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ENERGY SERVICES

Enhanced Oil Recovery Via Biosurfactant Squeeze Applications

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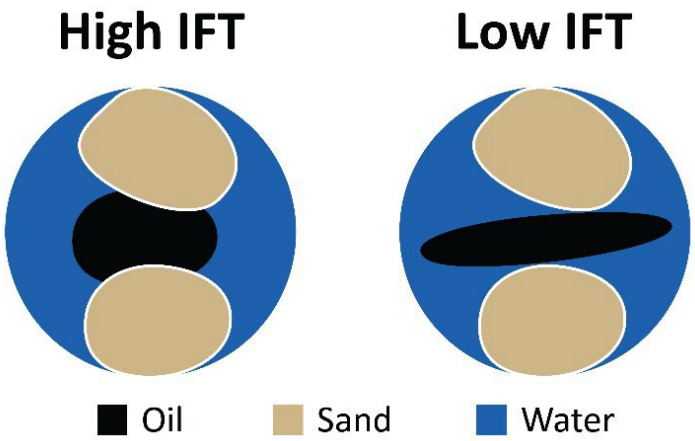
Project Summary

Goal and Activity

In 2021, Creedence Energy Services, along with technology partner Locus Bio-Energy, was awarded OGRC with a project goal to appreciably increase oil production over the expected decline curve of oil wells.

Enhanced oil recovery was expected to be achieved by:

- Reduced Interfacial Tensions (IFT) of produced fluids (increased oil mobility)
- Reduced Surface Tension (ST) of produced fluids (decreased lifting force required)
- Altered wettability of the formation mineralogy (more oil released from rock)



Absorption of Biosurfactants lowers the adhesion between Rock and Oil

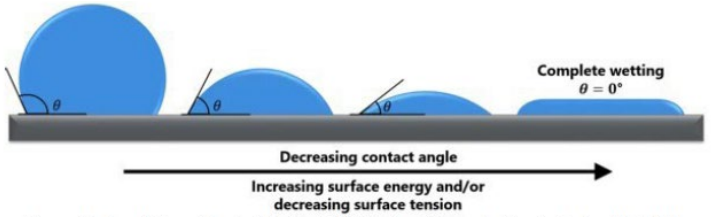


Figure 15: Correlation of Contact Angle of a Water Droplet on a Surface-to-Surface Wettability

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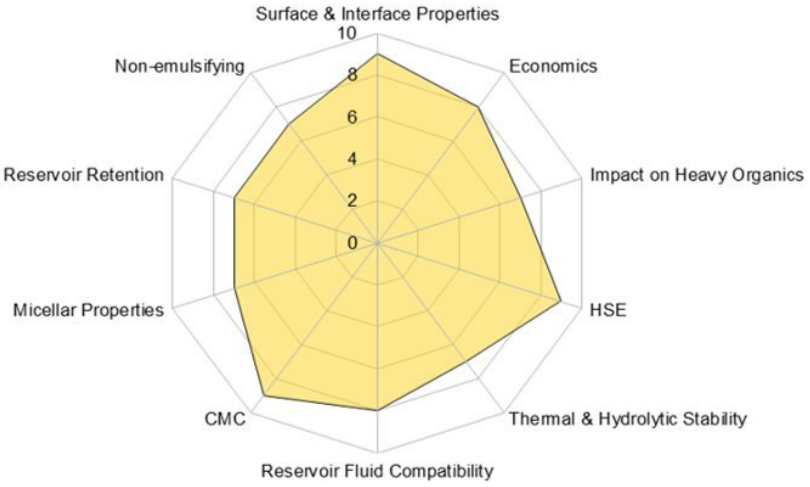
Biosurfactant Blend Development

Product Vetting and Validation

The biosurfactant is produced from the fermentation of canola oils and sugar.

Different fractions can be isolated and blended to achieve specific desired outcomes.

Biosurfactants can be coupled with additives and co-solvents for application specific requirements.



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Individual Well Analysis

KPIs and Metrics

Trial well applications were evaluated by the following metrics:

- Daily fluid production vs forecasted production
- IFT of produced oil in deionized water
- Specific gravity of produced fluids
- Surface tension of produced water
- Oil analysis and composition pre and post application

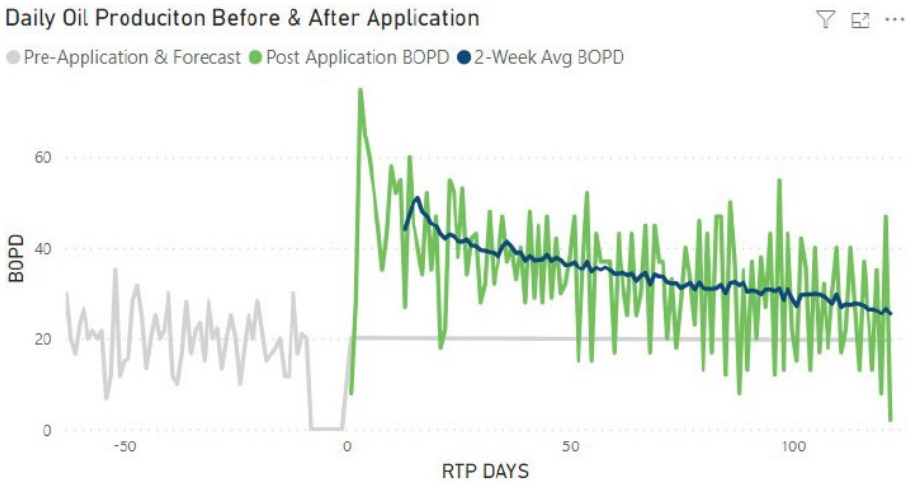

Figure 25: Frink 1-17H Daily Oil Production. Grey Line represent pre-treatment production or pre-treatment average. Green line is post-treatment daily production. Blue line is post-treatment two-week average.

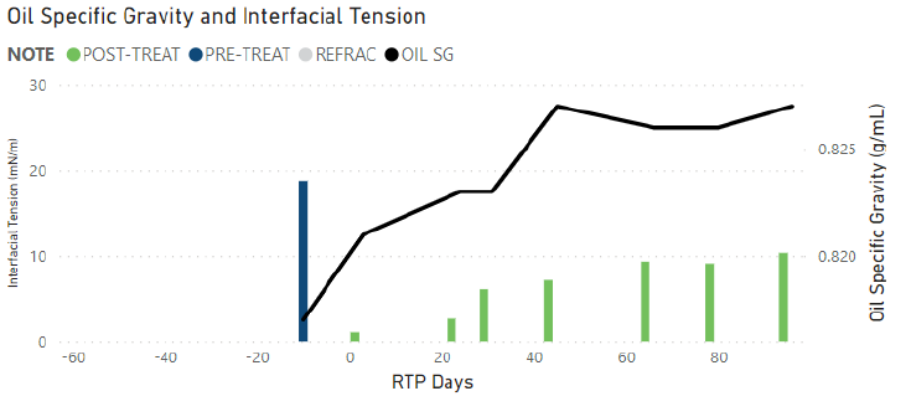

Figure 26: Frink 1-17H IFT and Oil Specific Gravity Measurements

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Application Summary

Bakken Wells

WELL NAME	DAYS ONLINE	INCREMENTAL OIL	OIL INCREASE	Initial Oil Cut	Pump Summary	IFT Response	Well Design
Sanish Well C	166	2681	104%	70%	Max Pressure 2405; 13.7 BPM; Maintained	As Expected	1-mile
Sanish Well W1	142	2351	76%	90%	Max Pressure 2480; 14.5BPM; Maintained	As Expected	1-mile
Sanish Well W	126	1727	74%	75%	Max Pressure 1500; 13.9BPM; Maintained	As Expected	1-mile 11 stages
Sanish Well F	123	1764	72%	75%	Max Pressure 1500 psi; 11.6 BPM Increased Rate	As Expected	1-mile 7 stages
Sanish Well S108	160	2064	62%	65%	Max Pressure 2282; 13.2BPM; 14.3 to 13.2 drop	Testing Underway	1-mile
Sanish Well S118	167	1952	62%	60%	Max Pressure 1320; 14.3 BPM; Maintained	Testing Underway	1-mile
Missouri Flats Well 12	147	1482	31%	11%	Low and Slow: Max 4bpm	LTE	2-mile
Sanish Well W2	75	570	25%	85%	Max Pressure 2180; 14.3 BPM; Maintained	Testing Underway	1-mile
Red Bank Well 1	204	1371	22%	23%	Low and Slow; Max 4bpm	Ultra-Low	2-mile
Missouri Flats Well 25	160	666	14%	31%	Low and Slow: Max 4bpm	LTE	2-mile
McGregor 1	199	708	11%	65%	Pressured Up	Ultra-Low	2-mile
Ross Well 28	238	20	1%	35%	Max Pressure 2200; 11.5 BPM Increased to 14 BPM	LTE	1-mile 13 stages
Epping 1	208	-741	-9%	55%	Pressured Up	Ultra-Low	2-mile
East Nesson Well 1	193	-783	-14%	65%	Pressured Up	Ultra-Low	2-mile
Sanish Well A1	69	-1828	-35%	80%	Max Pressure 700 psi	Testing Underway	2-mile

Cumulative Incremental Oil Production
14,004 bbl

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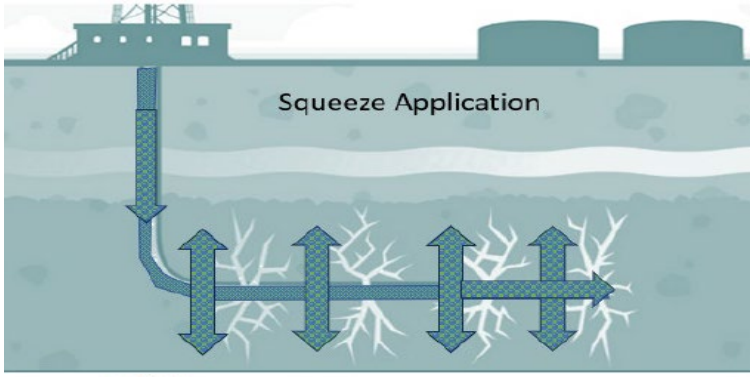
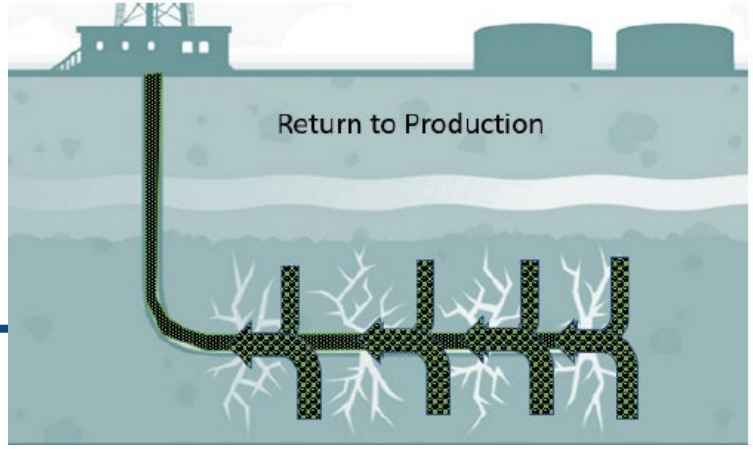
Successful Application

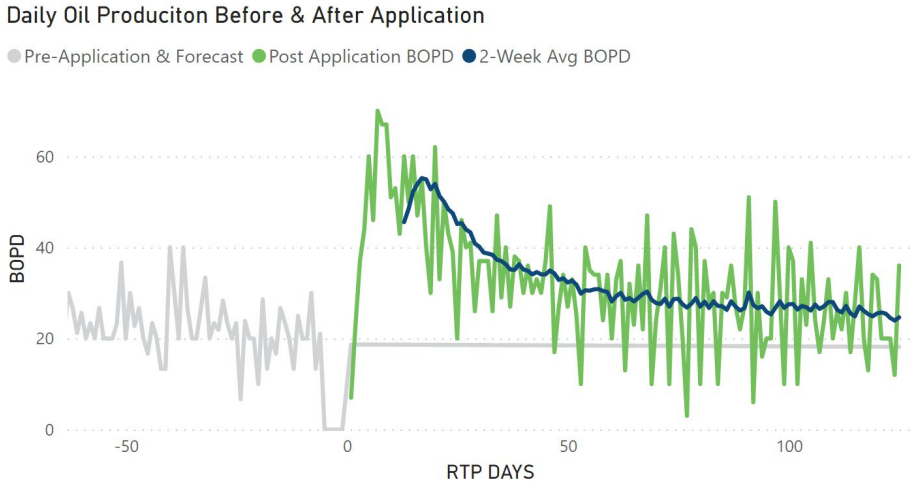
Well Response and Correlating KPIs

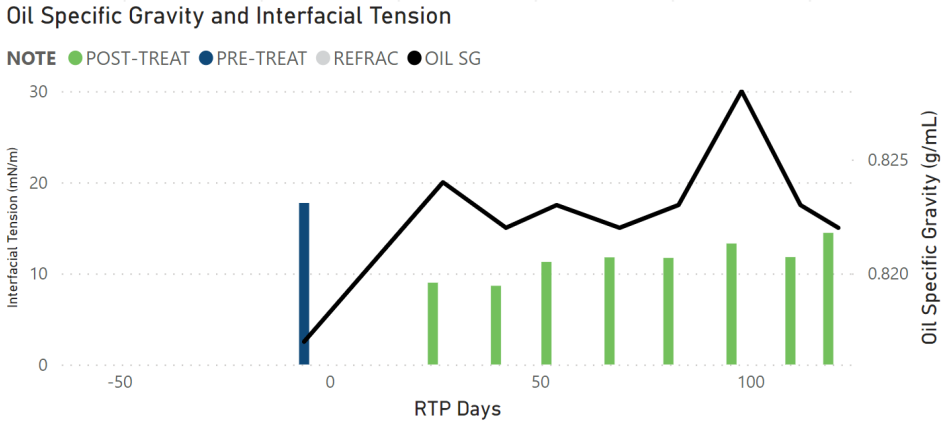
Successful Wells

- Pill has able to be delivered/pumped into currently producing zones or across the lateral
- No wellbore intrusions
- Able to maintain rate without pressure increases
- Biosurfactant depletes as expected according to IFT









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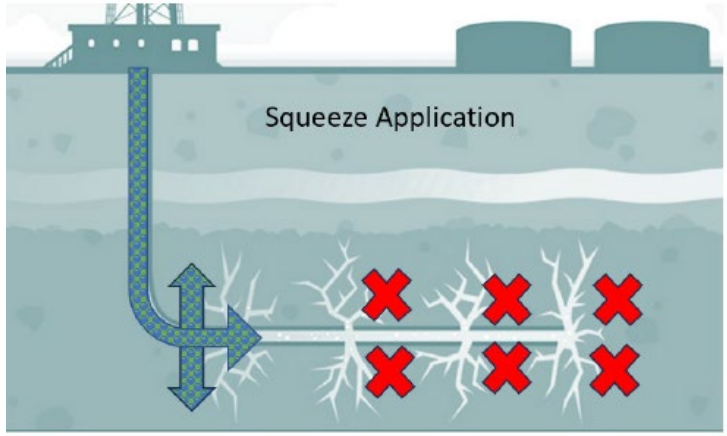
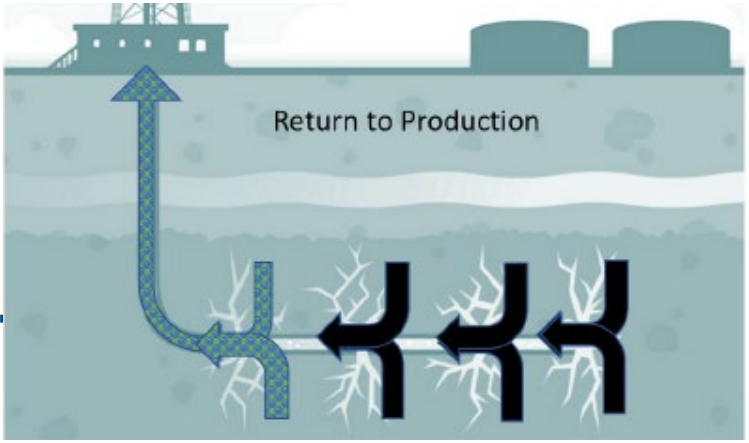
Unsuccessful Applications

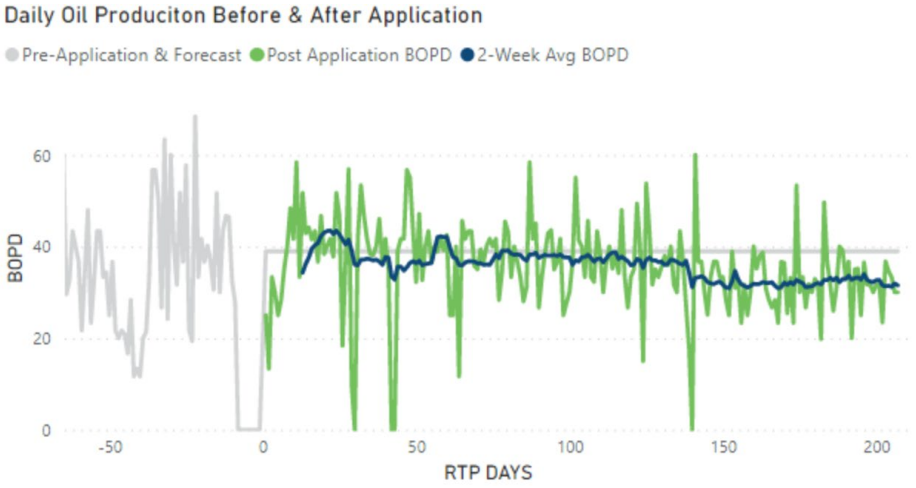
Well Response and Correlating KPIs

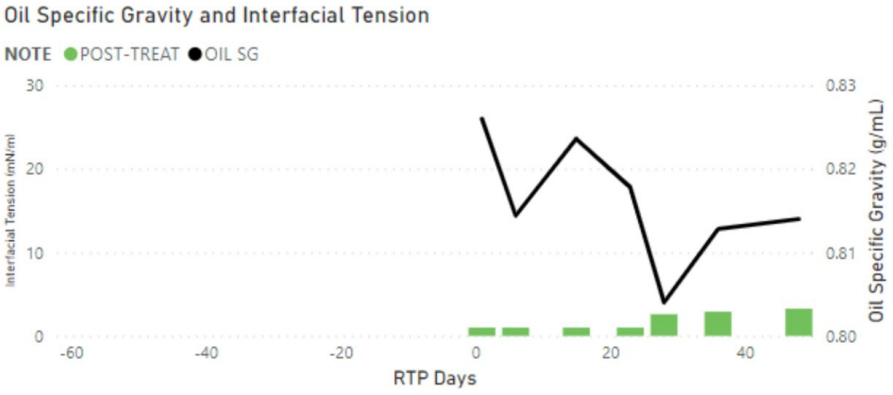
Unsuccessful Wells

- Pill was diverted into small number of zones
- Intrusion(s) prevented applications across lateral int highest producing zones
- Chemical did not reach zone of maximum production









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Lessons Learned

Conclusions

- Lab Testing, Combined Well Response, and Sample Analysis tell us that **we have successfully developed a powerful piece of the EOR puzzle in the Williston Basin**
  - And this piece fits in a lot of areas in the overall EOR picture

→Biosurfactant Chemical Uplift Activity Works When Chemistry Is Geomechanically Delivered

- Geomechanical delivery remains biggest challenge to fully realize uplift benefit

- In addition to traditional methods of uplift (IFT, ST, and wettability) biosurfactant has shown unique ability to mobilize heavier oil and affect FeS

Continuing Work

Geomechanical Delivery

- Trial applications made possible through this study tell us this chemistry works for enhanced oil recovery when it is properly delivered.

- Delivery is key

- More advanced completions (post ~2012) require a more advanced delivery mechanism than simple, low-volume bullhead squeeze. These wells need:
  - Drastically higher amounts of water
  - Isolation tools
  - Diversion techniques
- To ensure delivery to the highest pressure, most productive zones of a well

Far-Field Displacement

Permian Frac Trial

FORMATION	C-STIM 1010C	Premium Surfactant A	Premium Surfactant B
Jo Mill	Permian Well E152	Permian Well G171	Permian Well H162
Lower Spraberry	Permian Well E153	Permian Well F263	Permian Well H183
Middle Spraberry	Permian Well E151	Permian Well F161	Permian Well H181
Wolfcamp A	Permian Well E254	Permian Well G272	Permian Well H284
Wolfcamp B Lower	Permian Well E55	Permian Well F162	Permian Well H285

Production Data - First Three Month Cumulatives (in thousands)

FORMATION	GAS	OIL	WTR	GAS	OIL	WTR	GAS	OIL	WTR
Jo Mill	89	78	72	84	94	63	83	106	128
Lower Spraberry	99	72	81	51	63	78	41	45	61
Middle Spraberry	78	115	182	59	56	109	64	76	207
Wolfcamp A	90	86	133	44	61	31	103	88	79
Wolfcamp B Lower	85	89	231	54	66	121	44	59	116
TOTALS	**441**	**440**	**699**	**292**	**340**	**402**	**335**	**374**	**591**

	C-STIM 1010C			Premium Surfactant A			Premium Surfactant B		
FORMATION	GAS	OIL	WTR	GAS	OIL	WTR	GAS	OIL	WTR
Jo Mill	89	78	72	-6%	17%	-14%	-7%	26%	44%
Lower Spraberry	99	72	81	-94%	-14%	-4%	-141%	-60%	-33%
Middle Spraberry	78	115	182	-32%	-105%	-67%	-22%	-51%	12%
Wolfcamp A	90	86	133	-105%	-41%	-329%	13%	2%	-68%
Wolfcamp B Lower	85	89	231	-57%	-35%	-91%	-93%	-51%	-99%
% Difference from C-STIM 1010C				**-34%**	**-23%**	**-42%**	**-24%**	**-15%**	**-15%**

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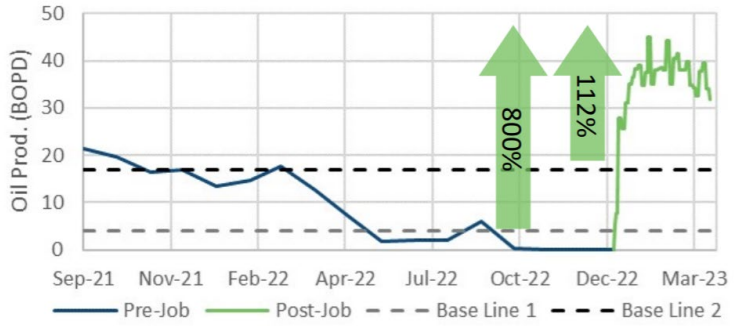
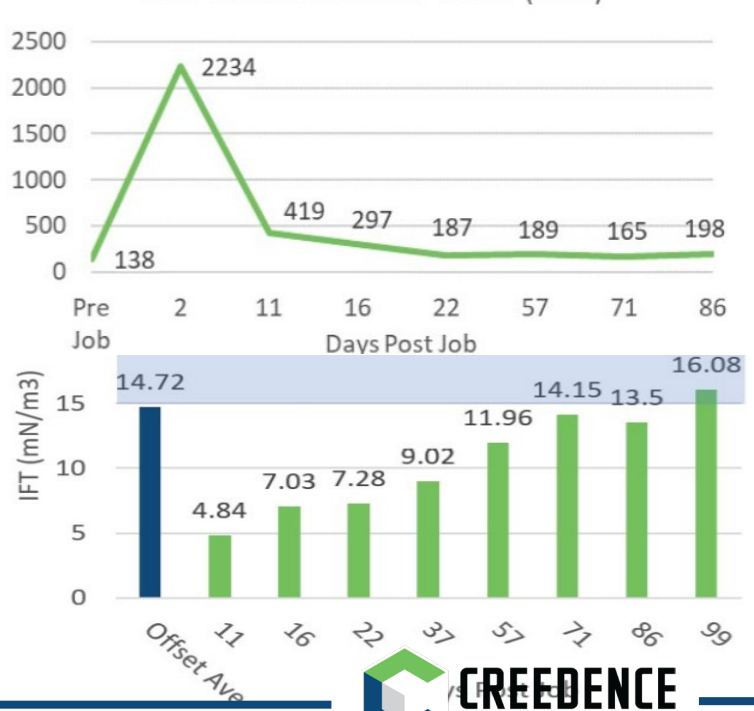
Continuing Work

Acid Stimulations Boosted with Biosurfactants

- >120 Acid Stimulations boosted by biosurfactant additives
- In addition to traditional acid stimulation remediation, this proprietary blend:
  - Increases oil mobility
  - Increases paraffin mobilization
  - Uniquely attacks less than acid soluble iron sulfide scales
- Is less sensitive to delivery challenges of standalone biosurfactant squeeze





Conclusion & Summary

EOR via Biosurfactant Application

- The OGRC's grant to trial our biosurfactant chemistry drastically accelerated development of this technology
- The OGRC and NDIC has Creedence's gratitude
- With the grant, we were able to successfully develop an important piece of the puzzle to advancing Williston Basin EOR
- We are pushing ahead with more applications and techniques to continue EOR development thanks to the baseline data developed in this study.