UNIVERSITY OF BERGEN
Faculty of Mathematics and Natural Sciences

Results from the CO_2 Foam EOR Field Pilot at the East Seminole San Andres Unit, Permian Basin

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December 9, 2021

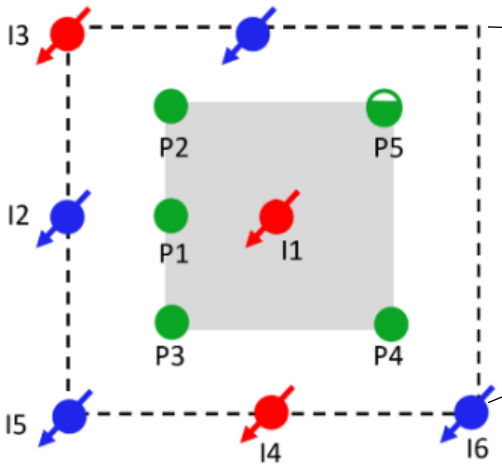
2021 CO_2 Conference
Midland, TX

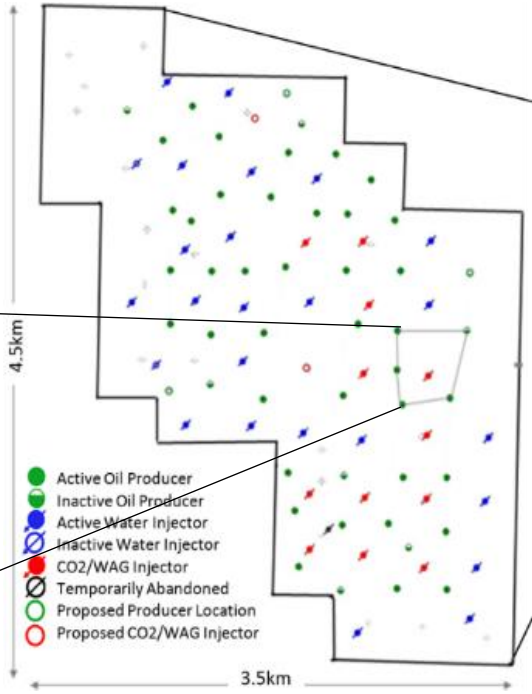
2021 CO_2 Conference
December 6-9

RICE

Contents

Pilot Pattern





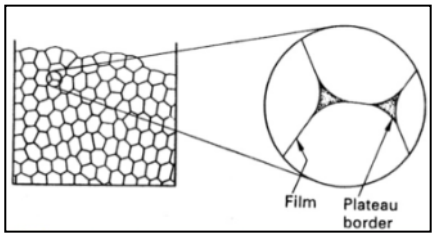
San Andres

Reservoir Characteristic	Value
Depth	5200 ft
Permeability	1 to 250 md (avg: 13 md)
Porosity	3% to 28% (average: 12%)
Pay thickness	110 ft
Reservoir pressure (initial)	2500 psig
Reservoir pressure (current)	3400 psig
Fracture pressure	3900 psig
Reservoir temperature	104°F
Oil gravity	31 °API
Formation brine salinity	70,000 ppm

Surfactant alternating gas (SAG):
10 days surfactant, 20 days CO_2
Injecting at half the historical rate

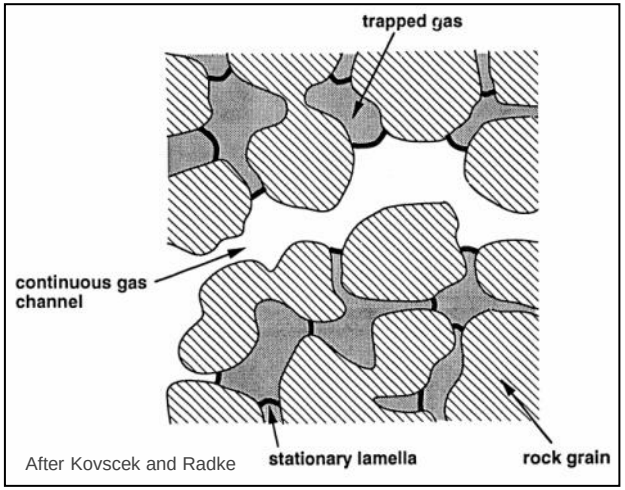
Pilot start: May 2019 — Pilot end: August 2020 — May 2021

CO_2 Foam Fundamentals



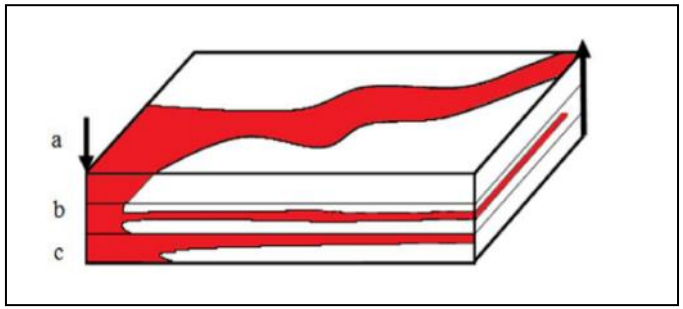
What?

Dispersion of gas in liquid
Stabilized by surfactant



How?

Decreases relative permeability
Increases viscosity
Injection strategy: SAG or co-injection



Sc-CO_2 EOR mobility challenges: a) poor aerial sweep, b) gas channeling, c) gravity override (Hanssen et al., 1994)

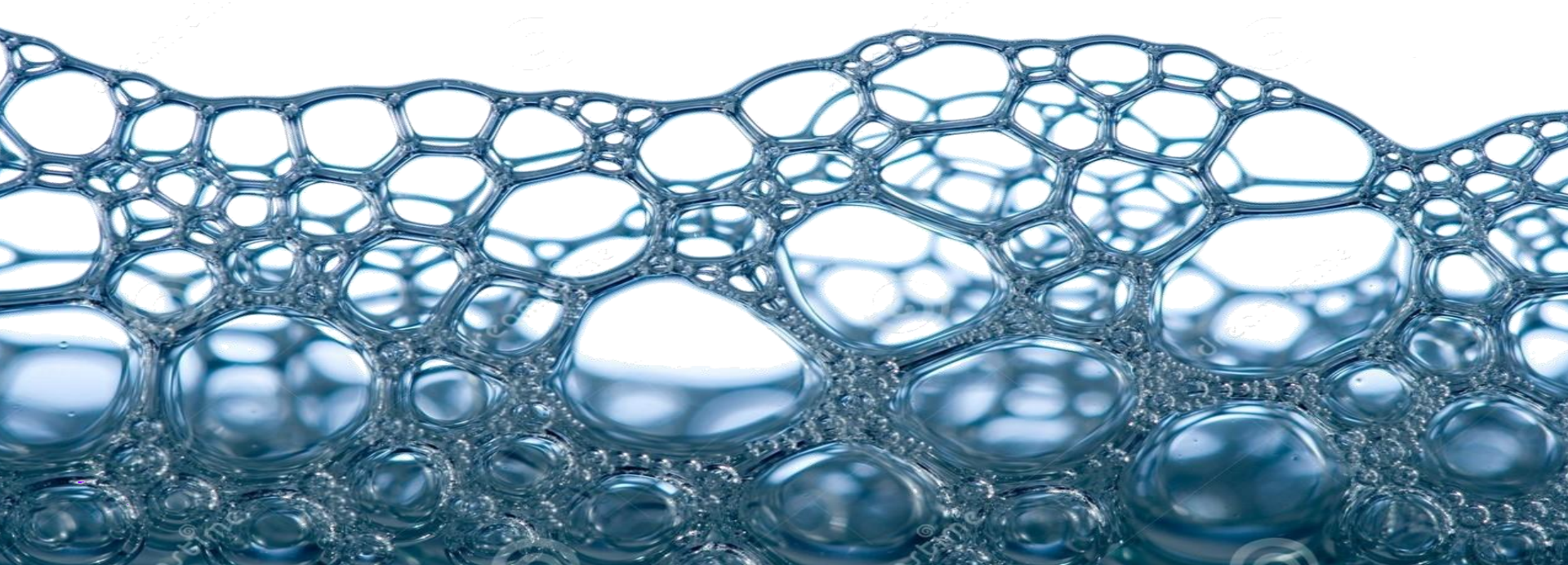
Why?

Conformance and mobility control
Improve reservoir sweep

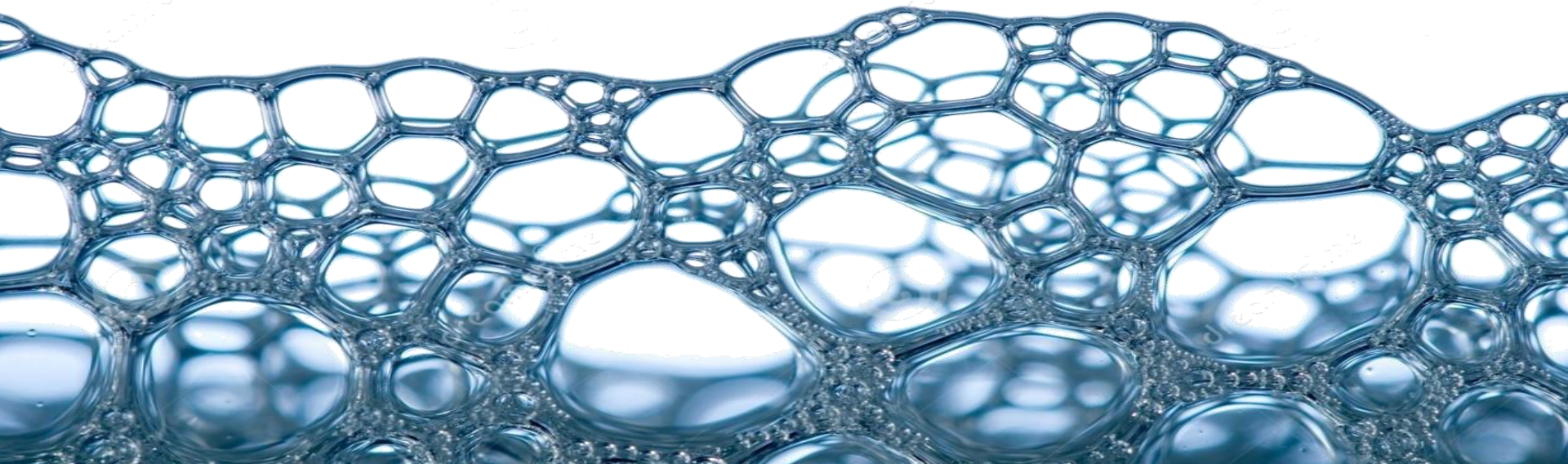
Pilot Objectives

In-depth CO_2 mobility control

Improve CO_2 sweep efficiency, oil recovery and CO_2 utilization



Foam Formulation Design



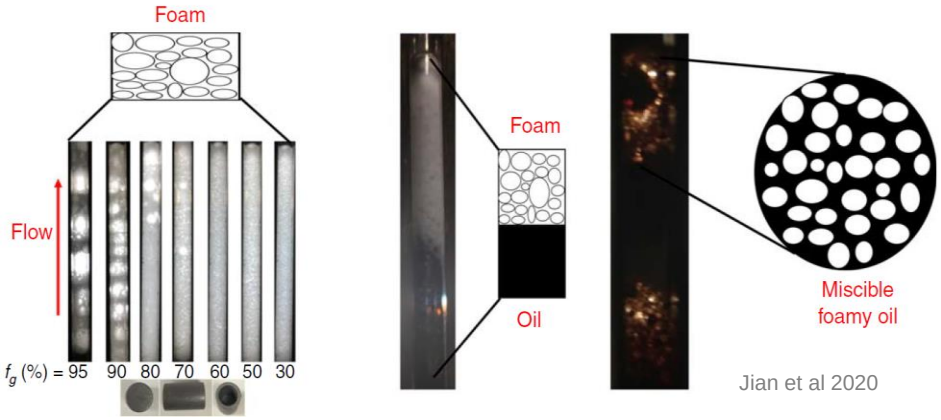
Laboratory Screening

Foam Stability:

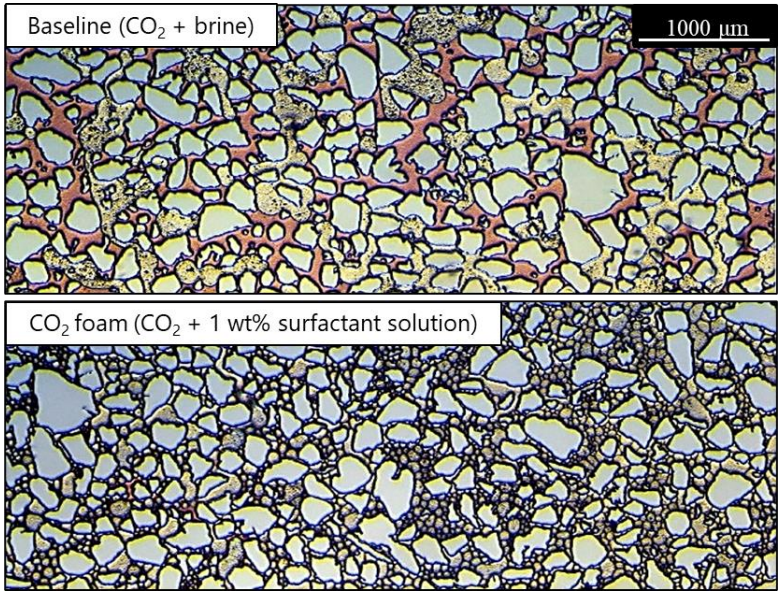
- Bulk tests, effect of oxygen scavenger, scale inhibitor, effect of crude oil

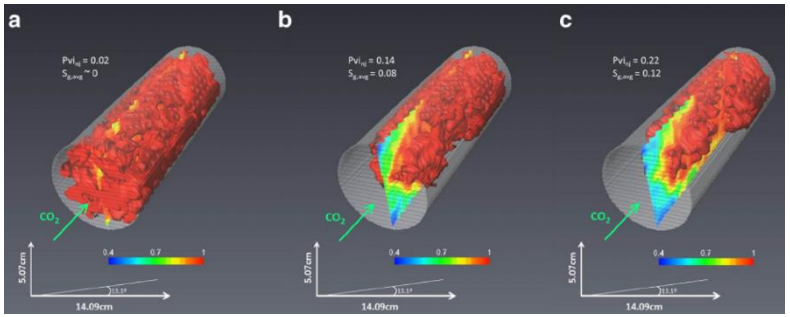
Foam Rheology (pore and core):

- Surfactant concentration, foam quality and rate, EOR and CO_2 storage potential

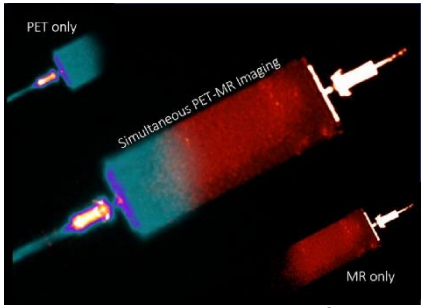


Jian et al 2020





Fernø et al 2015



Brattekås et al 2018

Foam Formulation

- Minimal adsorption

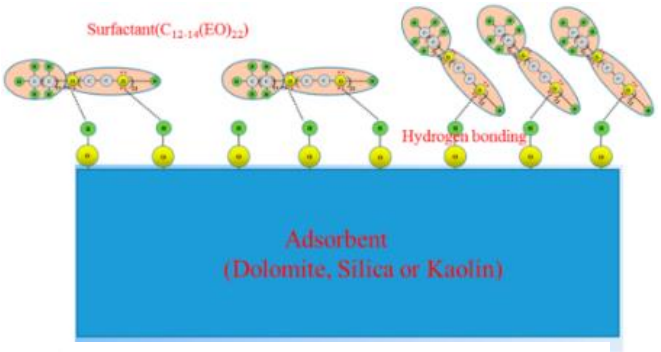
Nonionic Surfonic L24-22, a linear ethoxylated alcohol ($C_{12-14}E_{22}$)

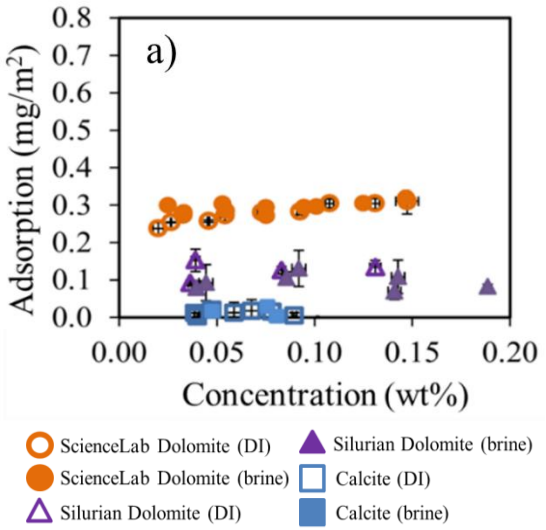
- Adequate foam strength

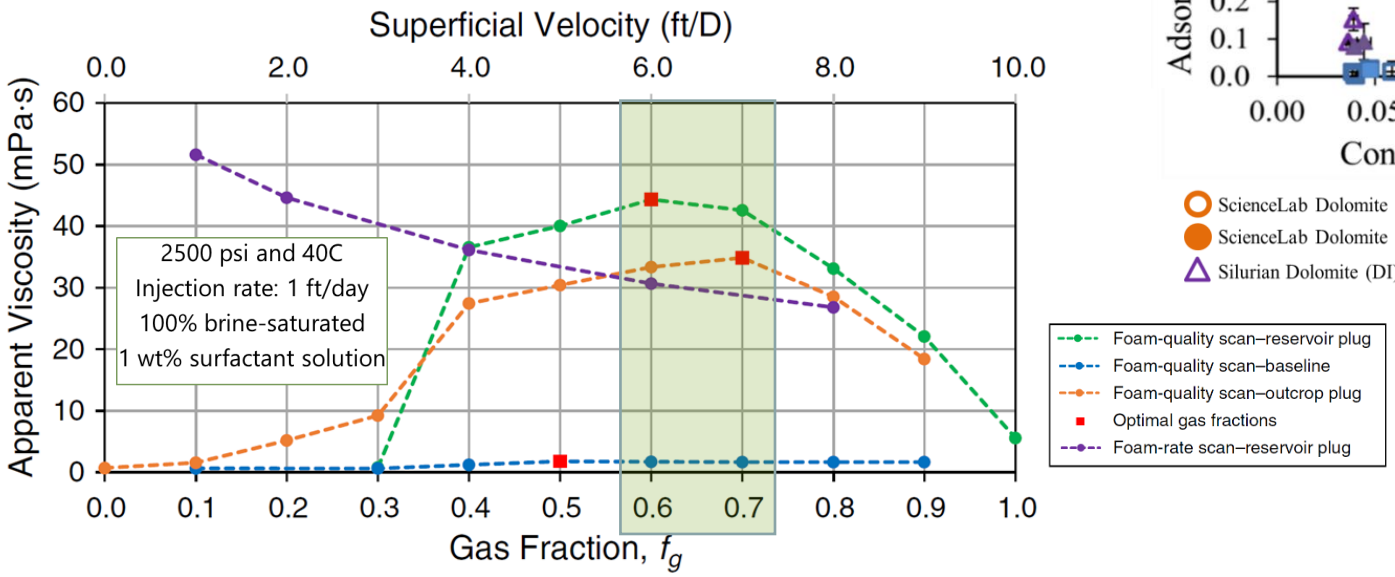
Foam quality: 60% to 70%

- Chemical stability

Surfactant concentration: 0.5 wt%

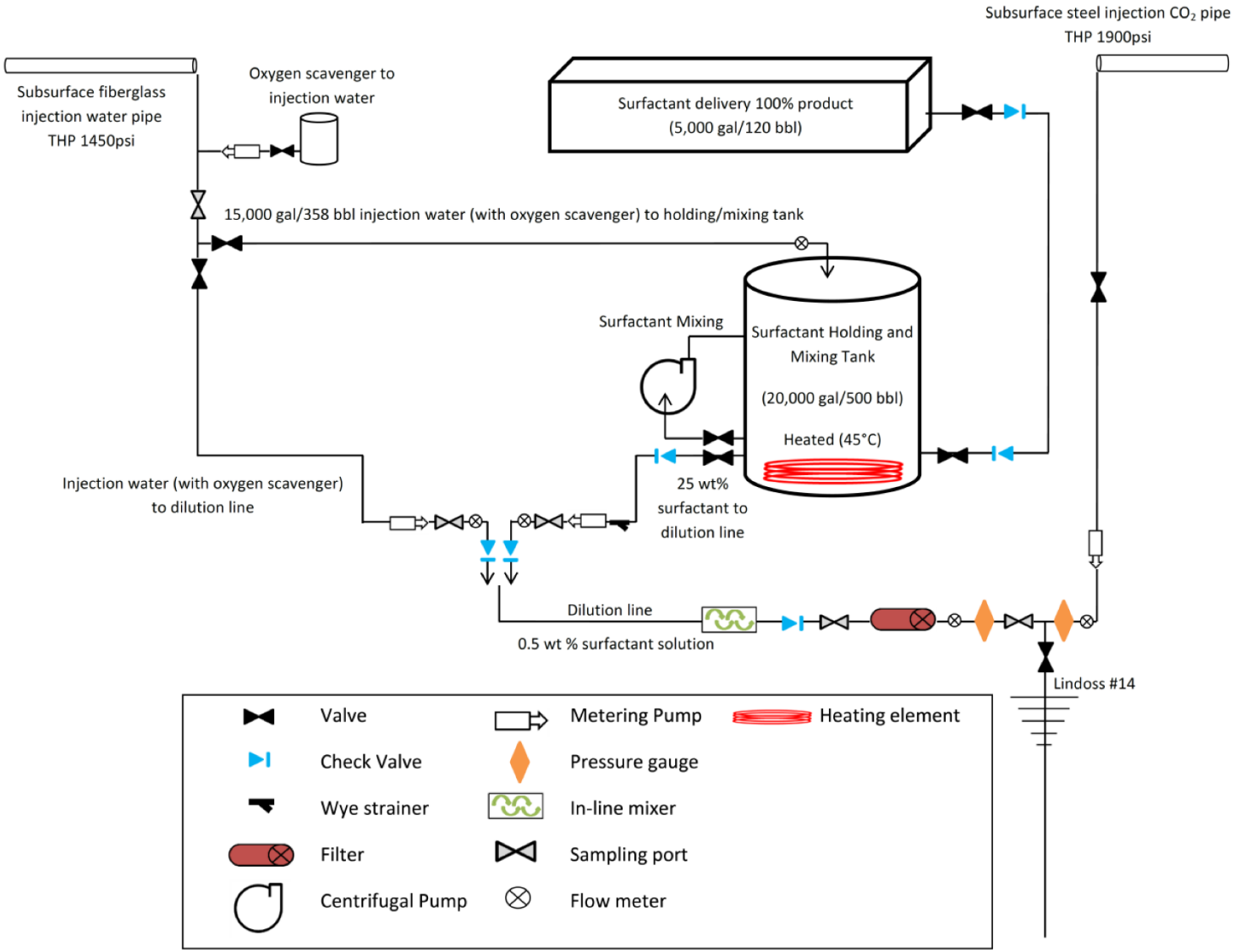




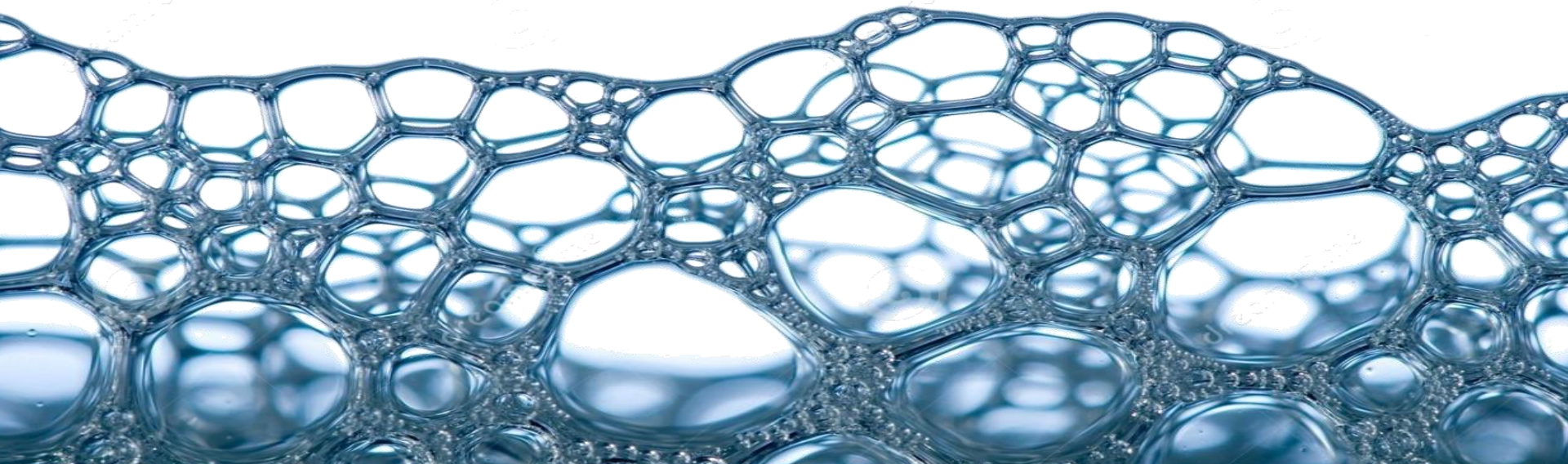


Core Identity	Length (cm)	Diameter (cm)	Pore Volume (mL)	Porosity (%)	Permeability (md)
Reservoir	5.7	5.0	15.2	13.8	22.1
Outcrop	7.5	5.0	35.3	24.2	20.5

Field Injection Unit



Data Collection and Monitoring



Data Collection and Pilot Monitoring

- Obtain baseline and monitor pilot performance to evaluate reservoir response to foam injection.

- Characterize **interwell connectivity** and CO_2 and water injectivity.

	SAG Cycle																							
	Pre		1		2		3		4		5		6		7		8		9		10		11		Post
Slug																								
IWTT		x																					x	
Injection Profiles	x	x			x	x					x	x			x	x			x	x			x	x	x
Produced water collection			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x
DHPG reading		x			x							x				x								x	x

Water CO2 Surfactant

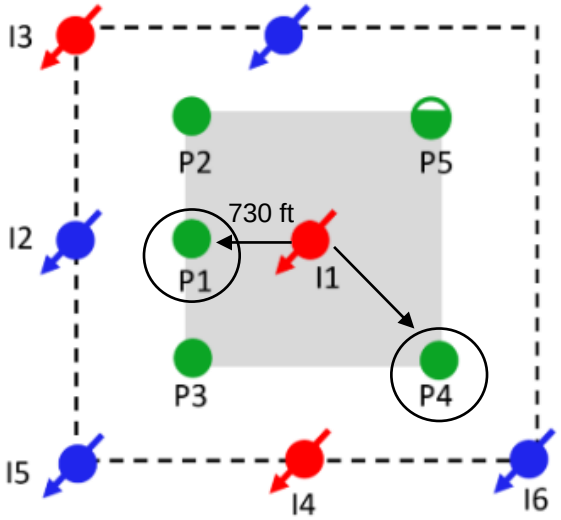
CO_2 IWTT

Objectives

- Determine baseline CO_2 breakthrough time (BT) and migration rate
- Compare it to BT time after foam injection

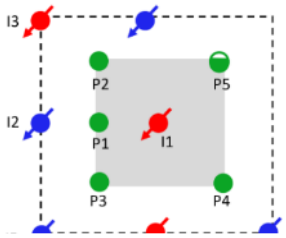
Non-radioactive gas tracer injected into I1

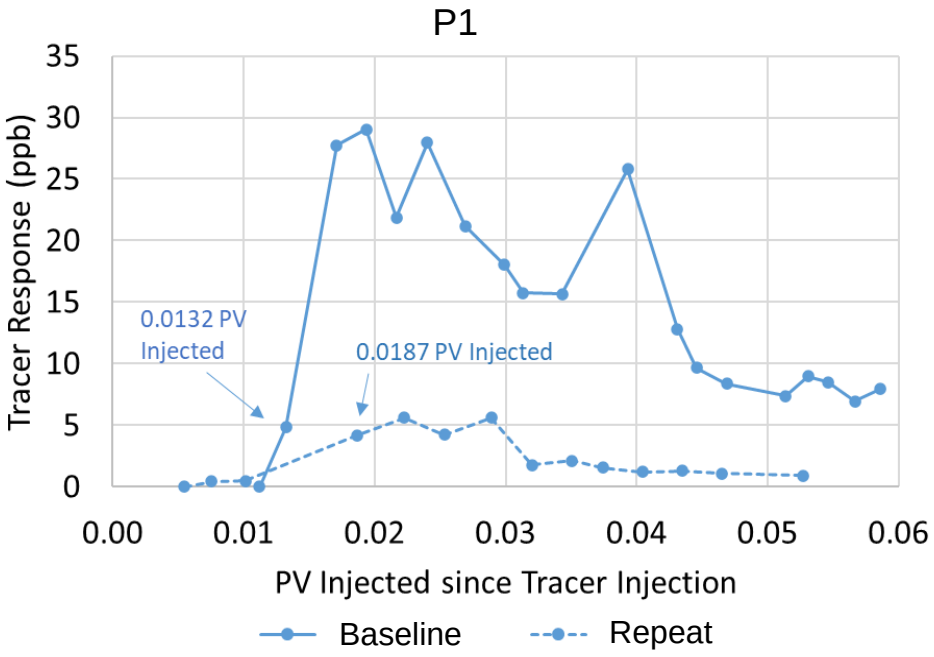
Monitored P1, P2, P3 and P4

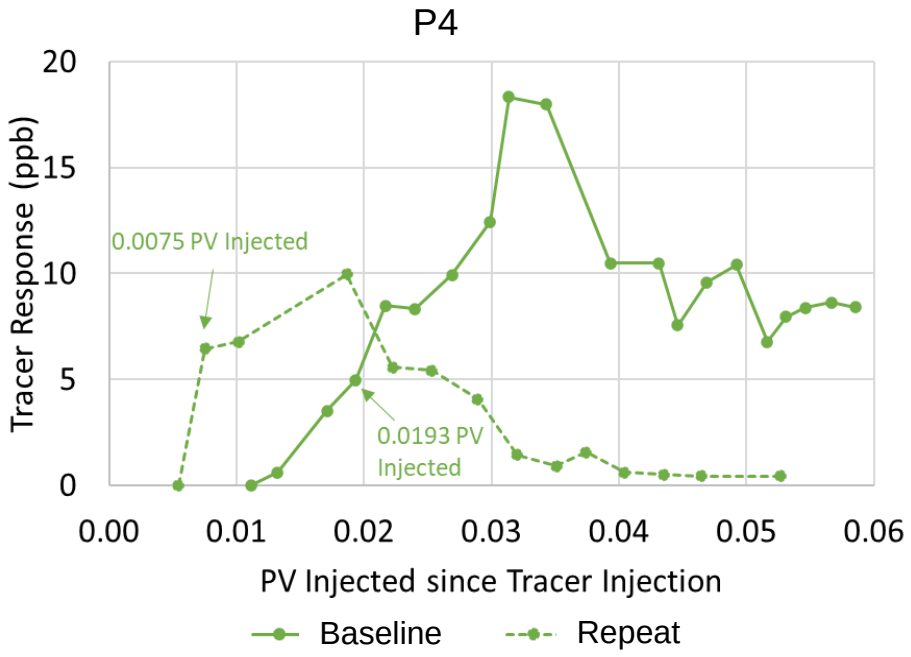


Foam was expected to increase CO_2 breakthrough time.

IWTT – Results

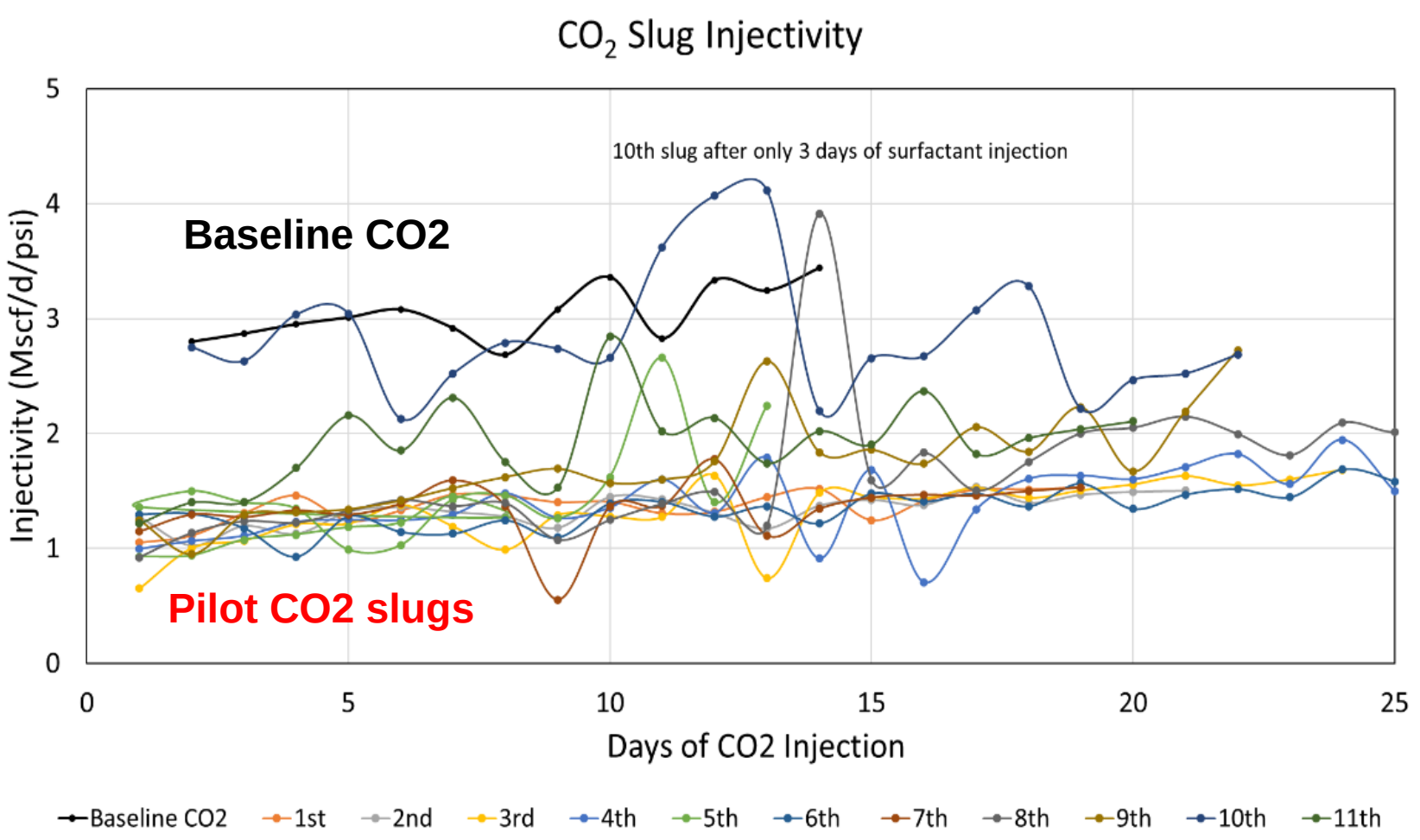




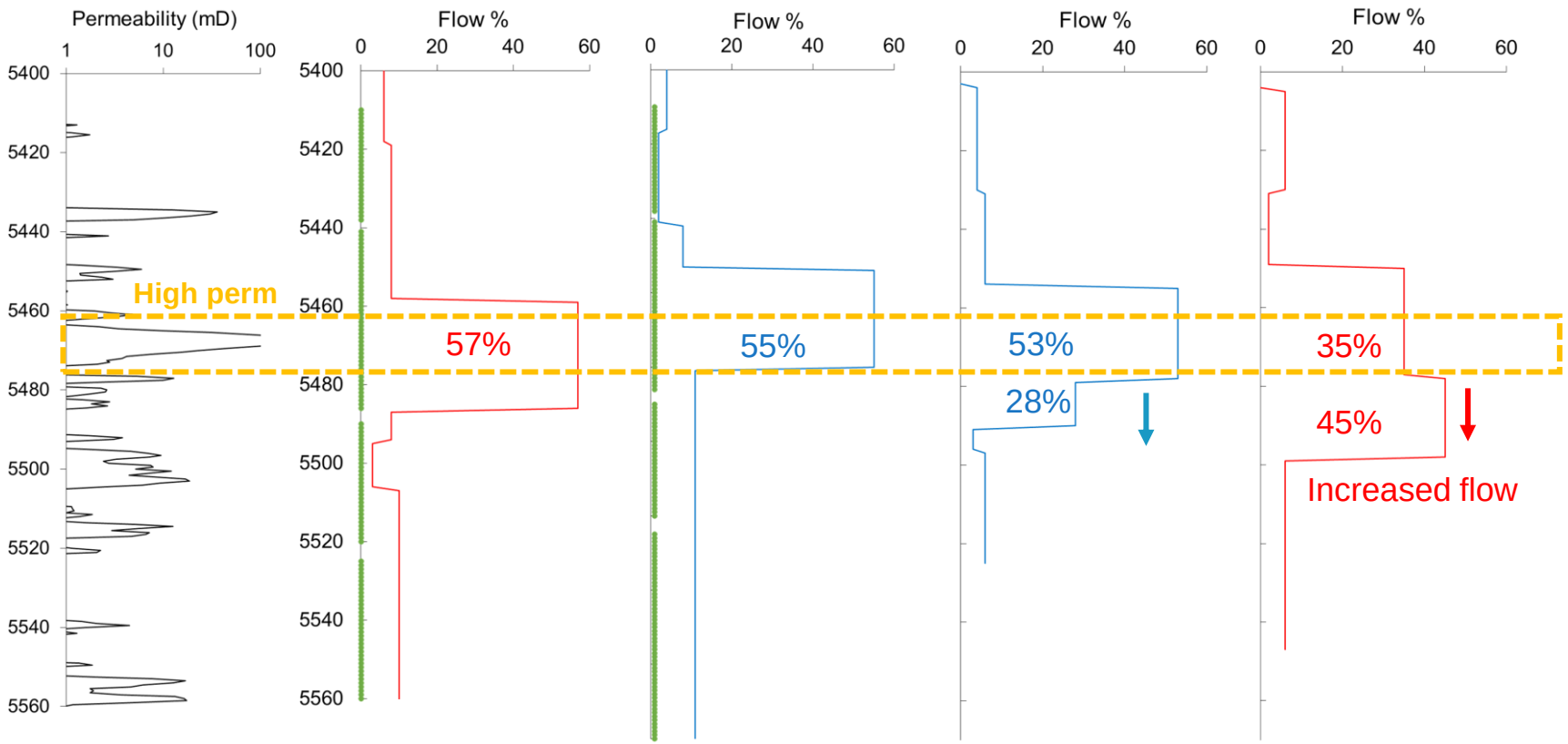


- CO_2 breakthrough from I1 to P1 delayed by 43% during the foam pilot
- Baseline tracers broke through at a higher concentration
  - Tracers during foam injection mostly went through matrix due to reduced CO_2 channeling in a high-permeability zone

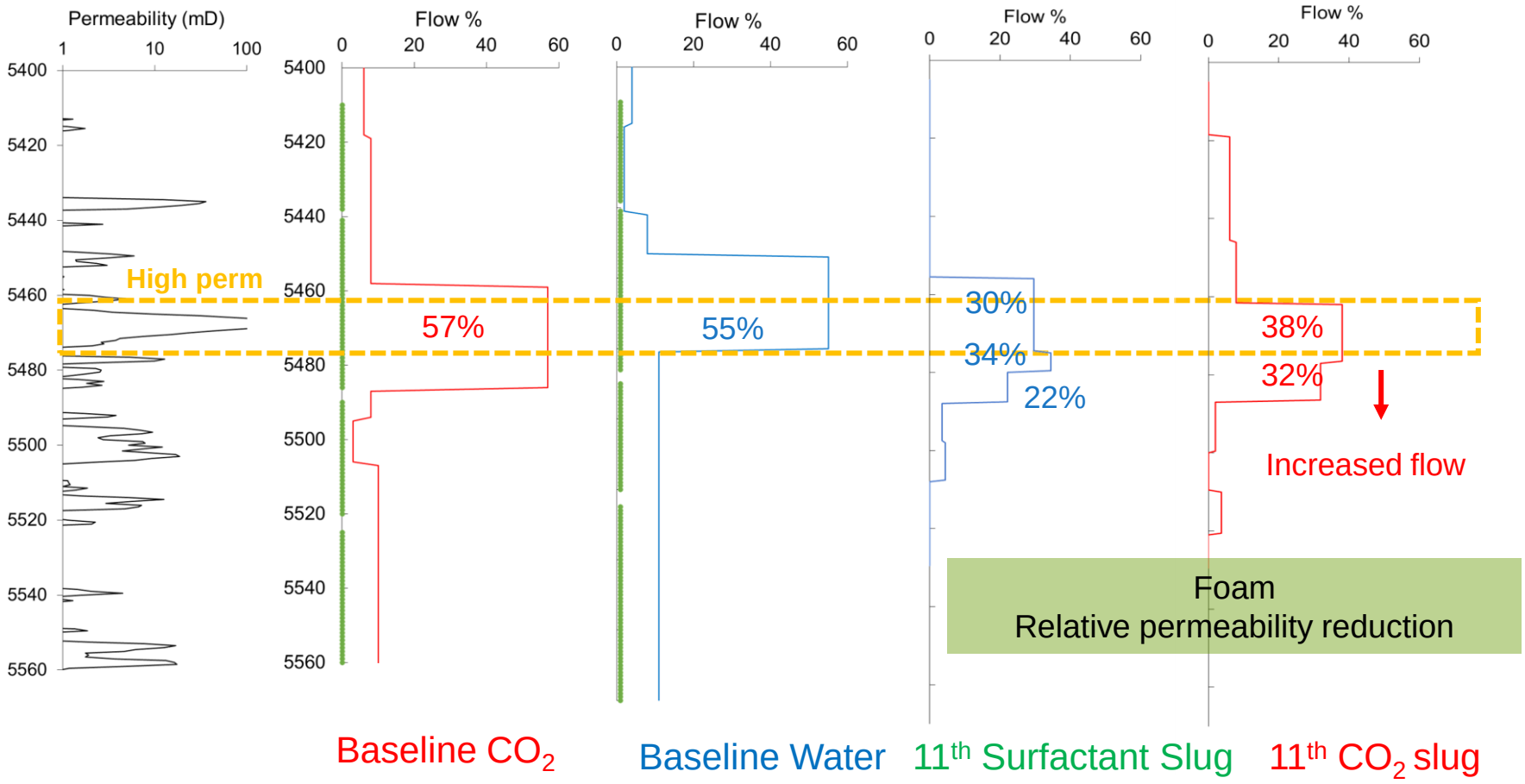
Pilot Injector: CO_2 Injectivity Index



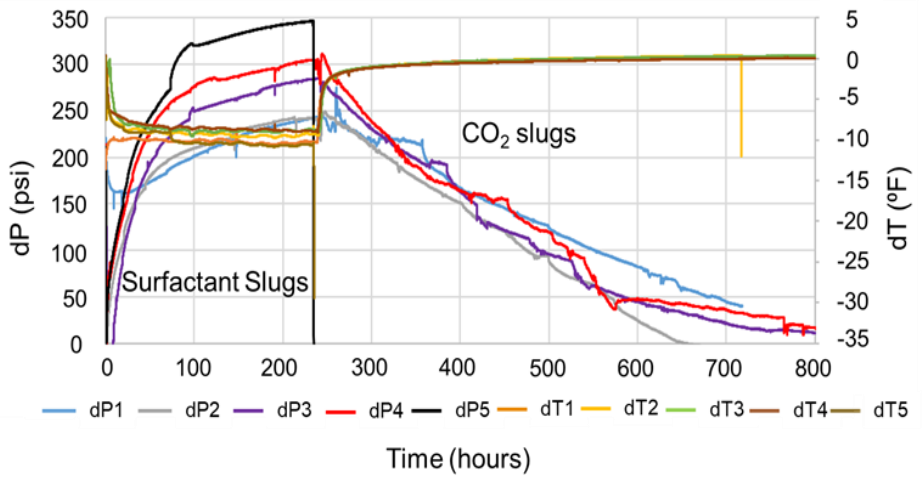
Injection Profiles – Foam Injector



Injection Profiles – Foam Injector



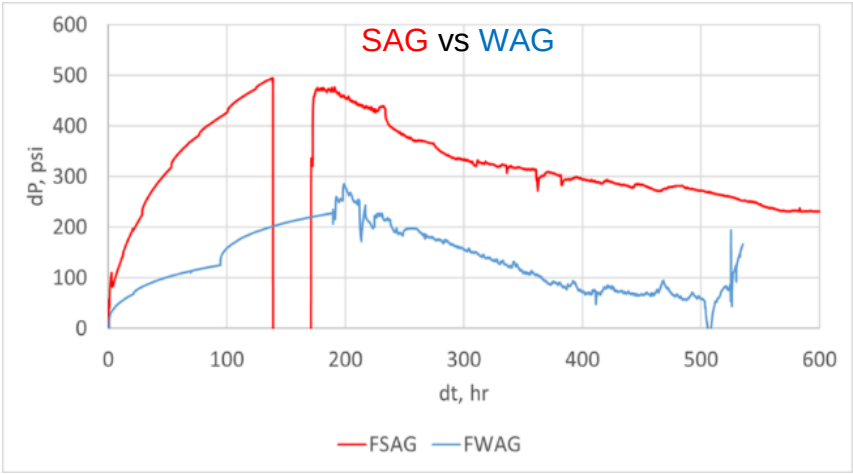
Transient Analysis



Larger dP of each consecutive cycle

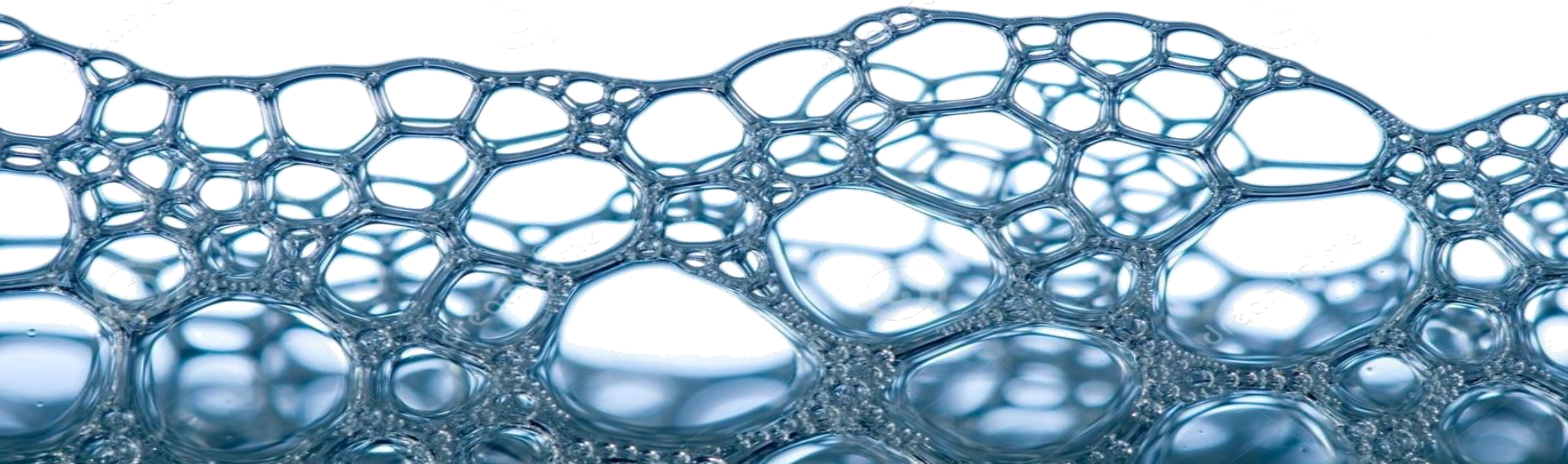
Indicating reduced mobility and a foam bank developing further into the reservoir.

Reduced mobility during the SAG compared to the WAG



Pilot start: May 2019 Pilot end: August 2020 May 2021

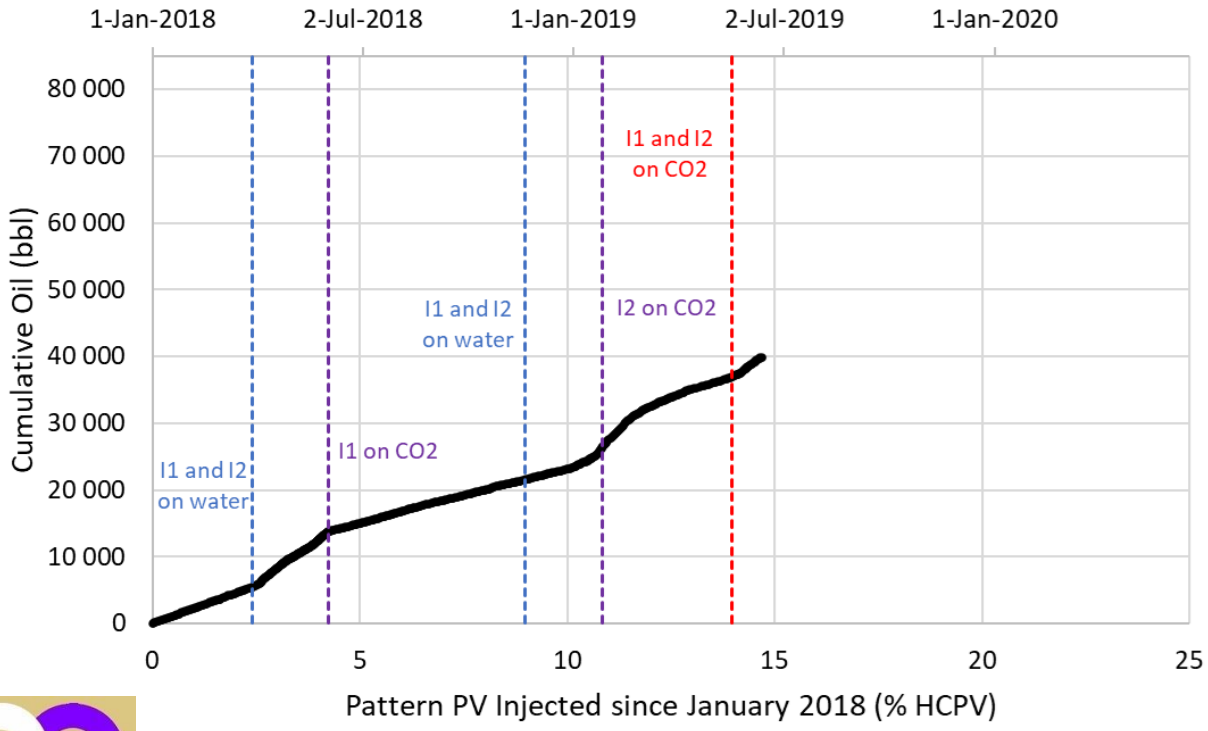
Production Analysis

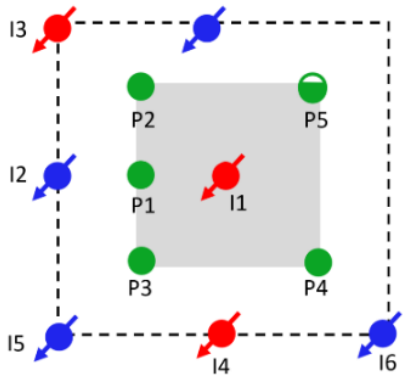


Production Analysis

- Cumulative oil recovered as a function of pore volume injected.

- Projection of the baseline performance.
  - 1.5 years prior to the start of the pilot with consistent data and minimal operational disruptions in the pattern.





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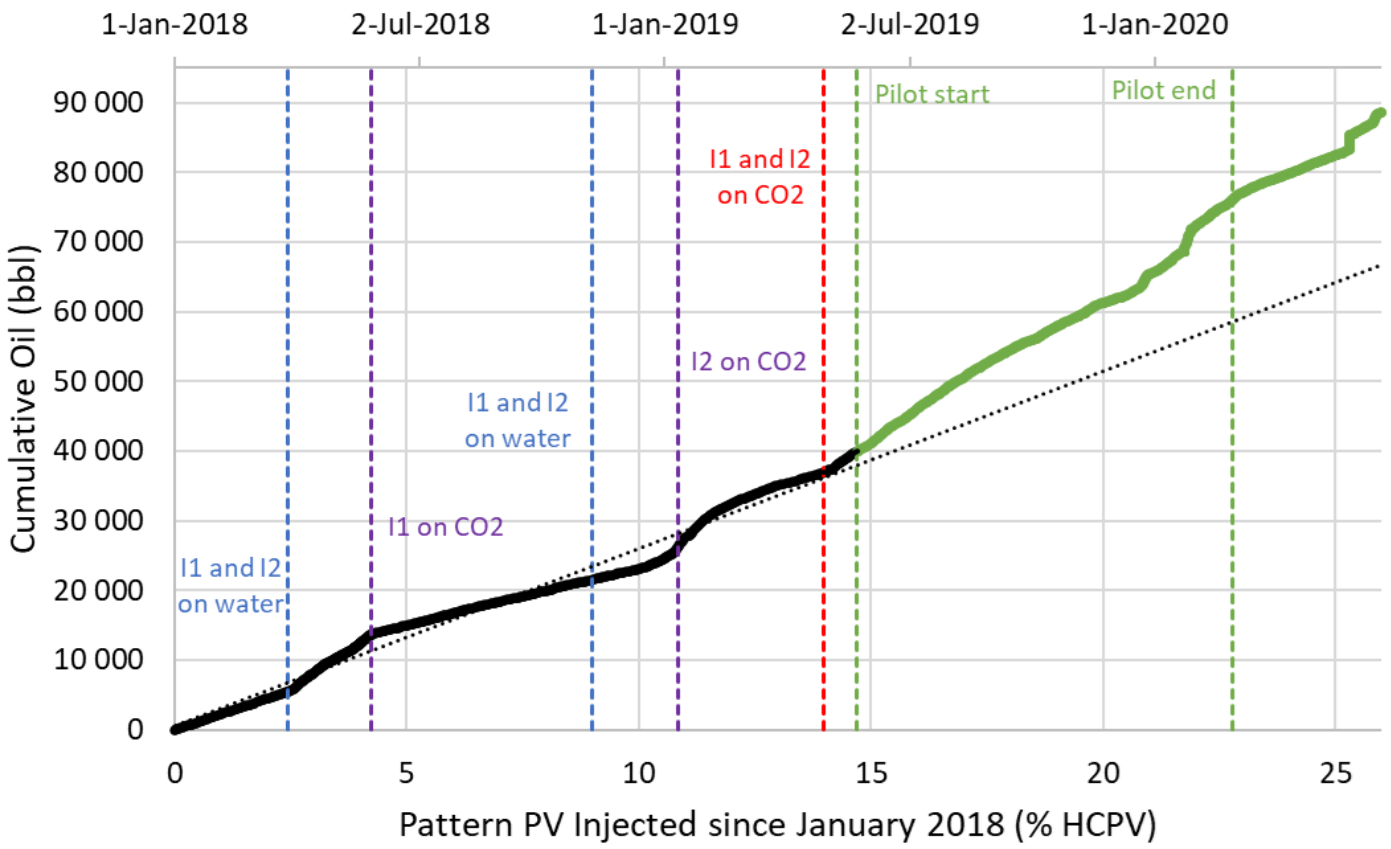
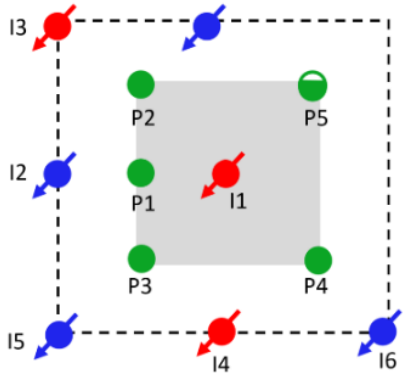
Production Analysis – Pilot Pattern

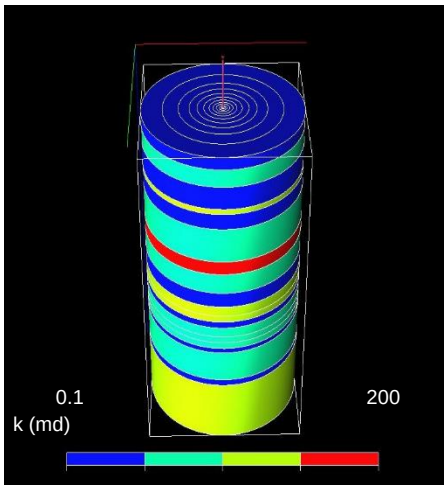


+20,000 bbls

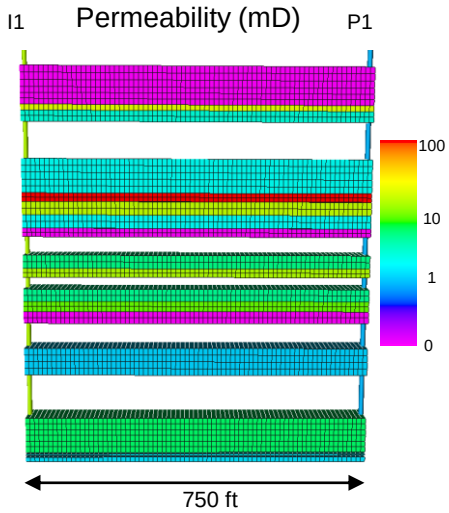


Objective-Driven Models for Pilot Interpretation

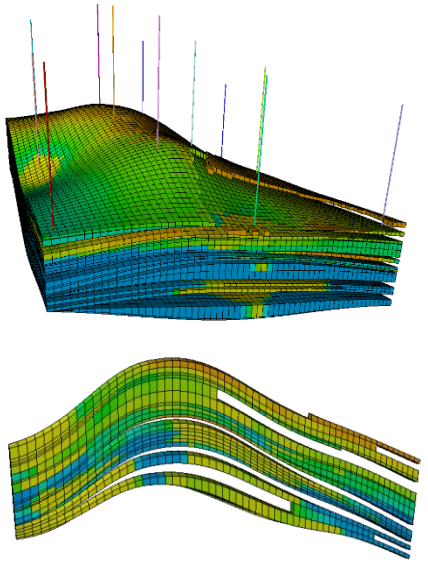
Near Injector Radial Model



Cross Section



Sector Model



Focus

Injectivity, foam generation and propagation

Interwell connectivity, fluid mobility, transmissibility

Production response

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Conclusions

Reduced CO_2 mobility

Increased CO_2 sweep

Improved oil recovery

Improved CO_2 utilization

Ongoing monitoring and analysis

Acknowledgements

The Norwegian Research Council CLIMIT and Gassnova Programs for financial support

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