

Enhancing Well Injectivity: Insights from Injection Lab Flowthrough and Coreflood Testing

European Well Performance Forum
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AGENDA

Background and Objectives

Fluid Design Importance

Flowthrough Testing

Core Flood Testing

Key Learnings and Recommendations

Background and Objectives

Challenges of Direct Matrix Water Injection

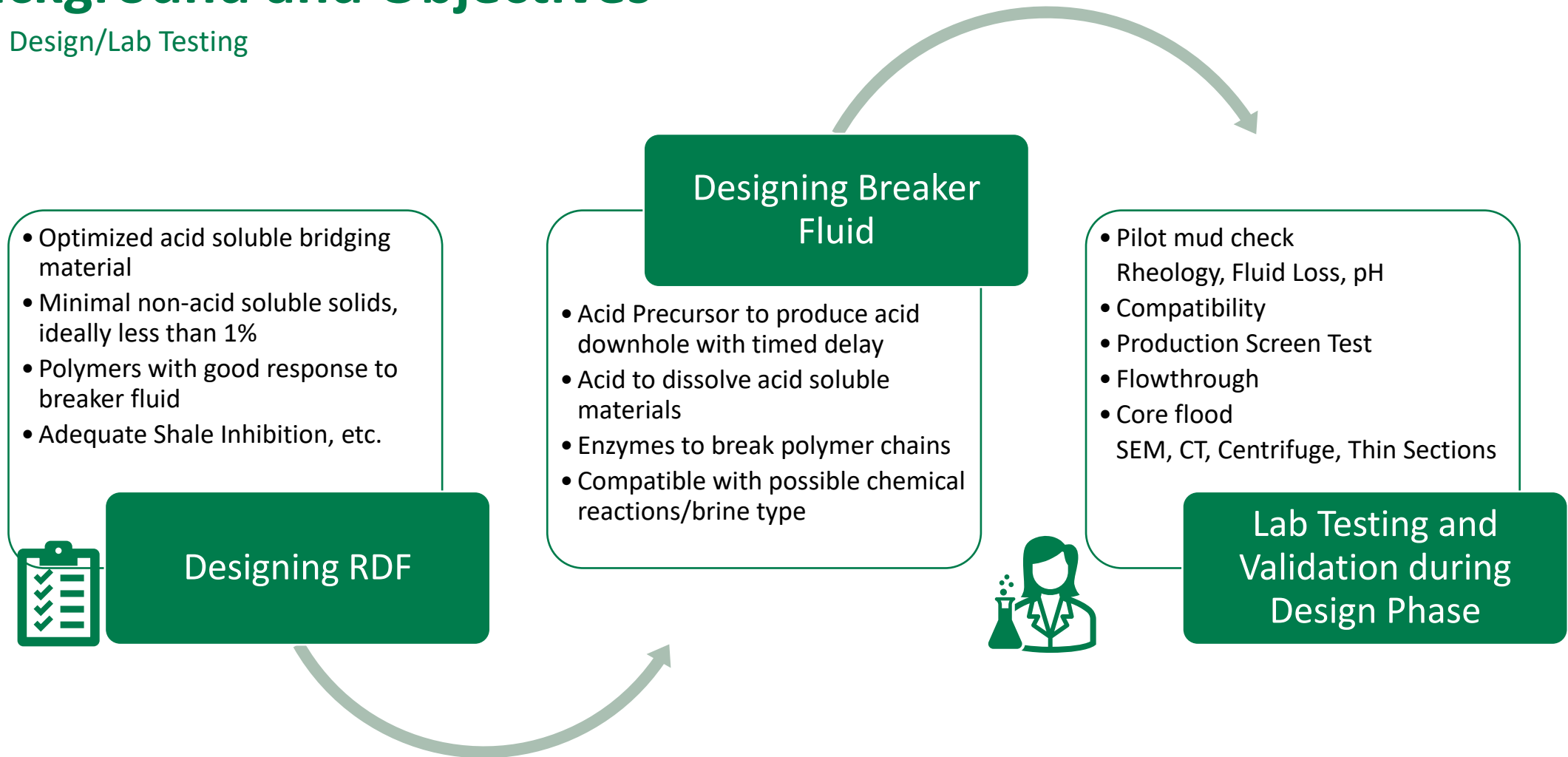


- Maintain reservoir pressure
- Improve sweep efficiency
- Mobilize trapped oil in lower permeability regions
- Enhanced oil recovery

Challenge	Impact	Mitigation
1. No flowback 2. Higher sensitivity to fines migration, clay swelling 3. Scaling and precipitation 4. Exceeding fracture pressure 5. Sensitive to damage from residual filter cake and drilled solids	1. Risk of injectivity impairment 2. Reduced injectivity 3. Plugging of pores 4. Fracturing risk	1. Careful fluid design and testing 2. High quality filtration, Fluids management 3. Scale inhibition 4. Pressure modeling, injection below fracture gradient 5. Synergistic RDF/Breaker fluid design

Background and Objectives

Fluid Design/Lab Testing



Fluids Overview

9.6 lb/gal Reservoir Drill-In Fluid

Optimized 9.6 lb/gal RDF Formulation				After 16 Hours Dynamic Aging at 167°F	
				Rheology Temperature °F	120°F
				600 rpm	52
Product	Function	Concentration	Unit of Measure	300 rpm	39
NaCl Brine	Base Fluid	25.4%	vol/vol	200 rpm	34
Water	Base Fluid	65.8%	vol/vol	100 rpm	26
MgO	Buffer	0.7	ppb	6 rpm	10
Proprietary Starch	Fluid Loss Control	7.0	ppb	3 rpm	8
Clarified Xanthan	Viscosifier	0.5	ppb	PV	13
Shale Inhibitor	Inhibit clay reactivity	7.56	ppb	YP	26
Calcium Carbonate	Bridging	30.0	ppb	10 second gel	8
Calcium Carbonate	Bridging	20.0	ppb	10 minute gel	10
Biocide	Bacteria Prevention	0.01	ppb	pH	9.60

Note* no simulated drill solids in formulation

Fluids Overview

9.7 lb/gal Breaker Fluid

Required to break down polymer, produce acid once open hole interval is filled to dissolve acid soluble solids

Optimized 9.7 lb/gal Breaker Formulation		
Product	Function	Concentration %v/v
Water	Base Fluid	59.95
12.5 lb/gal NaBr	Base Fluid	22.54
Acid Precursor	Dissolution of acid soluble materials	15.21
Buffer	Acid Precursor Buffer	1.3
Sodium Bicarbonate	pH Buffer	0.2 ppb as needed
Starch Enzyme	Starch breakdown	0.5
Xanthan enzyme	Xanthan breakdown	0.5

Flowthrough Test Procedure

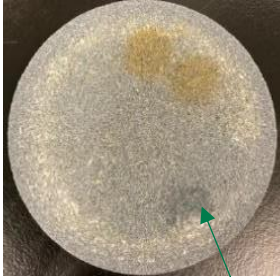
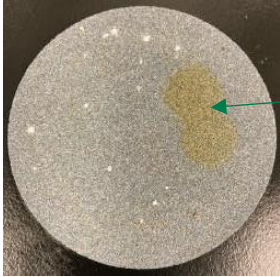
Injection Direction

Procedure

- Use 175 ml modified HTHP cell or 500 ml PPA test
- Flow 200 ml synthetic sea water through the disc at 5 PSI
- Record average time once rate stabilizes (T1)
- Build the filter cake with RDF
- Perform breaker treatment on filter cake after the required period of soak time at selected temp.
- Flow again 200 ml synthetic seawater through the disc at 5 PSI after filter cake treatment and record avg. time (T2)
- Return to Flow% = $(T1/T2) * 100$



Lab Flowthrough Test Results from WB RDIF Direct Injector

Breaker	9.7 ppg Breaker Formulation 1 Lab Results	9.7 ppg Breaker Formulation 2 Lab Results
Temperature, °C	75	75
Breaker Density, s.g.	1.16	1.16
Initial pH	6.5	7.02
Breakthrough time, min	125	165
Post Soak pH	3.3	3.52
Return to Flow Results (%)		
Injection	96.57%	98.23%
Photos		

Iodine drop indicates
no starch presence

HCl drop indicates
minimal CaCO_3 presence

Lab Flowthrough with SB RDIF Injector

OBM Injectors are Challenging

- Flowthrough test fluid varies- industry has not reached consensus (base oil vs water for flow fluids)
- Wettability changes pose difficulty for representation of actual downhole conditions
- Residual materials remaining can create severe potential for decreased injectivity
- Comparison of disc permeability shows distinct difference in results, in line with expectations in injection testing

Optimized 12.1 lb/gal Breaker Formulation	
Product	Function
CaCl ₂ /CaBr ₂ Brine	Base Fluid
Water	Base Fluid
Acid Precursor	Dissolution of acid soluble materials
Micro-Emulsifying Surfactant	Emulsion Breaker

	12.1 ppg SB RDIF 20 µm (New) Disc	12.1 ppg SB RDIF 40 µm (New) Disc
Temperature, °C	101°C (214°F)	101°C (214°F)
Breaker Density, s.g.	1.45 (12.1 ppg)	1.45 (12.1 ppg)
Initial pH	3.6	3.15
Soak Time (days)	6	6
Post Soak pH	2.58	2.28
Return to Flow Results (%)		
Injection	74.82%	90.00%
Photos		

Flowthrough Testing Variations/Concerns

Gravel Pack/ SRF/ Screen Testing

Gravel pack and screen testing are possible – results are consistent with production testing but can vary with injection using gravel or proppant pack



HCl drop
showed no
carbonate

Iodine drop
shows no
starch



Importance of maintaining <1% Drill Solids



Fig. 2—Assessment of Drill Solids (AIS) Impact on Injectivity

Storli et.al 2024. SPE-217865-MS.

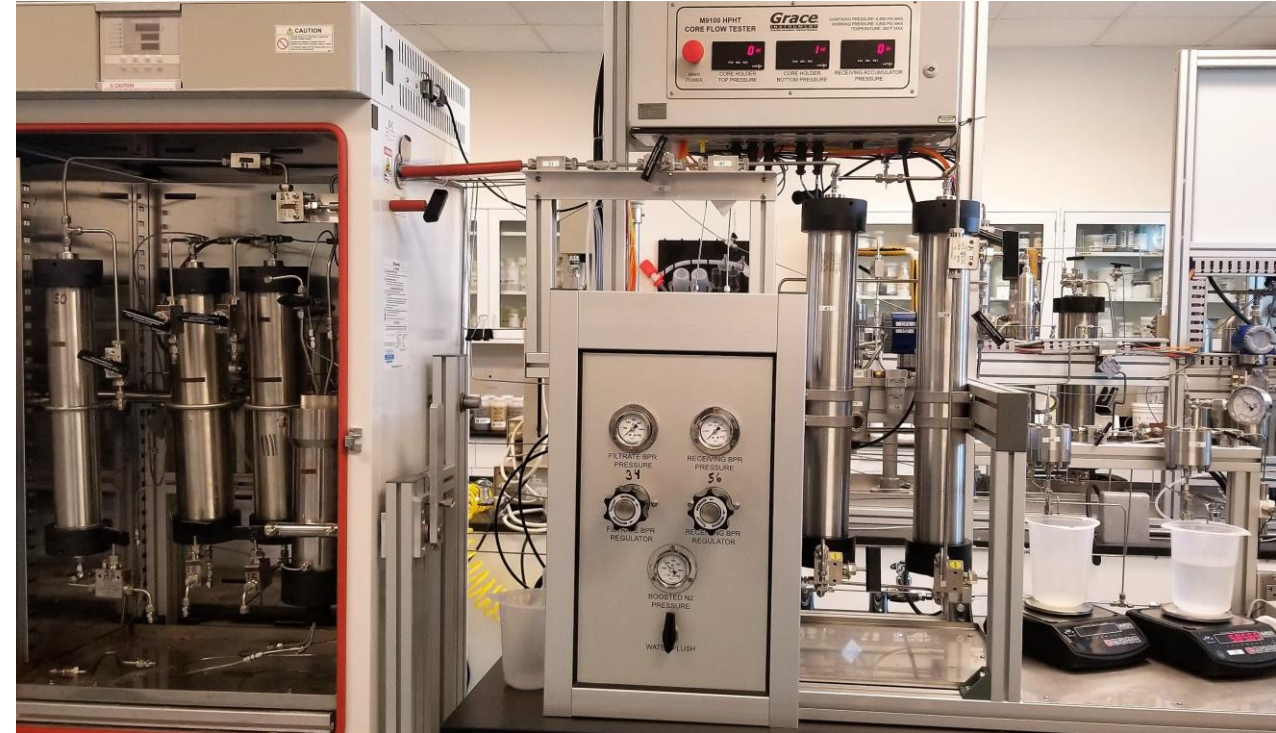
Topics of Concern During Flowthrough Testing:

- Displacing fluids create variabilities
 - Decanting fluid leaves residual materials behind
 - “Fluff” layer can “skew” breaker performance
- Disc at the top of cell vs disc at the bottom of cell vs lateral disc
- Various methods/pressures for capturing initial/final flow
- Any other concerns with testing from our audience?

CoreFlood Test Procedure

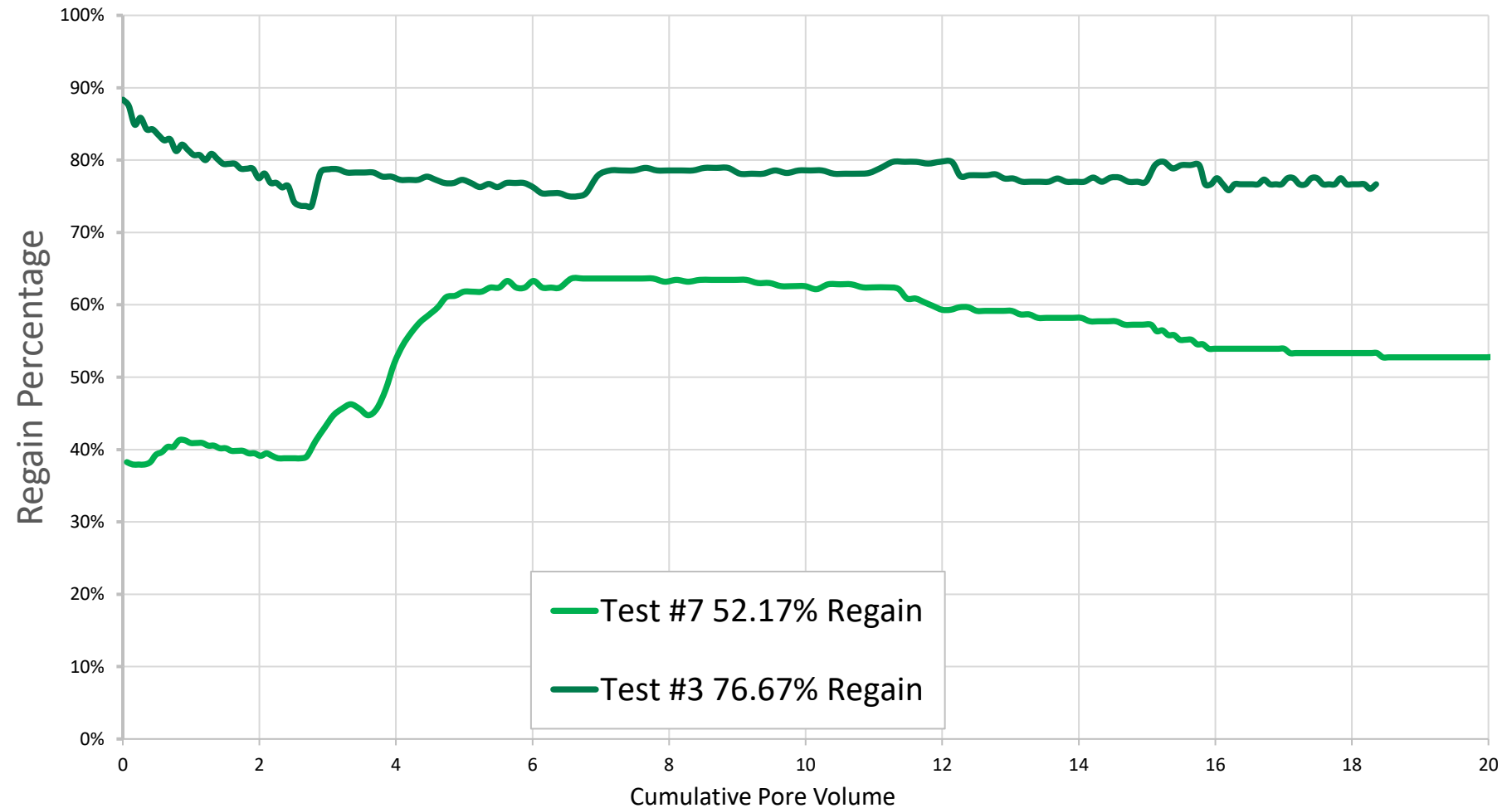
Procedure

- Core plugs selected from field-representative lithologies
- Core prepped, perm/porosity measured, saturated/desaturated
- Core is mounted in core holder with confining pressure and temperature to simulate downhole stress conditions
- Brine injected at multiple flow rates to determine initial permeability calculated using Darcy's Law
- RDF is flowed across the core face at set pressure to simulate dynamic invasion and filtercake deposition
- Filtration time and volume are tracked
- Core removed, spacer rings added for breaker volume
- Breaker flowed dynamically at low flow then allowed to soak statically
- Brine injected at multiple flow rates to determine return permeability calculated using Darcy's Law
- Regain permeability is calculated to quantify % return
- Cores are examined (SEM, CT, centrifuge, thin sections)

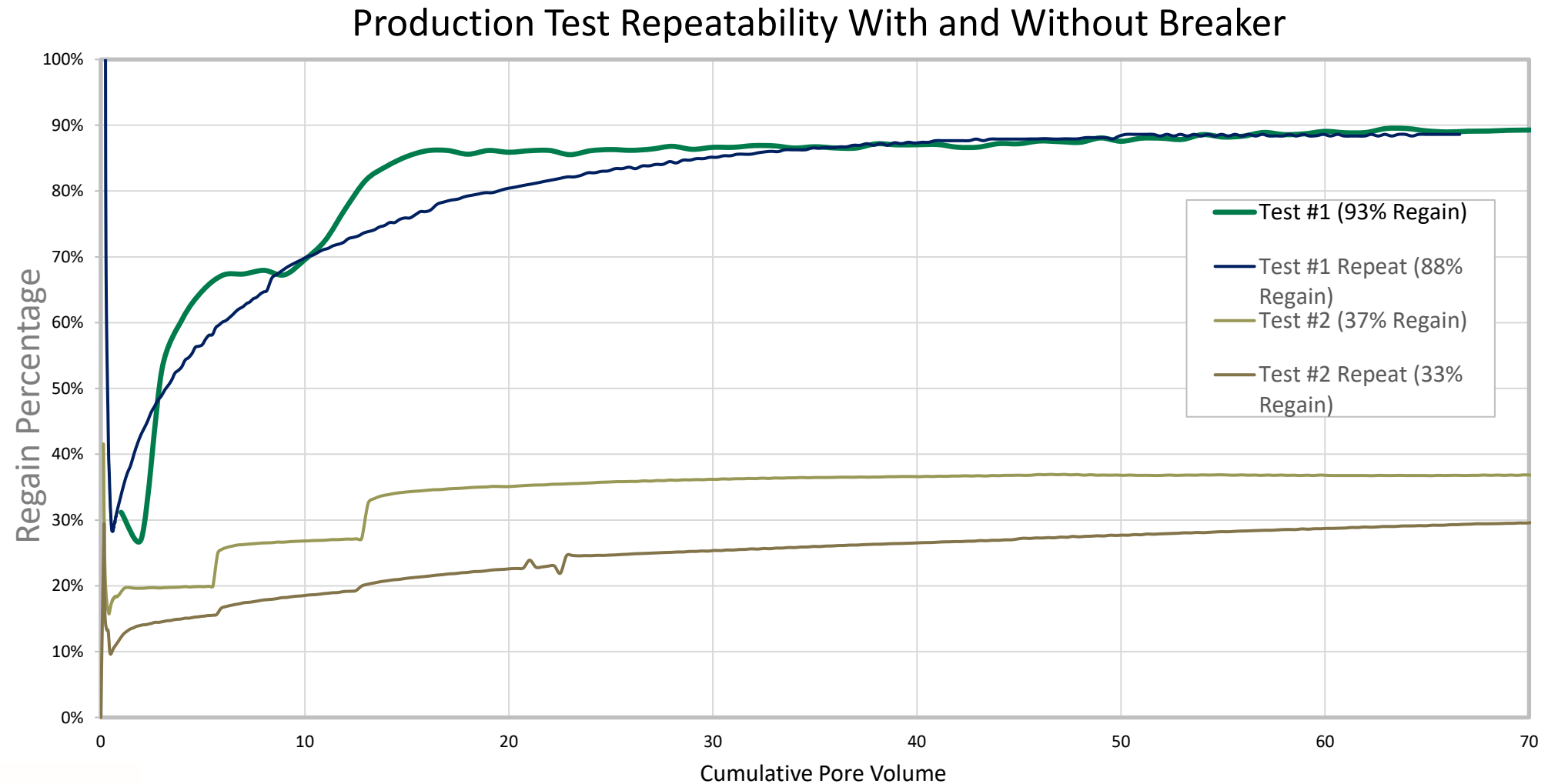


Coreflood Injection Test Results

2 Direct Injection Coreflood Comparisons



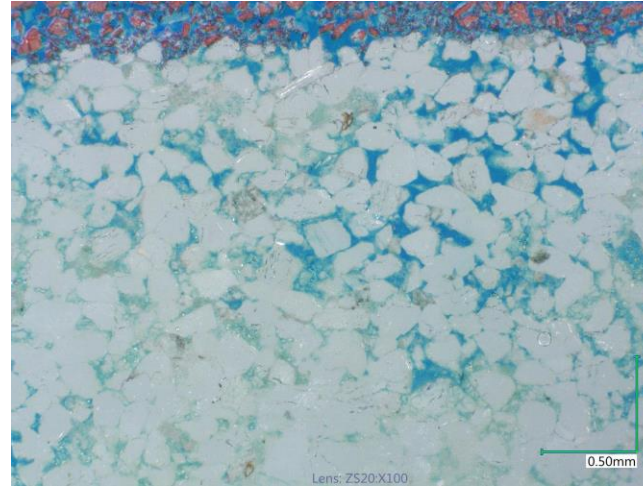
Coreflood Production Test Results



Identification of Damage Mechanism Through Core Analysis



Figure: New Core Sample



100X Magnification; Stained with alizarin red
Figure: Example of Sample after RDF



Figure : Sample after 5 day breaker soak

52.17% Direct Injection Regain



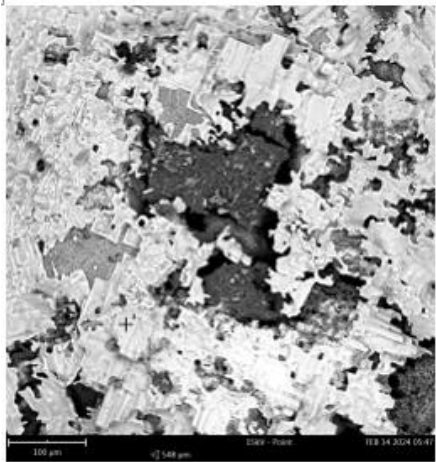
Figure: Sample after RDF

Figure: Sample after breaker soak, side view.

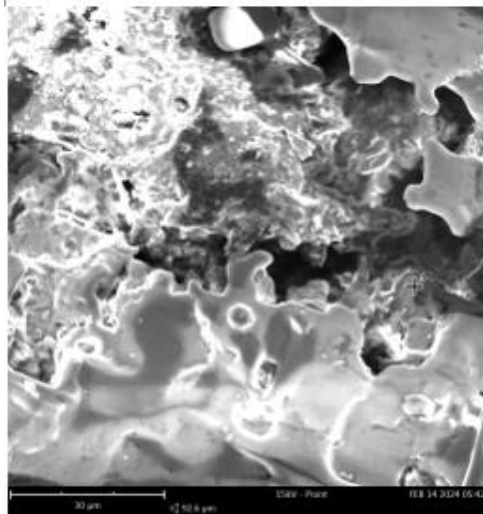
Figure : Sample after breaker soak, top view.

SEM

Identification of Mineral Composition on Wellbore Face

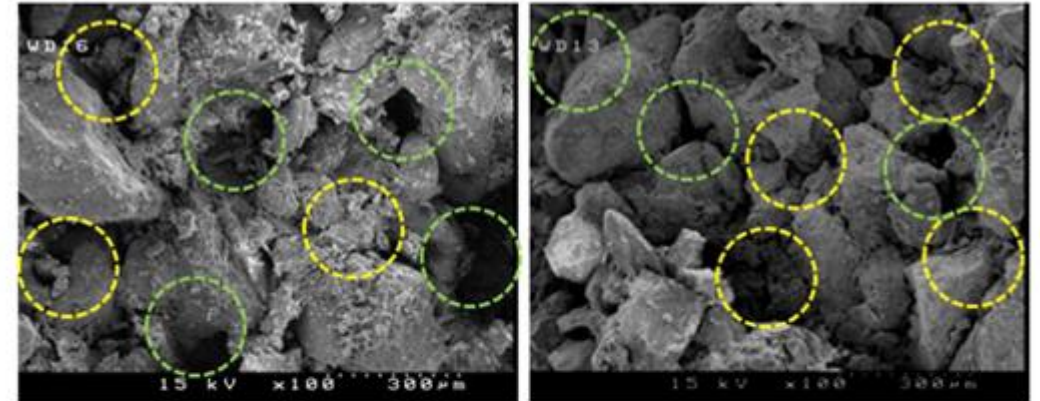


Element Symbol	Atomic Conc.	Weight Conc.
Cl	36.49	49.03
Na	39.51	34.43
C	23.25	10.58
Po	0.75	5.96



Element Symbol	Atomic Conc.	Weight Conc.
Cl	25.41	39.76
Na	32.33	32.80
C	36.70	19.45
Po	0.45	4.18
O	4.70	3.32

Identification of Solids Infiltration, Fines Migration



[VIEW LARGE](#)

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Scanning electron microscope images of the wellbore faces of samples 6 (left) and 2 (right) at x100 magnification. Mostly open pores are highlighted with green circles; mostly restricted pores are highlighted with yellow circles.

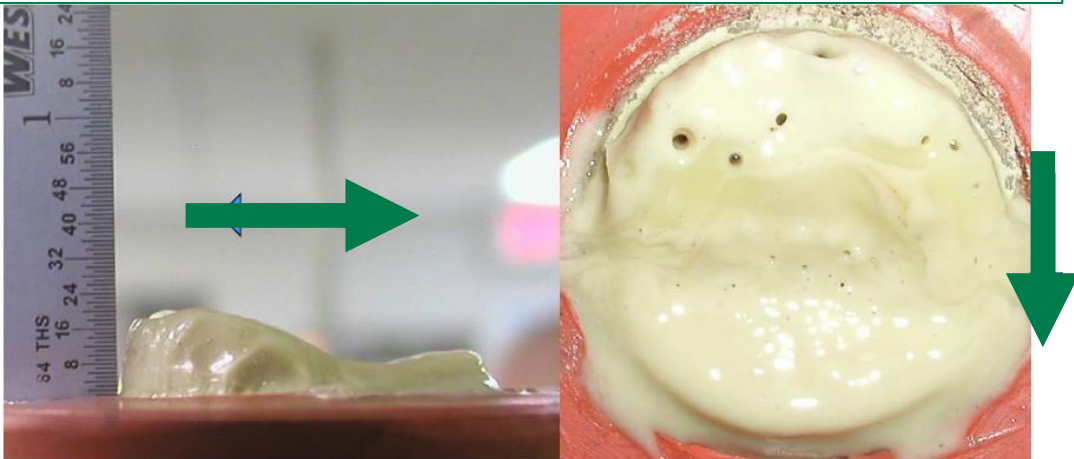
Green et al SPE 185889-MS

Variations and Concerns of CoreFlood Testing

Different Equipment and Bespoke Setup Means Different Testing Protocol

- Vertical vs. Lateral Core holder to simulate downhole conditions
- Core holder/accumulators in oven vs some eqpt outside oven
 - Temperature fluctuations have been found in our lab to create a significant difference in results (viscosity)
- Various core size limitations (Darcy's law should accommodate for this)
- Various fluid volume capacity with spacer rings (Volume of RDF, volume of breaker)
- Various capabilities of pressure transducers (high and low pressure)

Displacing RDF can be challenging- too little flow leaves excess fluid behind, while too much flow can strip away filtercake



Depressurizing the system, then replacing drilling spacer ring with breaker spacer ring can allow for removal of any excess RDF and ensure direct contact between the breaker and filter cake
But it can also disrupt the filter cake, seeing unrealistic downhole conditions with pressure and temperature changes



Testing Pros and Cons

Flowthrough Testing

Pros

- Ceramic discs offer homogenous, inert media
- Testing is overall easier than return permeability testing
- Consistency in test results
- Cost- effective & Time-effective
- Ability to test similar QC in field
- Can test gravel pack/SRF/screen designs with ease

Cons

- Ceramic disc doesn't take into account actual formation lithology
- Temperature limitations during initial and return flowback
- Pressure limitations
- Does not take into account fluid invasion damage

CoreFlood Testing

Pros

- Core samples provide realistic formation heterogeneity (representation)
- Can highlight field relevant challenges: fines mobilization, pore throat plugging, heterogeneity, incompatibilities
- 350°F and 6000 psi
- Core analysis to identify damage mechanisms possible

Cons

- Variability from core to core
- Hard to source actual core samples
- Fractured core samples cause improper data
- Results from identical testing shows variability
- Interpretation of results can be difficult due to a number of factors
- Costly and time-consuming

Key Learnings

Direct Matrix Injection Wells Face Unique Challenges

- Unlike production wells, injector wells must manage formation damage without flowback, making fluid compatibility and cleanup critical

Tailored Fluid Design is Essential

- RDFs must minimize non-acid soluble solids, use acid-soluble bridging agents, and include polymers responsive to chemical breakers
 - Maintaining low drilled solids content requires aggressive dump and dilute strategy – high fluid costs and logistical pressures, but worth it for the results (?)
- Breaker fluids should be designed with synergistic additives that chemically disrupt and/or remove all components of the filter cake, ensuring effective cleanup

Lab Testing Validates Design Effectiveness

- Flowthrough Testing offers a cost-effective, consistent method to evaluate cleanup efficiency, though it lacks formation realism and results may be a little too good to be true. Provides a good means of testing a large number of iterations relatively quickly without using up valuable core. Also tend to exhibit more consistent behavior than cores to identify trends
- Coreflood Testing provides more realistic formation heterogeneity insights but introduces variability and sourcing challenges

Quantitative Results Support Field Implementation

- Flowthrough tests showed up to 98% injectivity indicating excellent cleanup with no observed calcium carbonate or starch remaining
- Coreflood tests demonstrated regain permeability ranging from 52%-77%, highlighting variability, but confirming effective fluid performance as the metric was greater than 25% regain perm

SEM and Thin Section Analysis Enhance Understanding

- Imaging techniques like SEM and thin sections reveal residual damage, pore plugging, and fines migration, supporting deeper interpretation of test results

Way Forward

Standardize Testing Protocols

- Support industry efforts to develop standardized flowthrough and coreflood testing procedures for consistent benchmarking
 - This will be difficult to accomplish but setting some standards, even with various types of equipment will be beneficial

Collaborate Across Disciplines

- Work with geoscientists and reservoir engineers to align fluid design with reservoir-specific lithology, permeability, and mineralogy
- Planning and integration among service providers is critical to ensure successful injection



Thank you

Questions?

