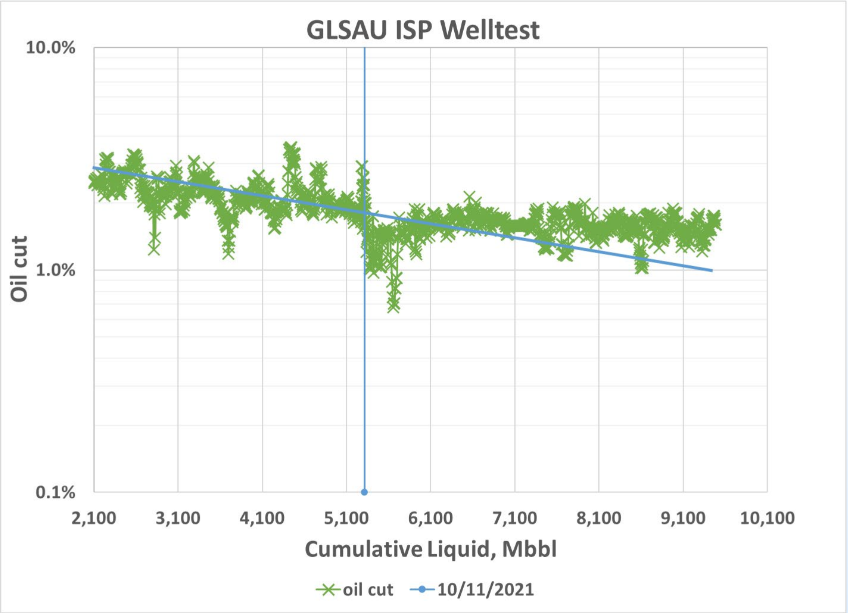


Refurbished Wells for Single-Well Tests

Well 157W

ISP Treatment Results

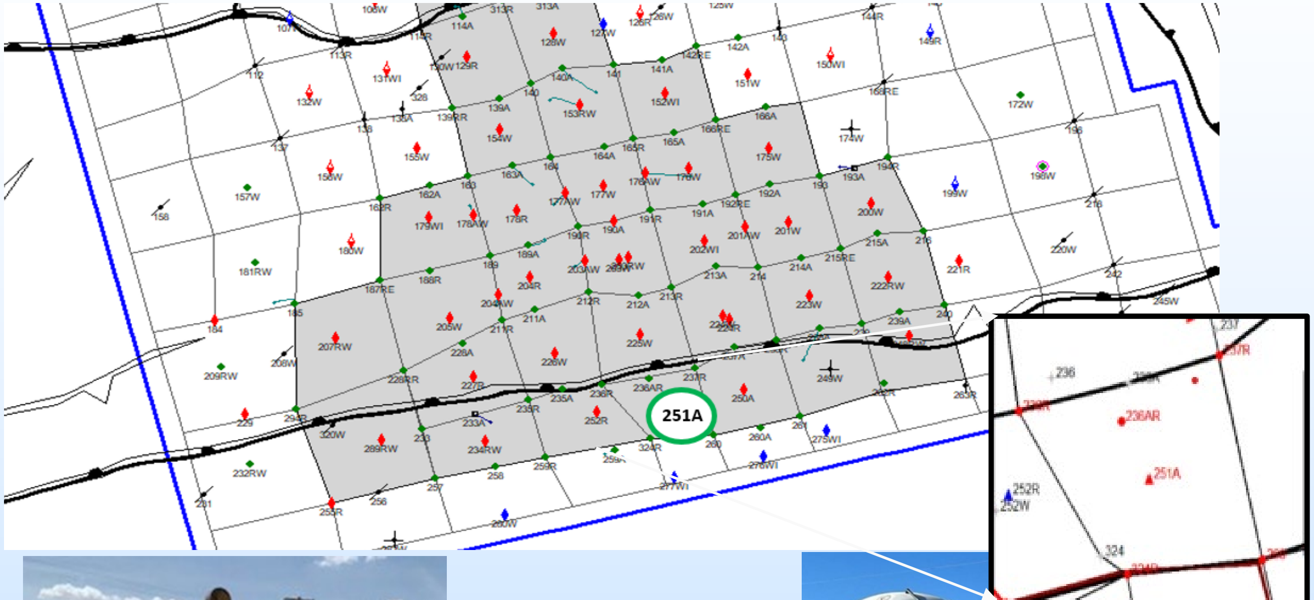
ISP Parameters				
Well	Surfactant Type	Shut In Time, Days	Dilution	Conc, ppm
163	S2	30	1/16	5000
172W	S2	32	1/16	2500
162R	S2	62	1/16	5000
157W	S2	32	1/16	5000
214A	S2	31	1	5000
164	S1	30	1	5000
198W	S1	33	1/16	2500
260A	S1	32	1/16	5000



Observations

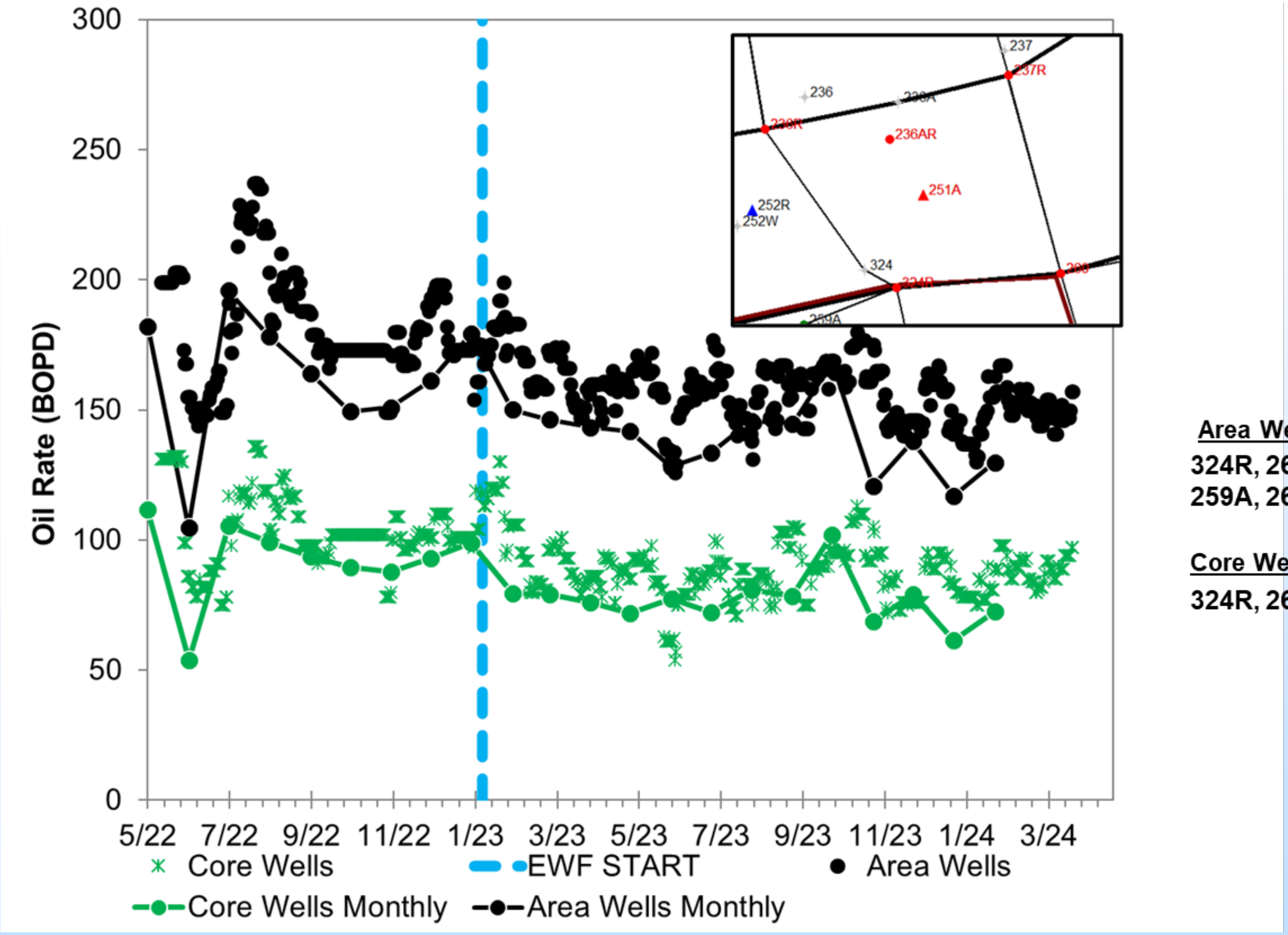
- **Surfactant injection volume – cover PV of 25' around the well**
- **30 days of soaking adequate**
- **Dilution required ~1/16**
- **Surfactant concentration 2500-5000 ppm**

Goldsmith Pattern Flood using EWF



Pattern 251A
- Rock quality good
- Relatively immature WAG – large oil target
- Short producer-injector distance – quick response

Pattern Performance 251A-Goldsmith



Area Wells

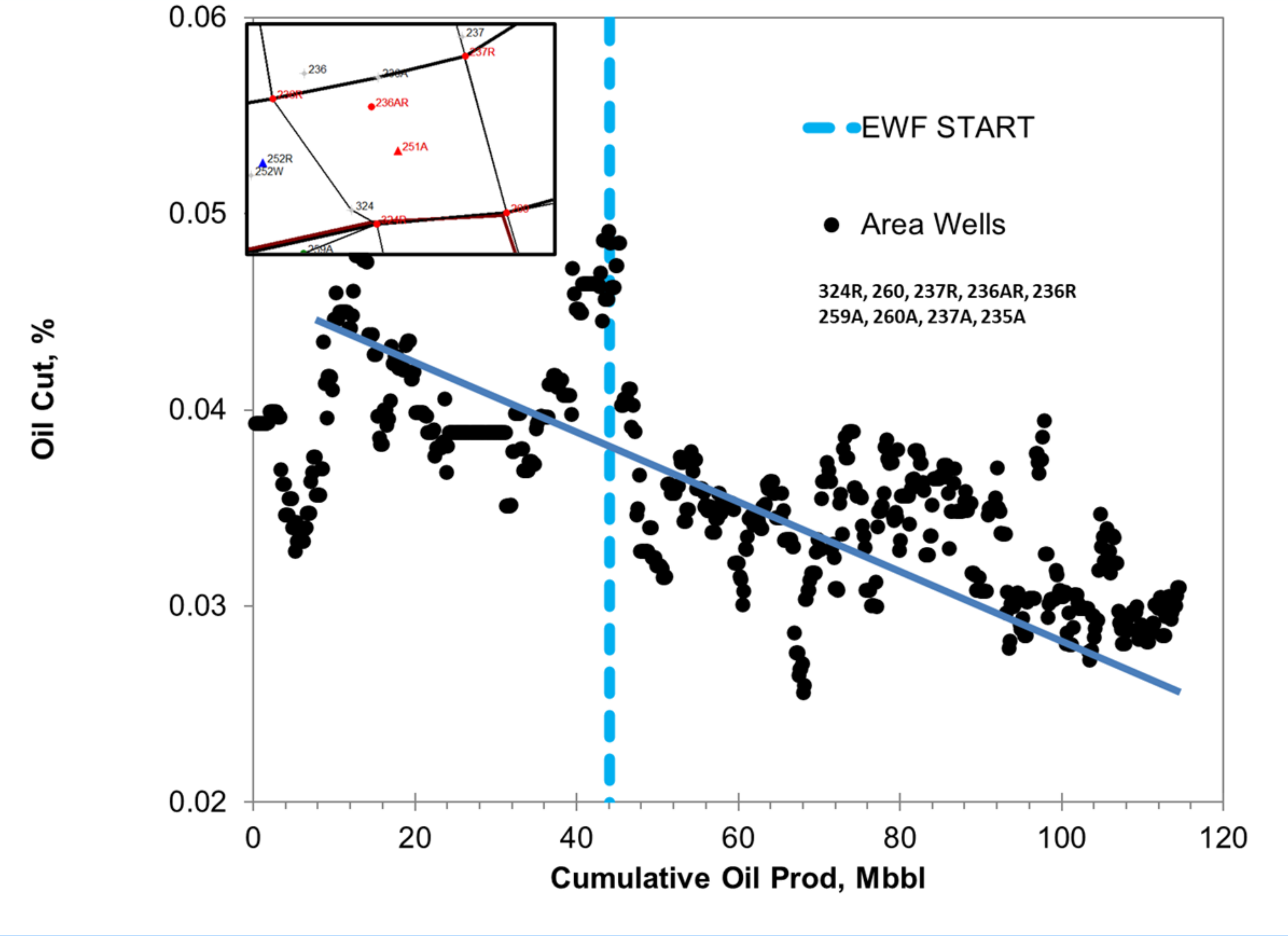
324R, 260, 237R, 236AR, 236R
259A, 260A, 237A, 235A

Core Wells

324R, 260, 237R, 236AR, 236R

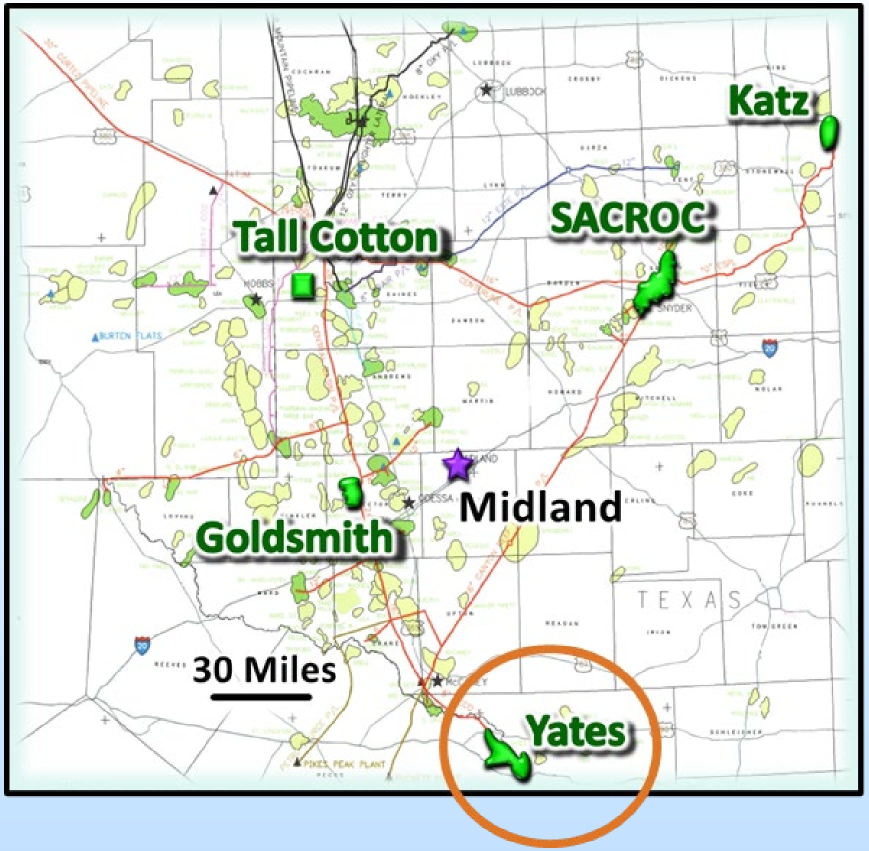
Oil production data shows increasing trend

Pattern Performance 251A-Goldsmith

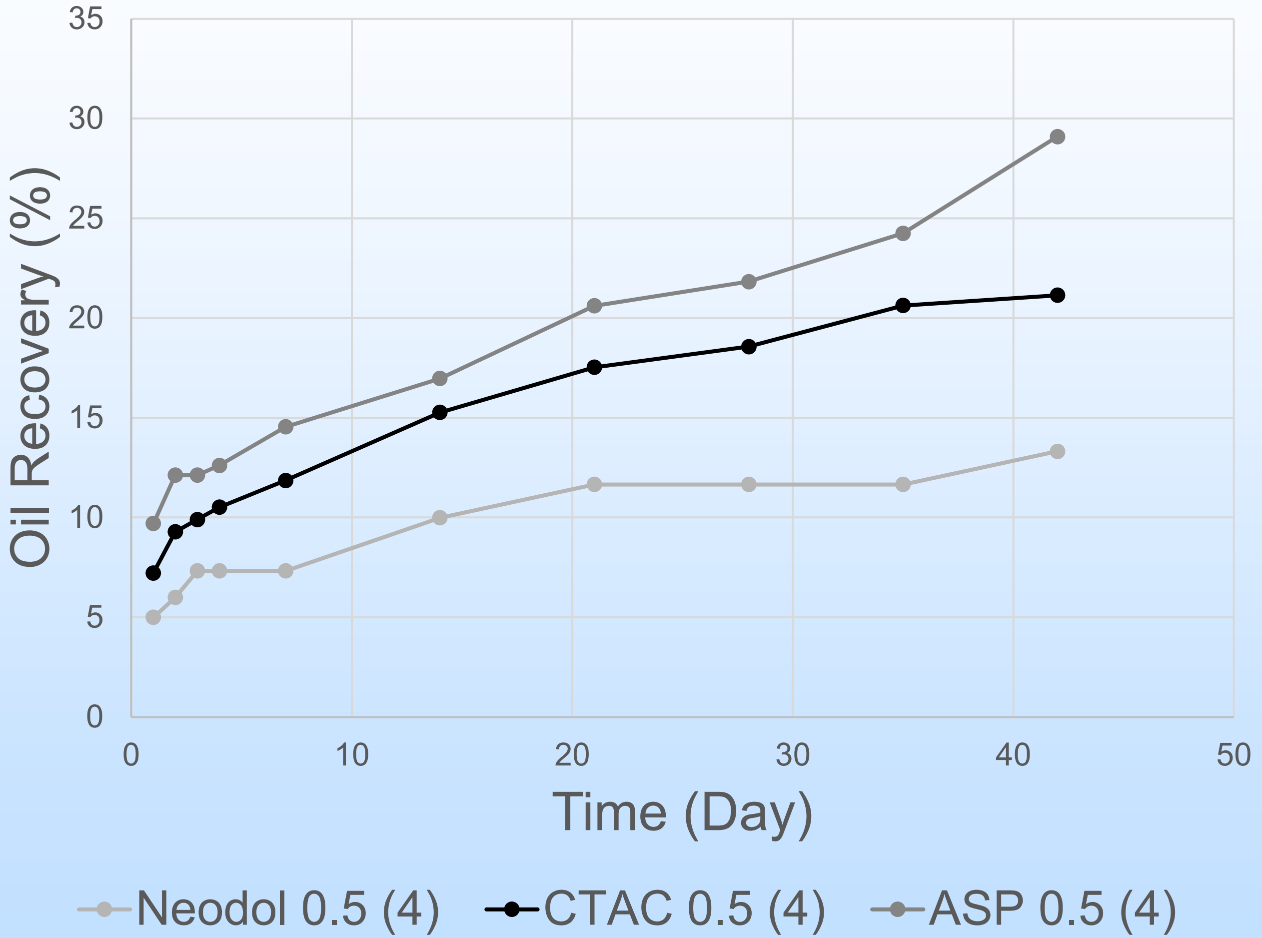


Oil cut data shows increasing trend

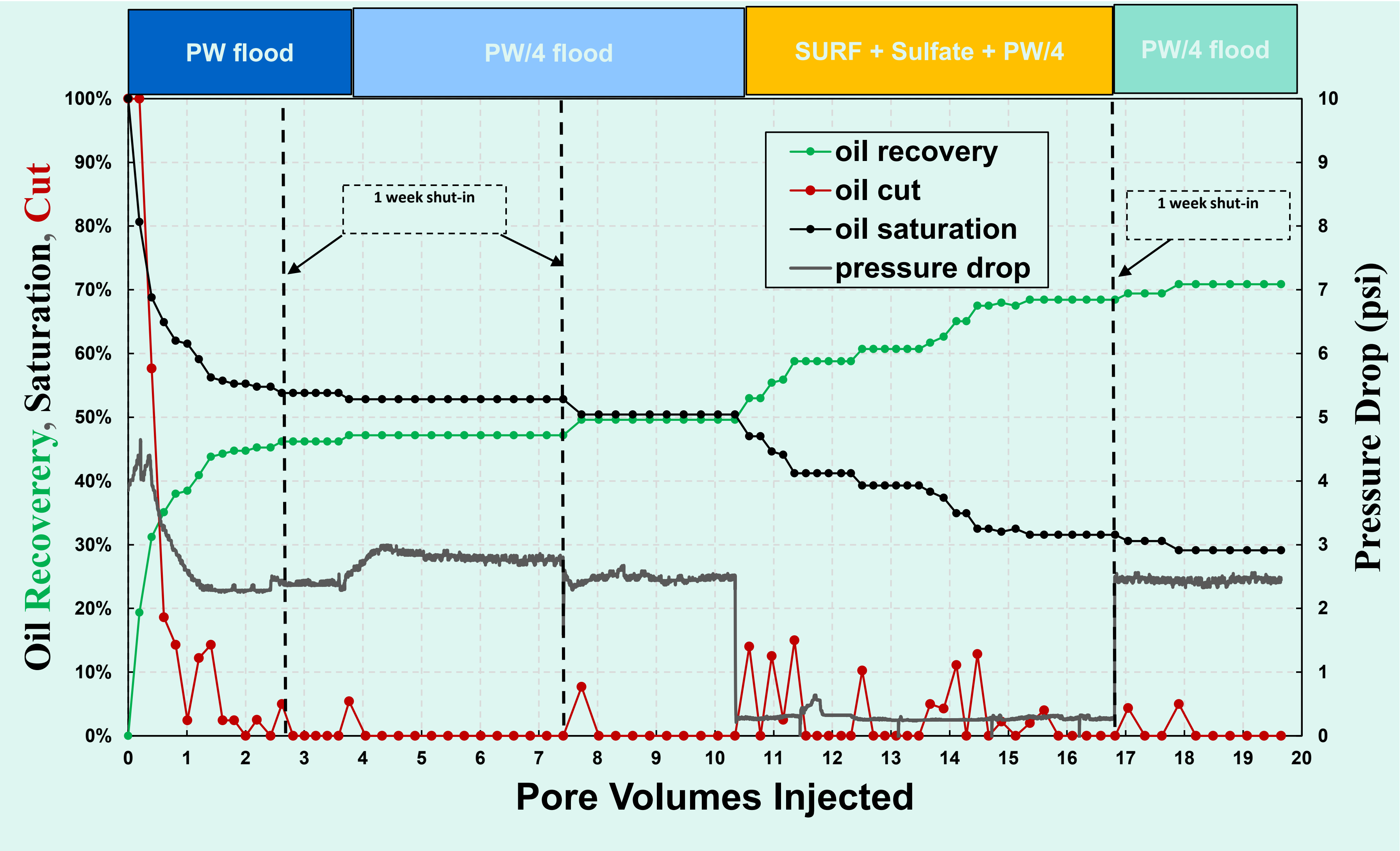
Field tests –Yates reservoir



Spontaneous Imbibition: Yates

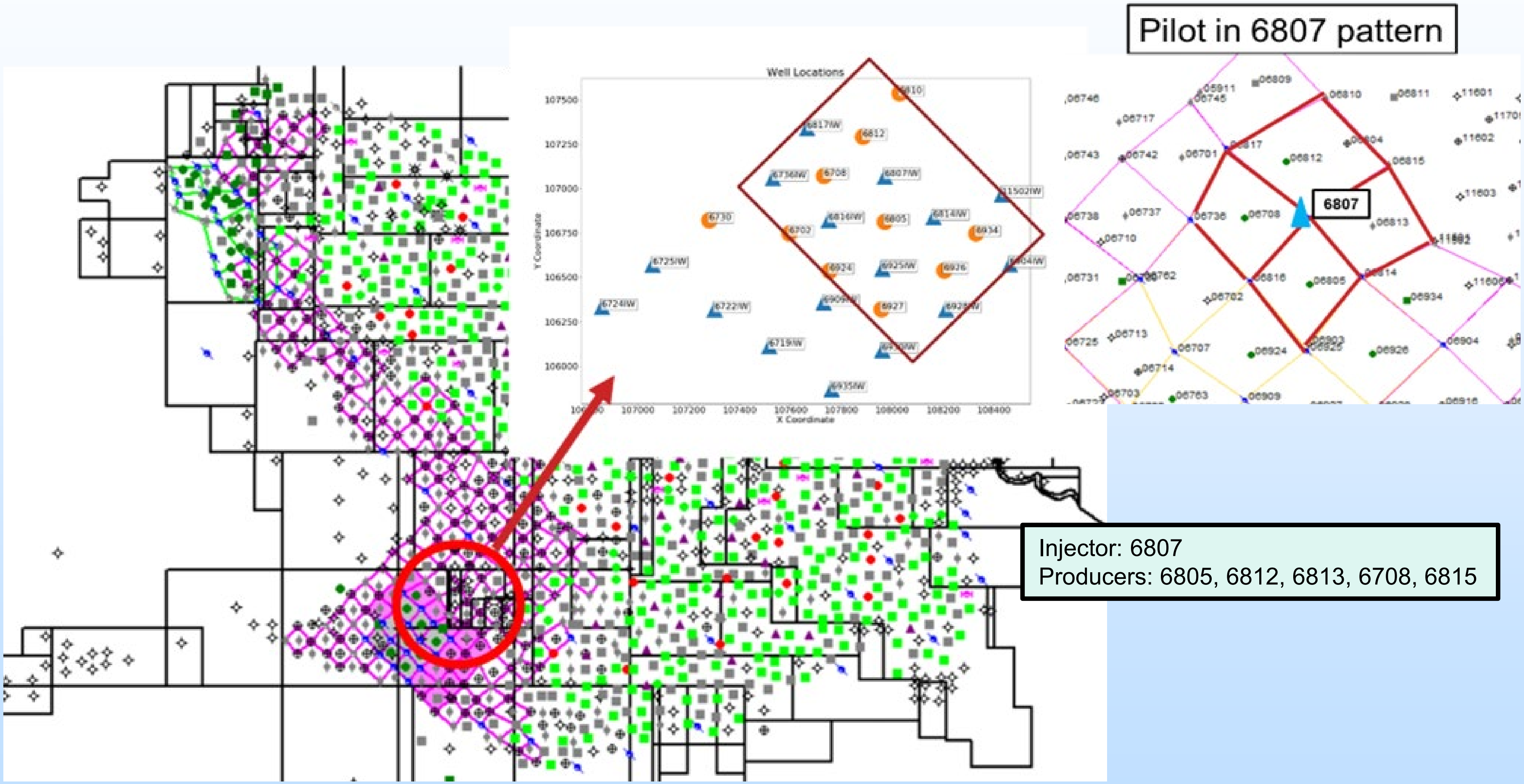


Core Flood: Yates



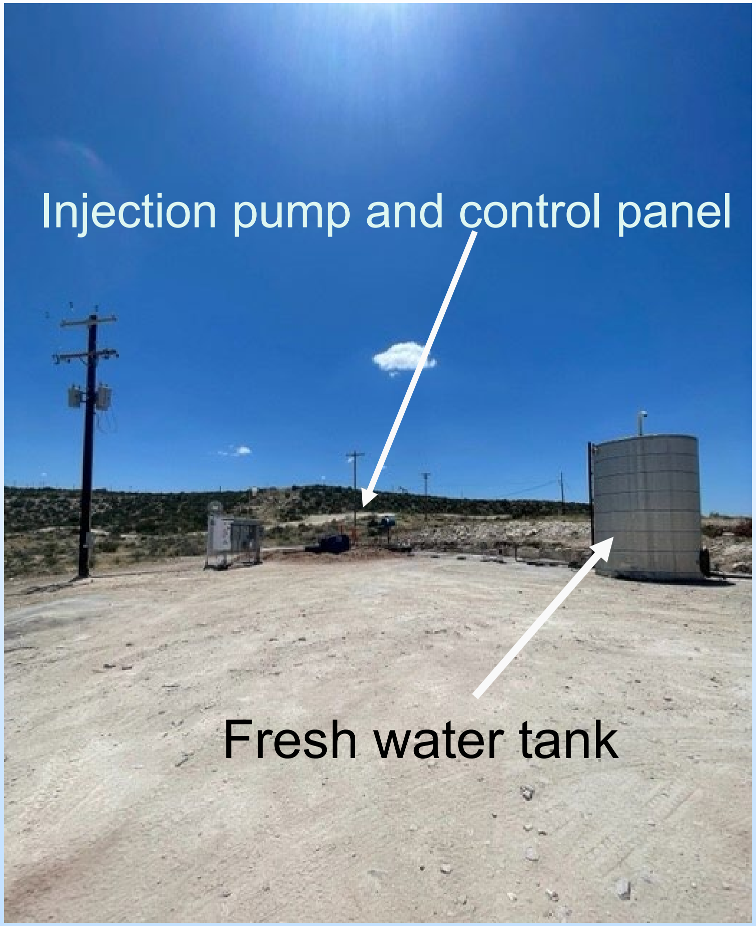
WF: 50%, SF: 20%

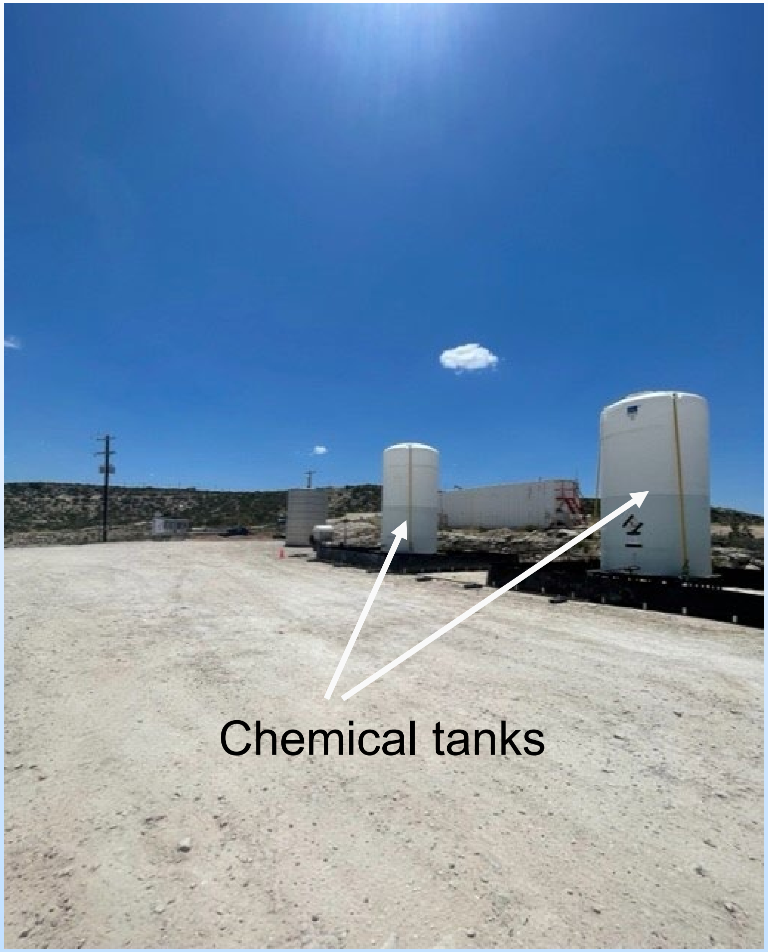
Yates EWF Pattern



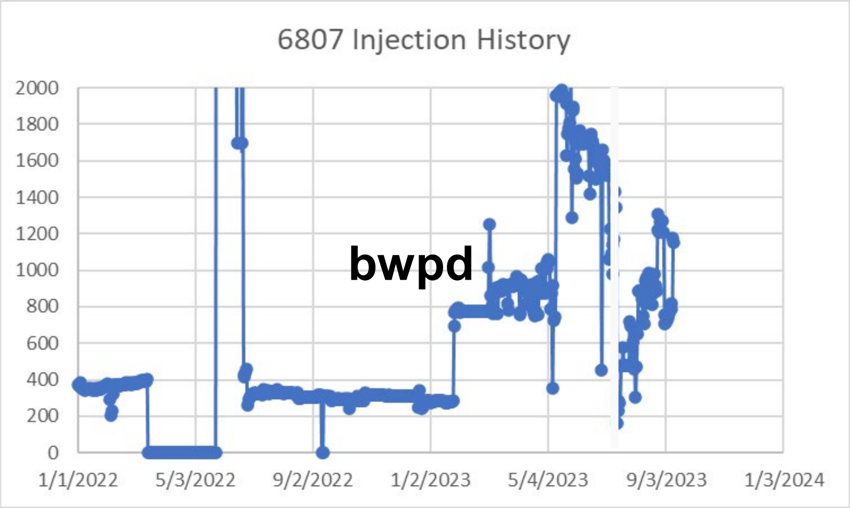
Yates EWF Pattern

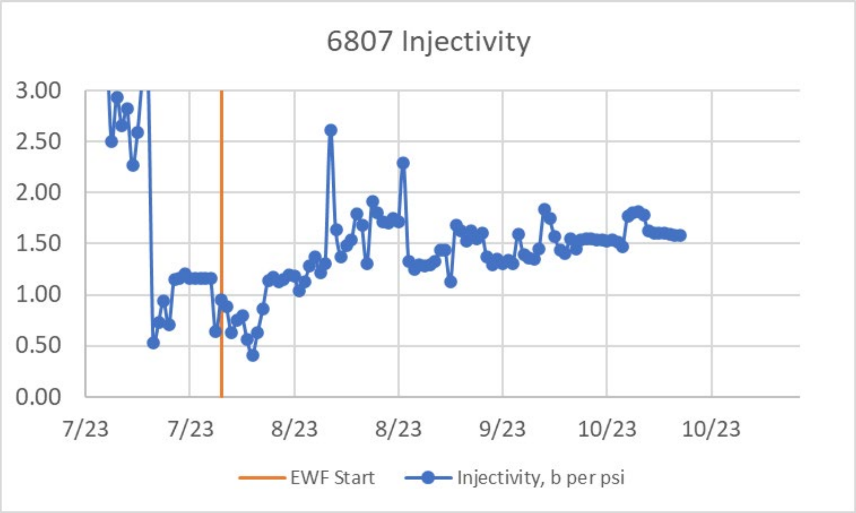
Injection equipment set up at the well site

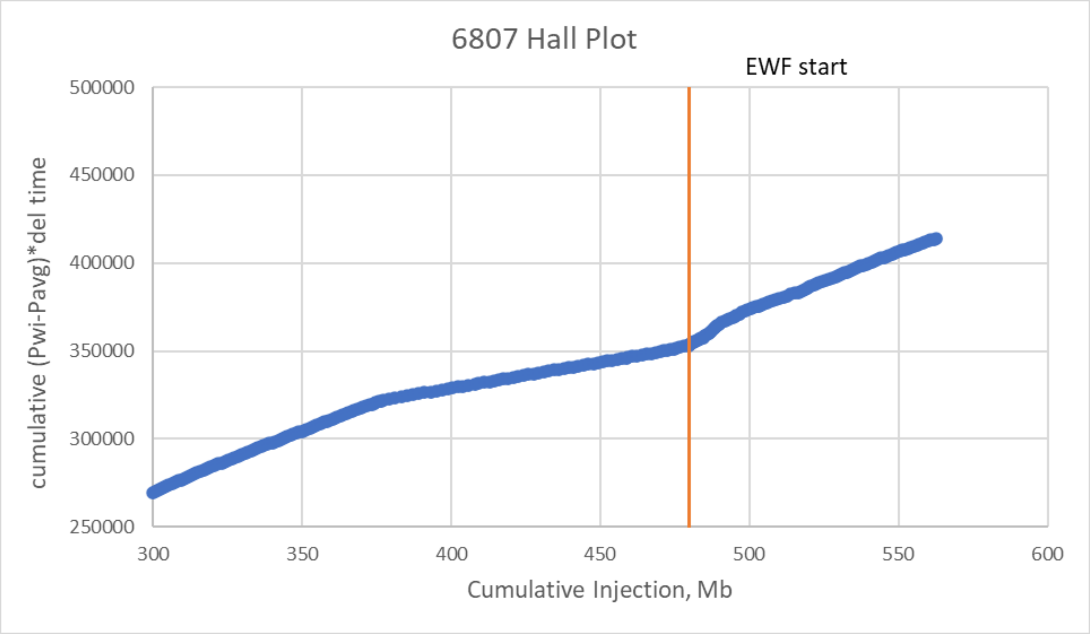




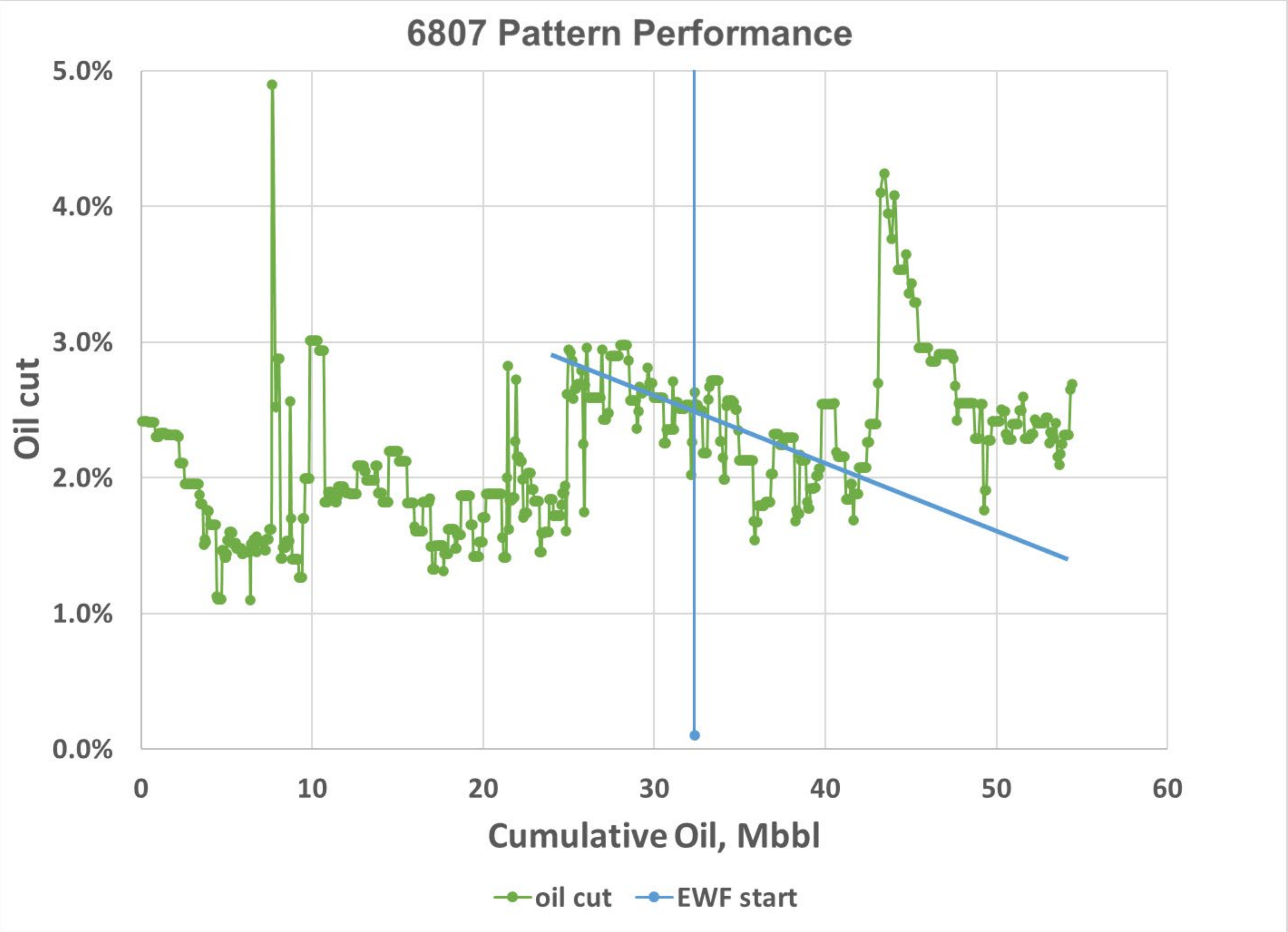
6807 Injectivity



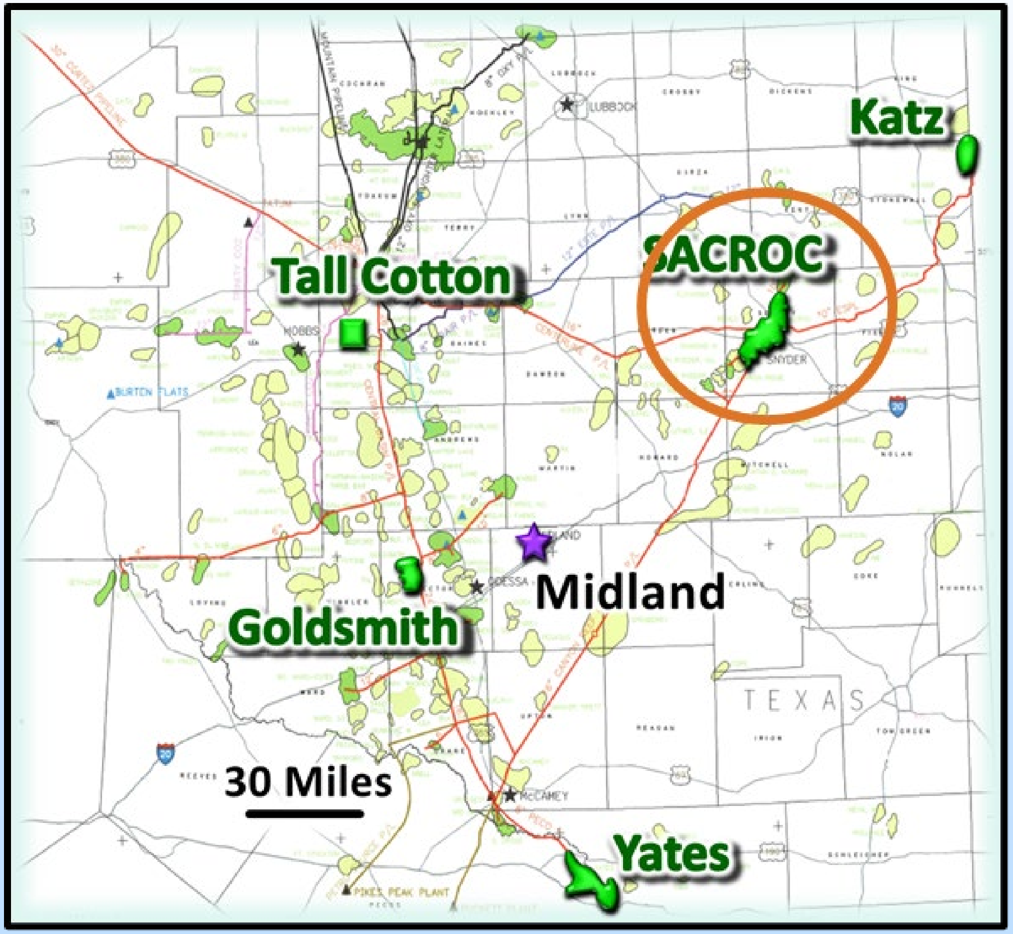




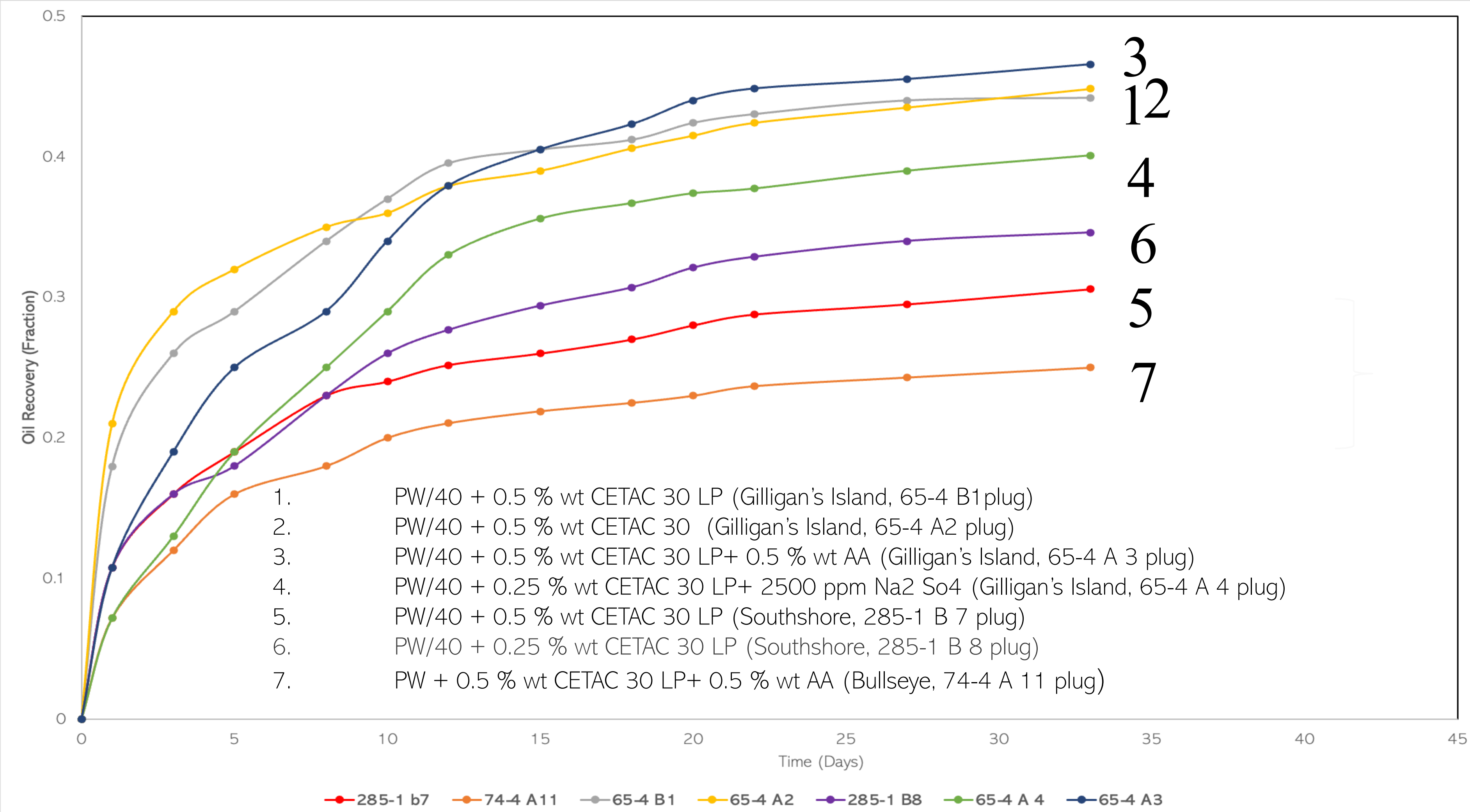
6807 Pattern Performance: Yates



Field tests –SACROC reservoir

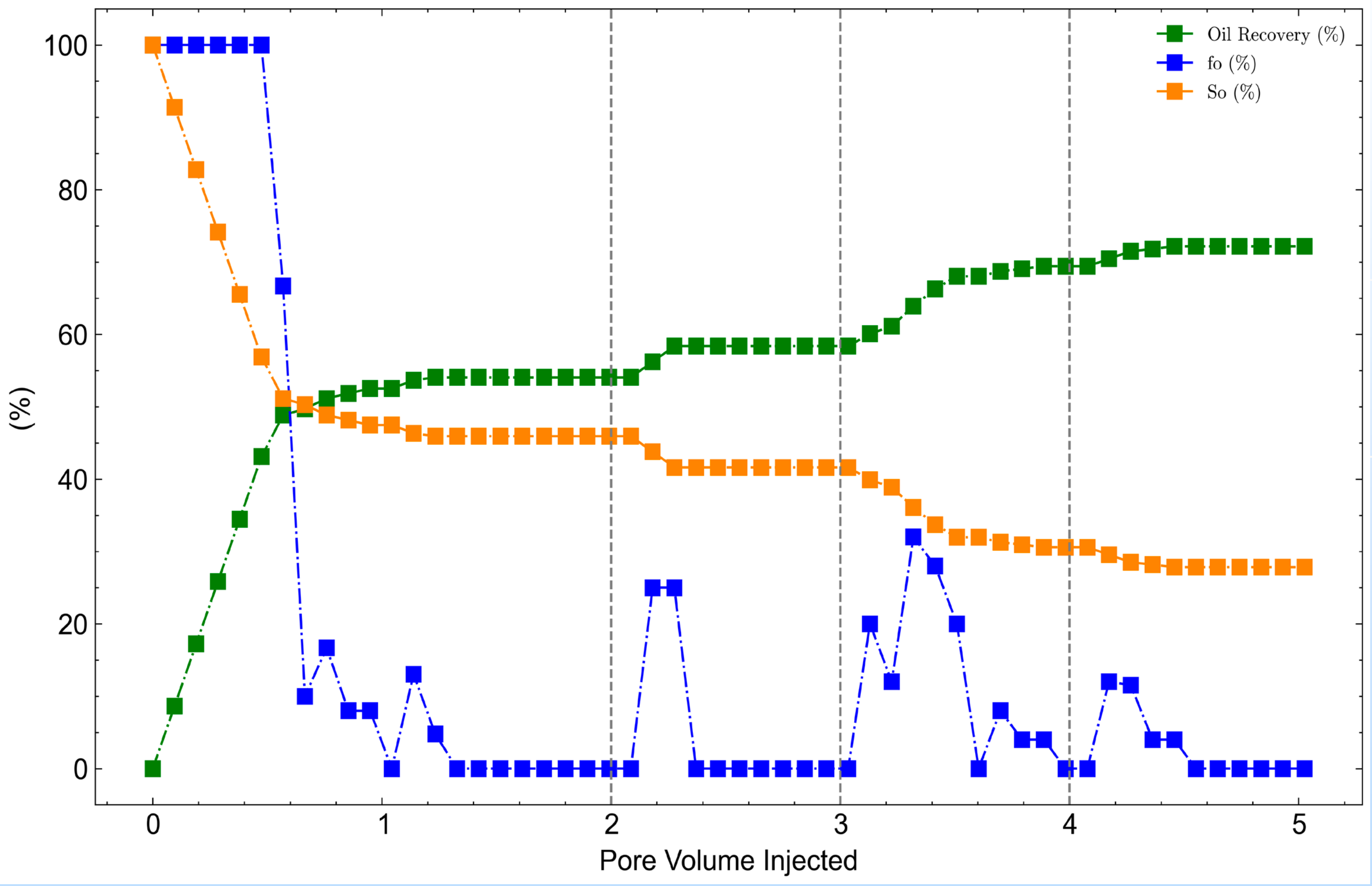


Imbibition in SACROC cores



Core Flood in SACROC

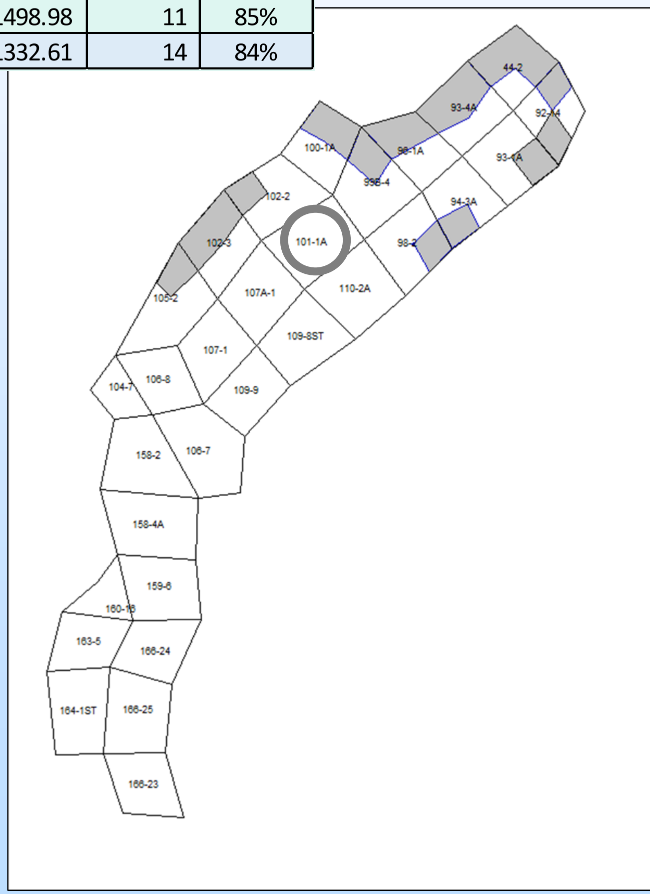
PW Waterflood PW/20 PW/20+ Surf PW/20

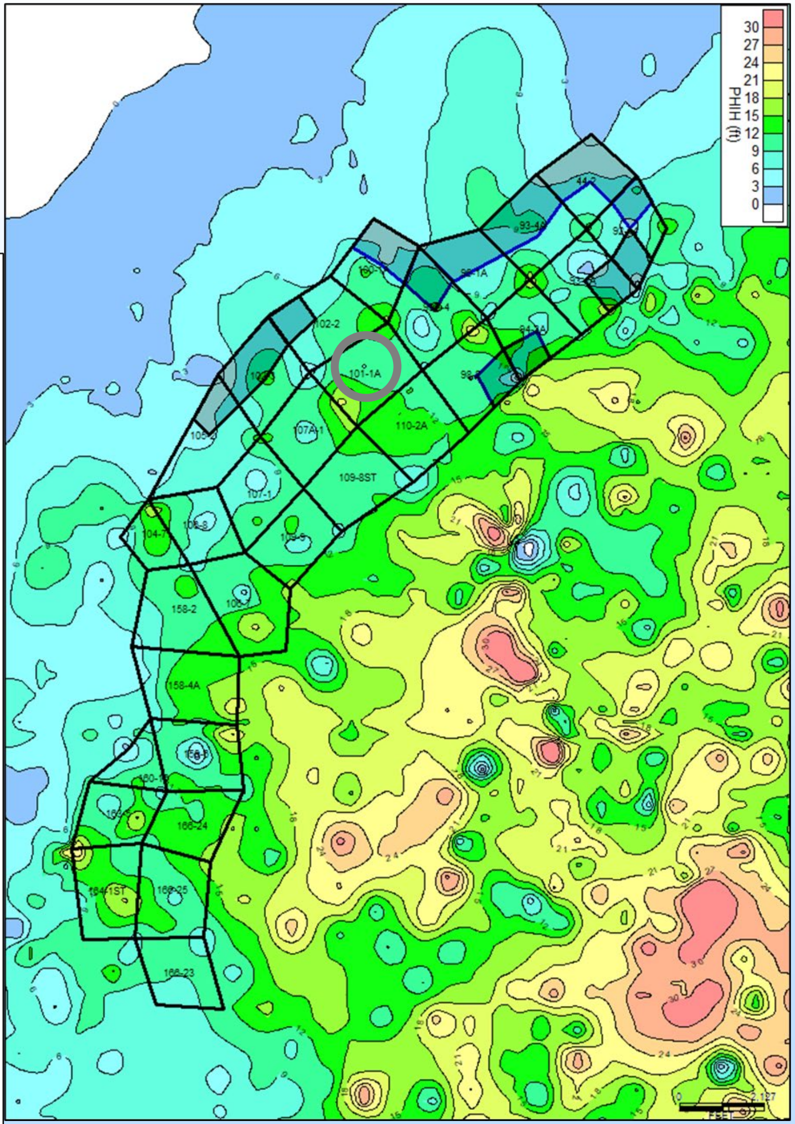


WF: 54.1%, LSF: 4.3%, LS+Surf: 13.3%

SACROC Patterns in Westside

Pattern	Start Date	OOIP, MBO	Cum Rec, %	Current WC, %
164-1	4/1/2020	4495.9	18	79%
101-1A	4/1/2020	4235.79	15	83%
159-6	4/1/2020	3793.51	11	83%
100-1A	4/1/2020	1654.43	8	87%
102-3	4/1/2020	1498.98	11	85%
96-1A	4/1/2020	1332.61	14	84%



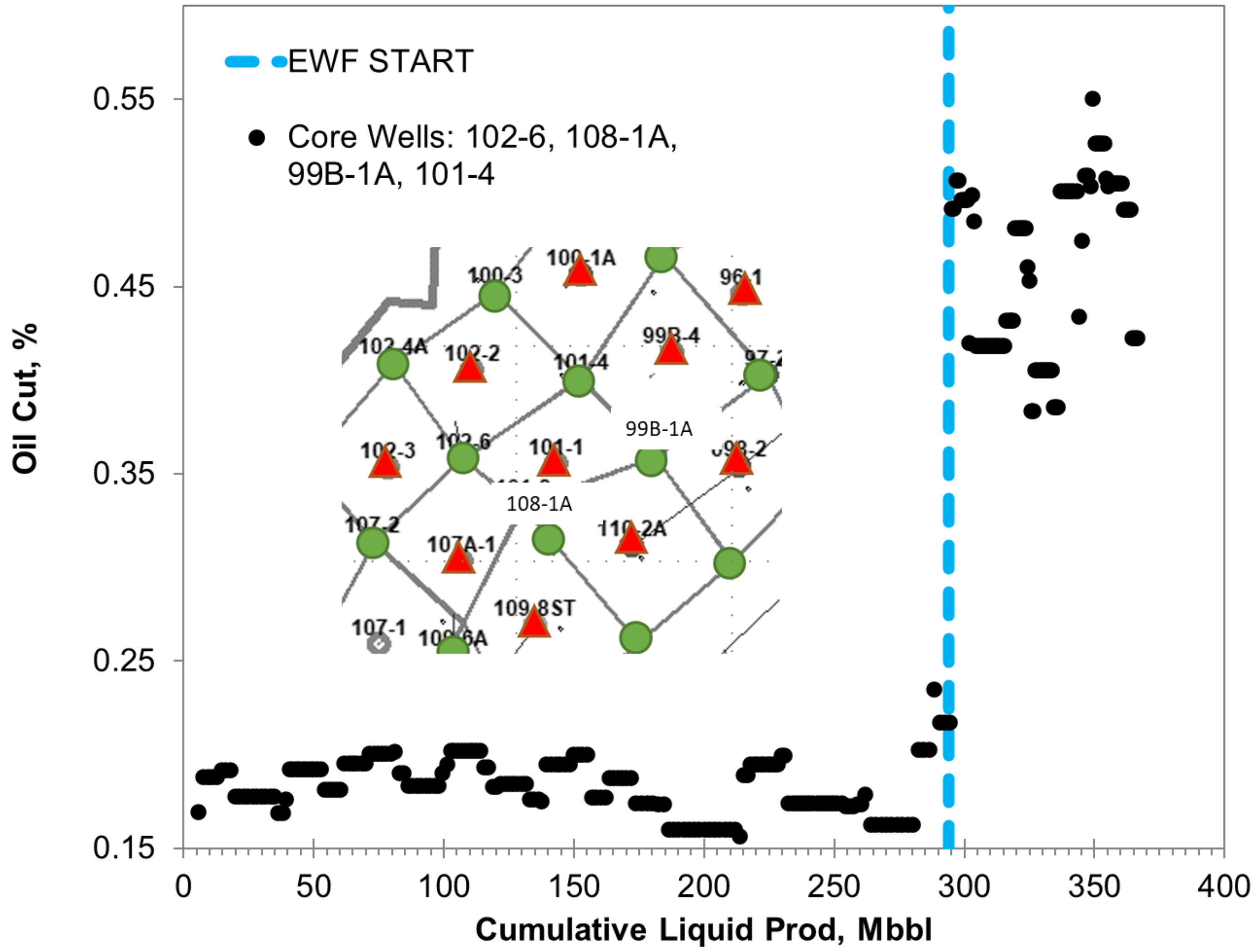


101-1A Pattern Site

Injection well

Chemical pump set up

101-1A Pattern Performance: SACROC



Accomplishments to Date

Goldsmith

- Optimized brine salinity
- Identified surfactants for wettability alteration
- Identified weak acids that can improve WA
- Identified mechanism of oil recovery from core floods
- Developed geostatistical reservoir characterization
- Conducted 8 Injection-Soak-Production well tests
- Conducting a multi-well test

Yates & SACROC

- Identified salinity & surfactant for wettability alteration
- Identified patterns for multi-well tests
- Injection in Yates and SACROC continuing
- Production responses are being monitored

Lessons Learned

– Surfactants with low salinity change wettability of oil-wet rocks at low T; weak acids help; nanoparticles do not change wettability, but keep calcite surfaces water-wet
– Wettability alteration does not necessarily improve oil recovery in well-swept regions, but it does improve oil recovery from bypassed regions
– Modeling wettability alteration by changing the relative permeability (the common approach) does not capture the physics; use Pc also
– ISP tests show incremental oil
– Multi-well tests show incremental oil; need to be conducted for longer

Next Steps

- Monitor the multi-well test in Yates and SACROC
- Model these tests
- Develop criteria for application for this technology
- Final report

Gantt Chart

Gantt Chart																		
Task	**Resource**		**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**	**Q14**	**Q15**	**Q16**
1. Project Management	KM	✓ ☐																
2. Injection Composition	KM, WS																	
2.1. Brine Composition	KM, WS		✓ ☐															
2.2. Surfactant Formln.	KM			✓ ☐														
2.3. Micromodel Dev.	WS				✓ ☐													
2.4. Imbibition	KM				✓ ☐													
2.5. Core flood	KM																	
Milestone-A						✓												
3. Design of Single Well Test	MPY, MPA																	
3.1. Collection of Field Data	MPA		✓															
3.2. Geostatistical Models	MPY			✓														
3.3. Modeling of Lab Tests	KM																	
3.4. Single-well Test Design	MPA, KM					✓												
3.5. Multi-well Tracer Design	MPA, MPY																	
Milestone-B	MPA					✓												
4. Single-Well Pilot Test	RV, MPA									✓								
Milestone-C	MPA																	
5. Design of Multi-Well Test	MPA, MPY											√						
Milestone-D	MPA																	
6. Multi-Well Pilot Test	RV, MPA																	
Milestone-E	MPA																	
7. Field Development Strategy	KM, MPA																	
Milestone-F	KM																	

Acknowledgements

- US DOE- NETL, Award # DE–FE0031791
- Center for Subsurface Energy & Environment, UT Austin
- Kinder Morgan