Welcome!

The program will begin soon.

You will not hear audio until we begin.

Recent Advancements in Viscosifying Friction Reducers for Hydraulic Fracturing

Mark Van Domelen

VP of Technology, Downhole Chemical Solutions

Moderated by Kyle Haustveit, Devon Energy

Webinars

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Outline

I. Introduction to Viscosifying Friction Reducers (VFR)
- ❑ General properties
- ❑ Advantages

II. Recent Technology Advances
- ❑ Effect of source water on VFR performance
- ❑ Impact of iron – preventing gummy bears
- ❑ Proppant transport
- ❑ Dry FR powder delivery

III. Case History from Vaca Muerta, Argentina

IV. Q&A

Polyacrylamide Friction Reducer Delivery Types

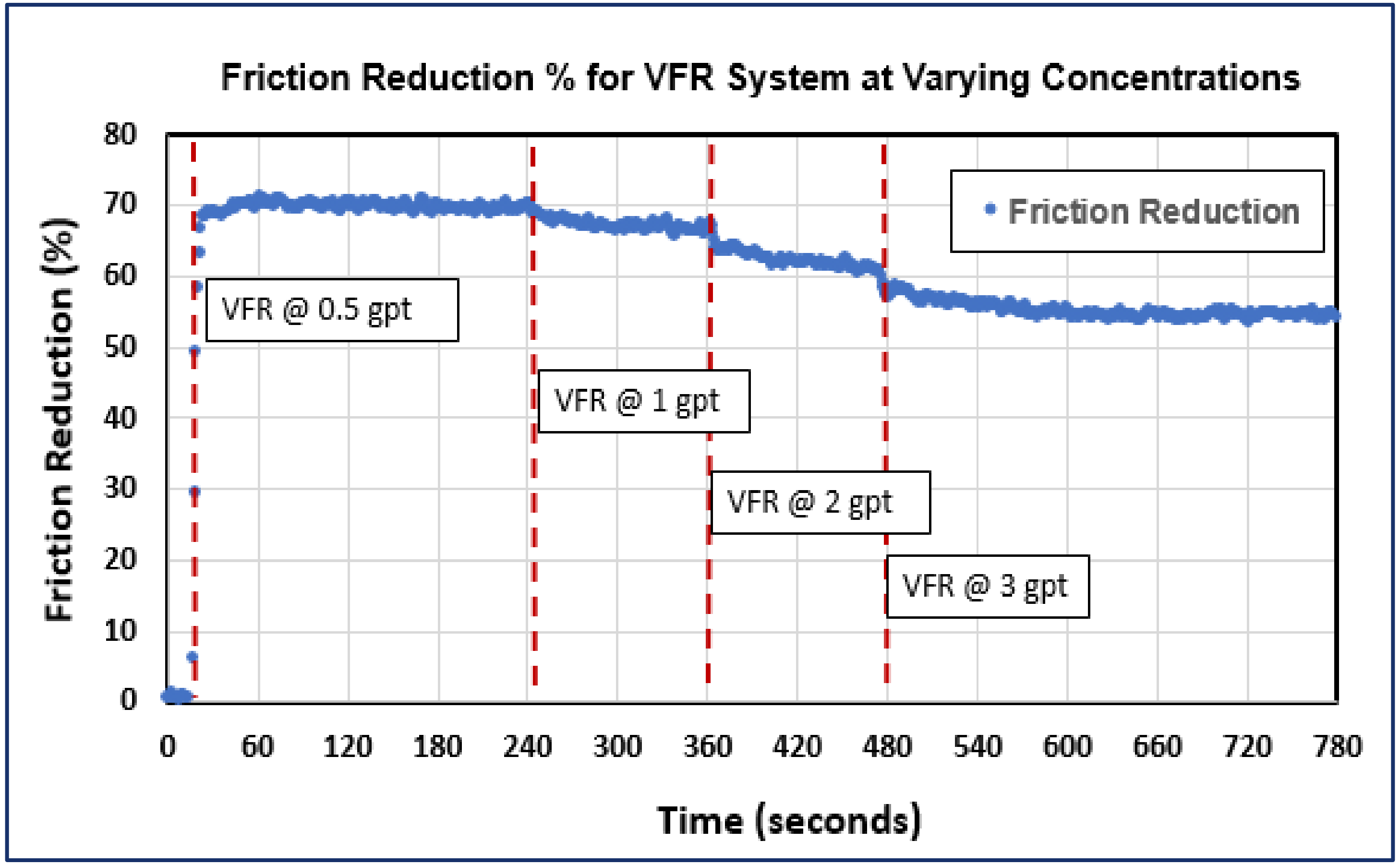
Liquid Emulsions
- Made in reactor
- High quality product with minimal settling issues
- Most common product used in industry today

Liquid Suspensions
- Do not require a reactor process
- Require multiple components to prevent polymer settling
- Can be difficult to pump due to high viscosity

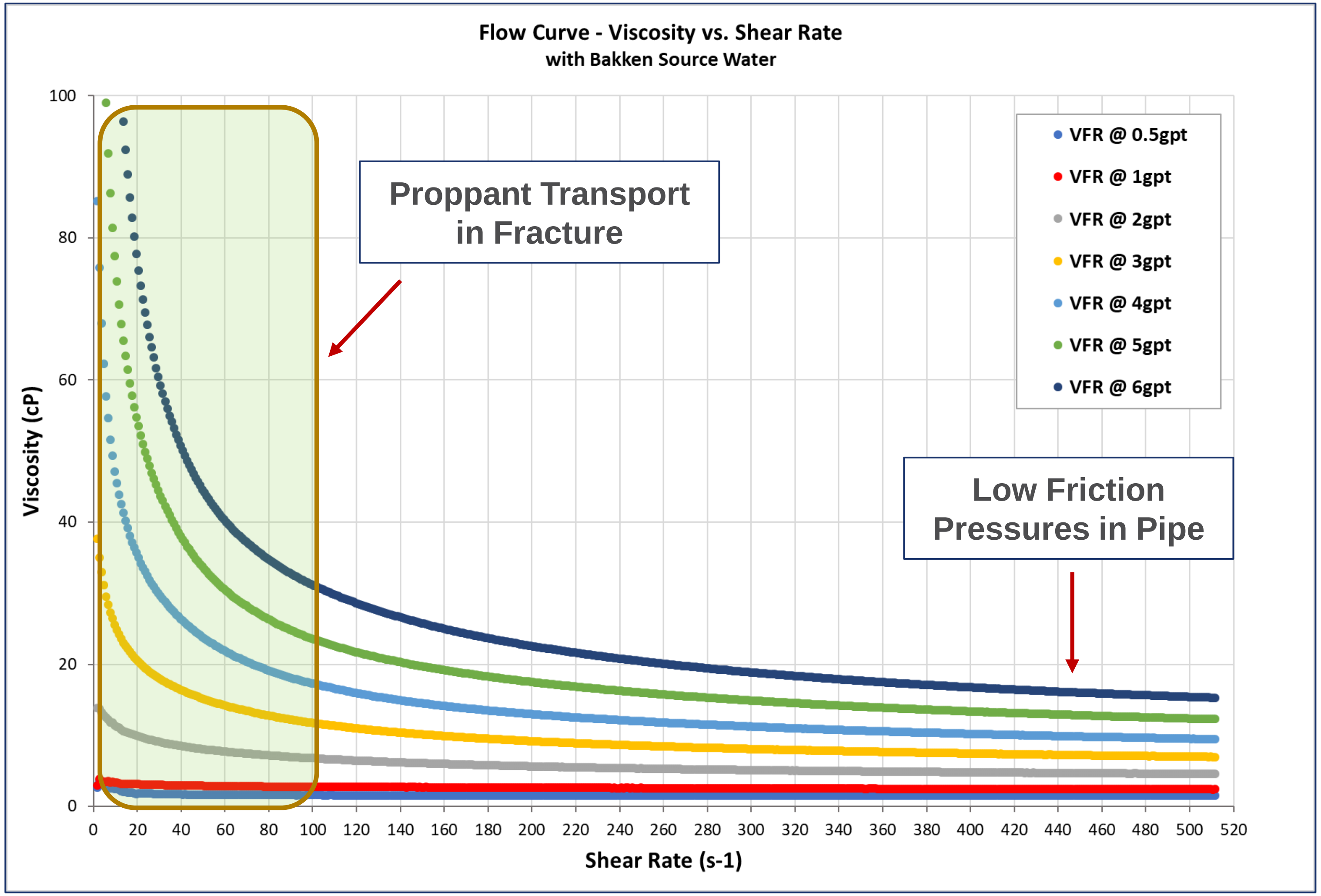
Dry Powder
- Relatively new to industry
- Eliminates liquids on location
- Requires proper equipment to achieve polymer dispersion/hydration

General Properties – Friction Reduction

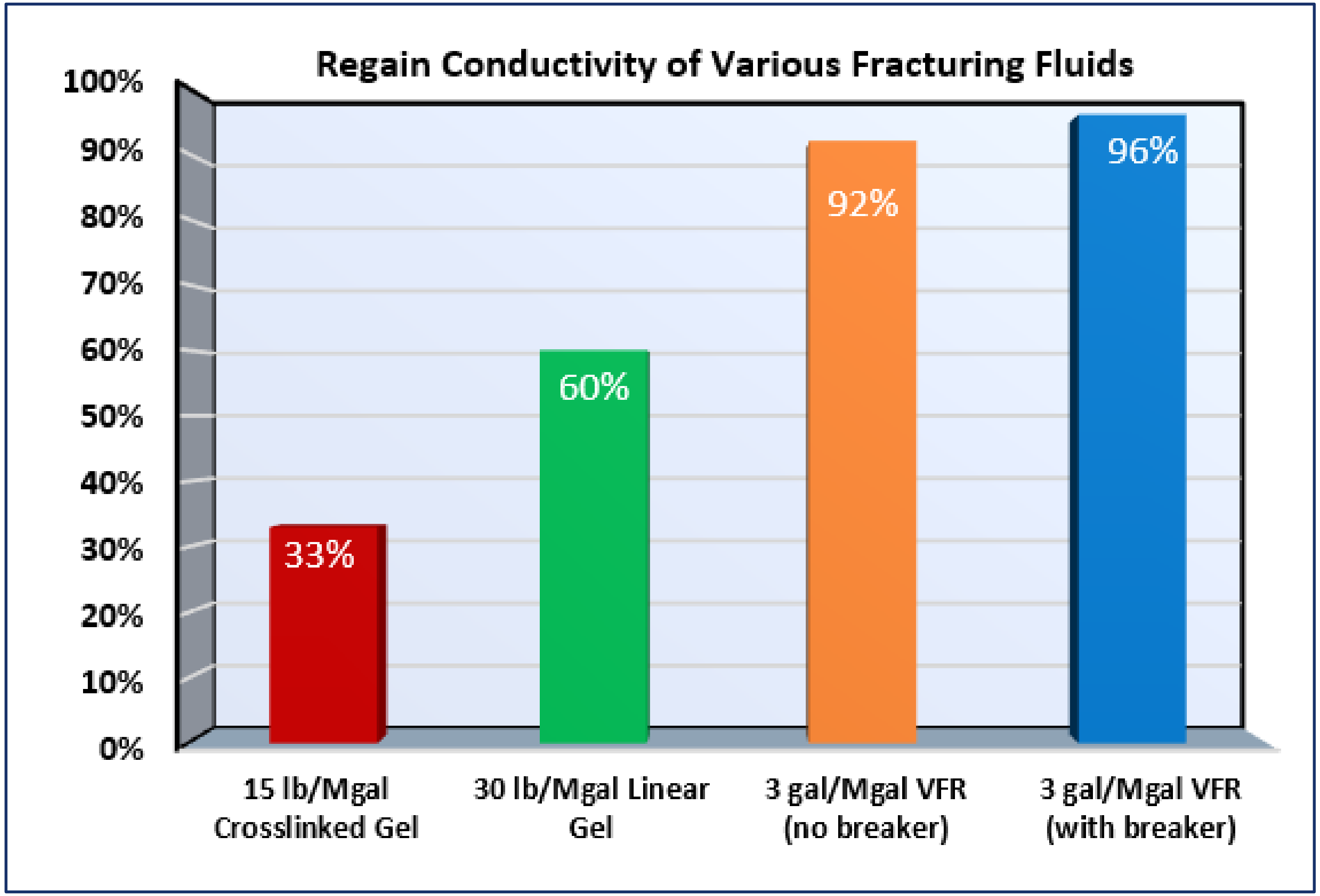
Flow Loop Test Data



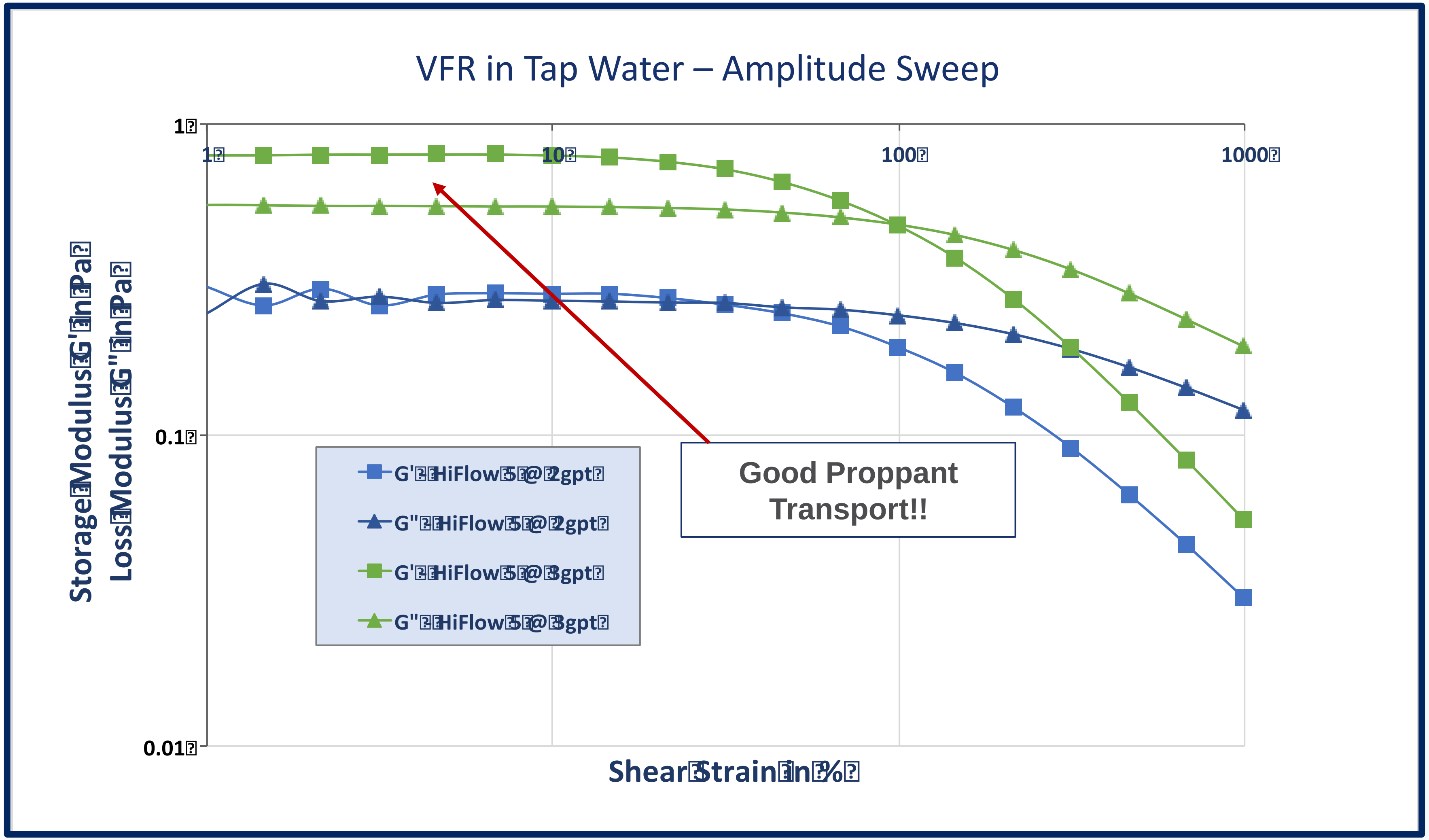
General Properties – Viscosity Profiles



General Properties – Retained Conductivity



General Properties – Elasticity



Comparing VFRs with other Fluid Systems

VFR vs. Slickwater

- *Better proppant transport*
- *Can place higher sand concentrations*
- *Reduced water volumes*
- *Reduce fracture interactions with offsets*
- *More frac stages per day*
- *Enhanced cluster efficiency**

VFR vs. Linear and Crosslinked Gel

- *Cleaner proppant pack => Better production*
- *Lower pipe friction*
- *Fewer chemicals on location*
- *No hydration unit needed*
- *Generally lower cost*

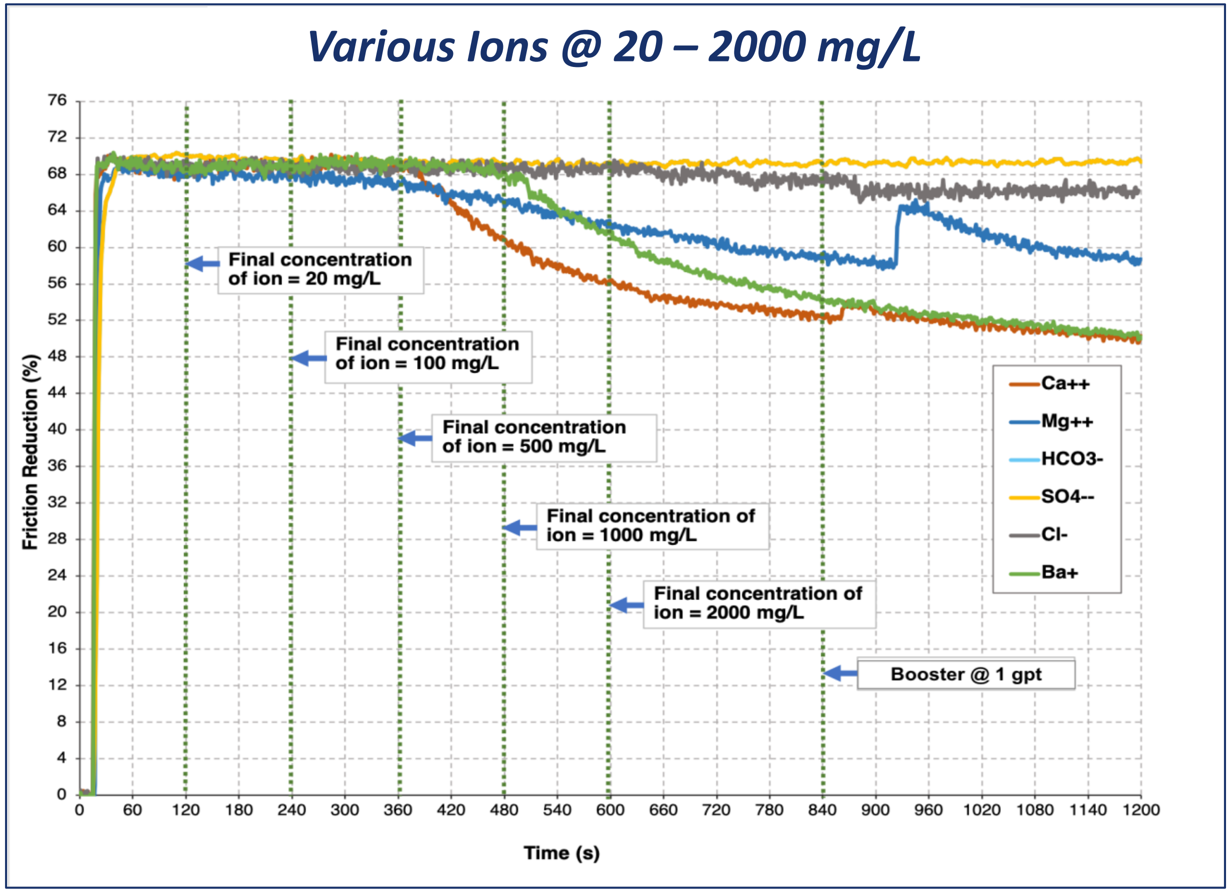
Recent Technology Advances

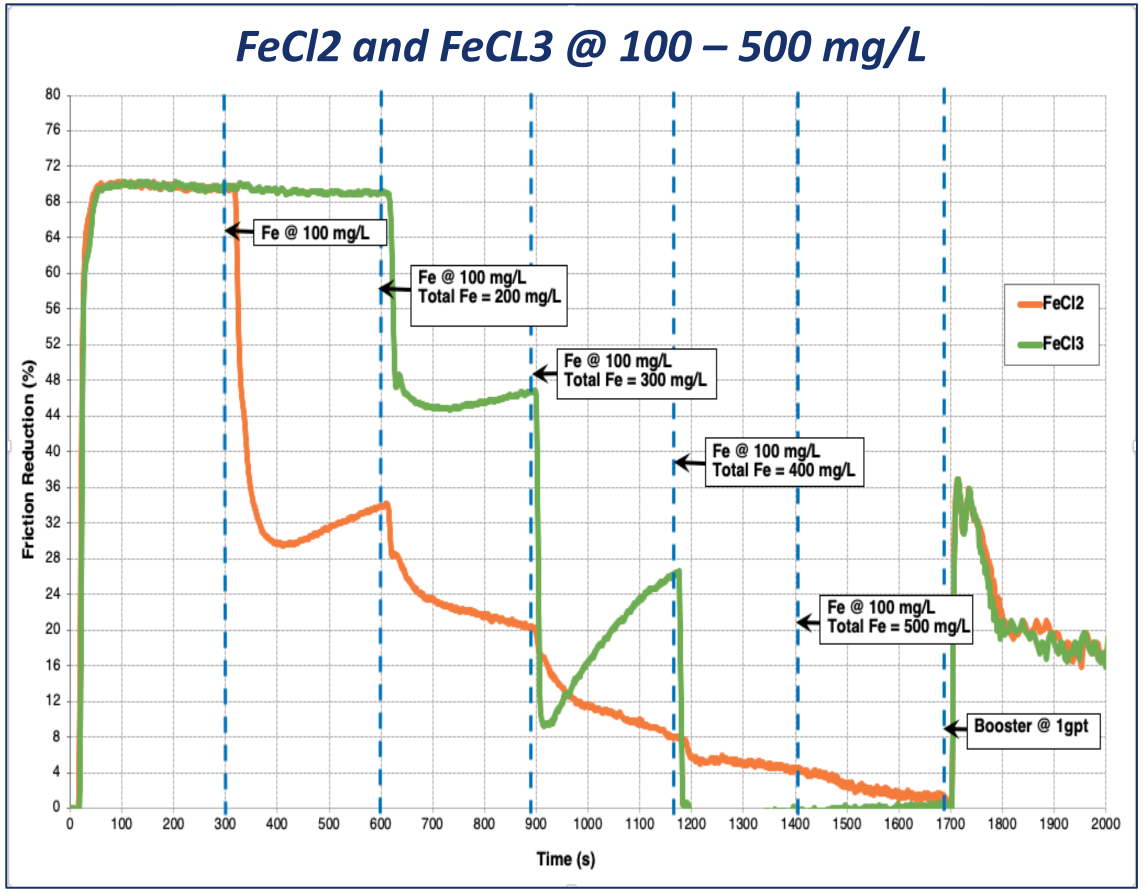
Effect of Source Water on FR Performance

SPE-195199-MS
Correlating the Performance of Friction Reducers with Source Water Chemistry
2019

Suchandra Hazra, Vanessa Madrid, Tatiana Luzan, *Dynachem Research Center*;
Mark Van Domelen and Chase Copeland, *Downhole Chemical Solutions*

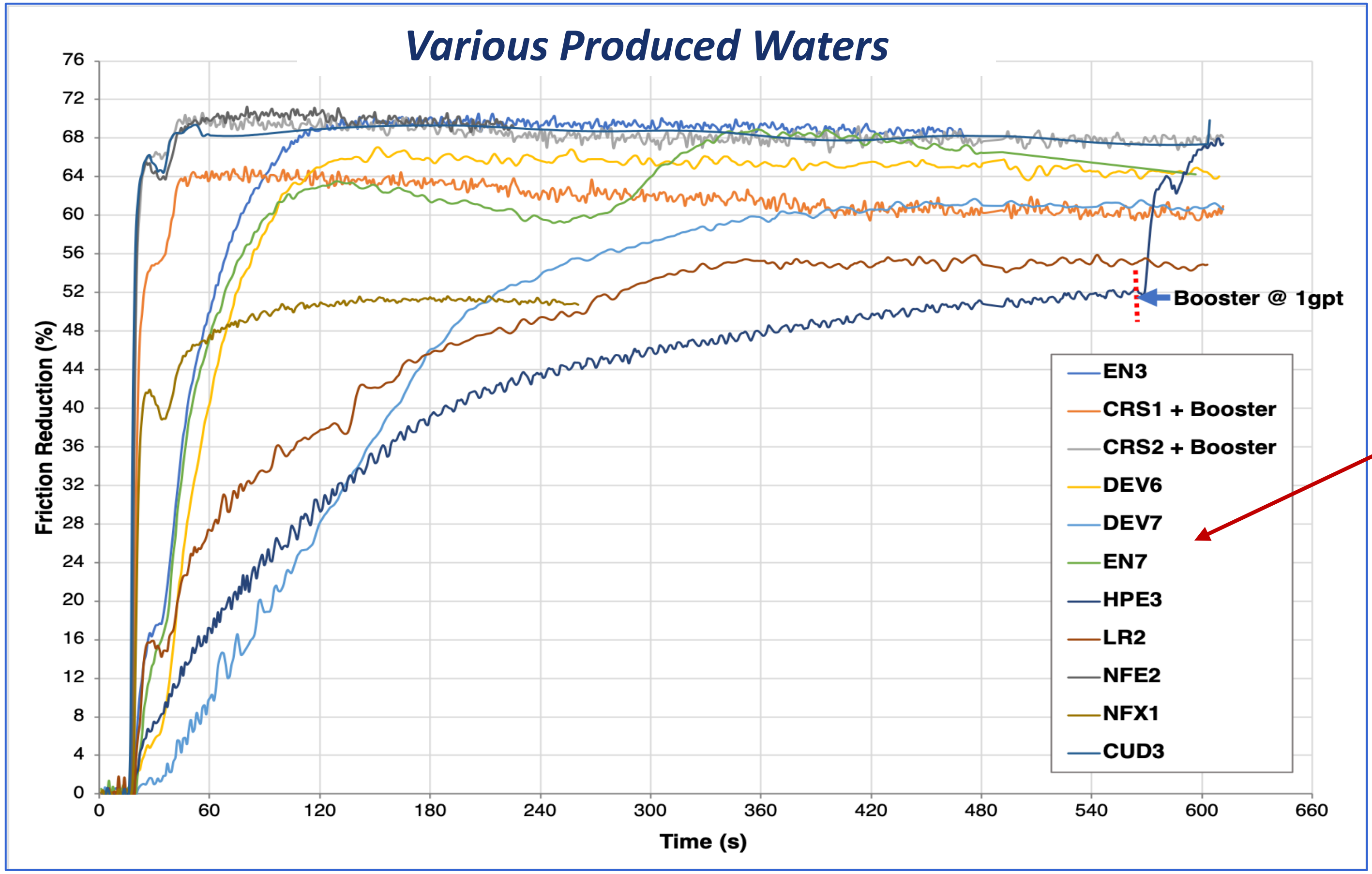
Results - Friction Reduction with Synthetic Waters and Single Ions

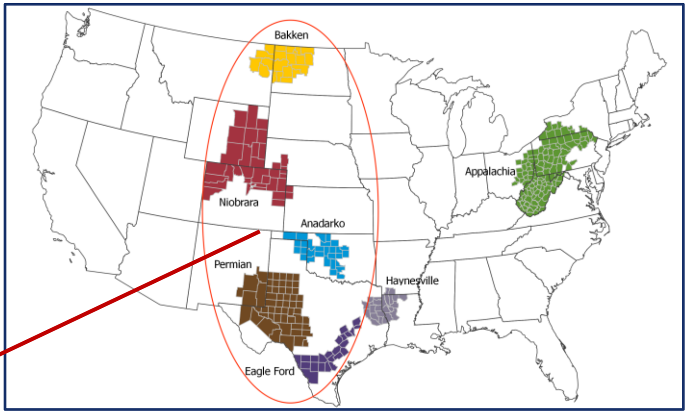




SPE-195199

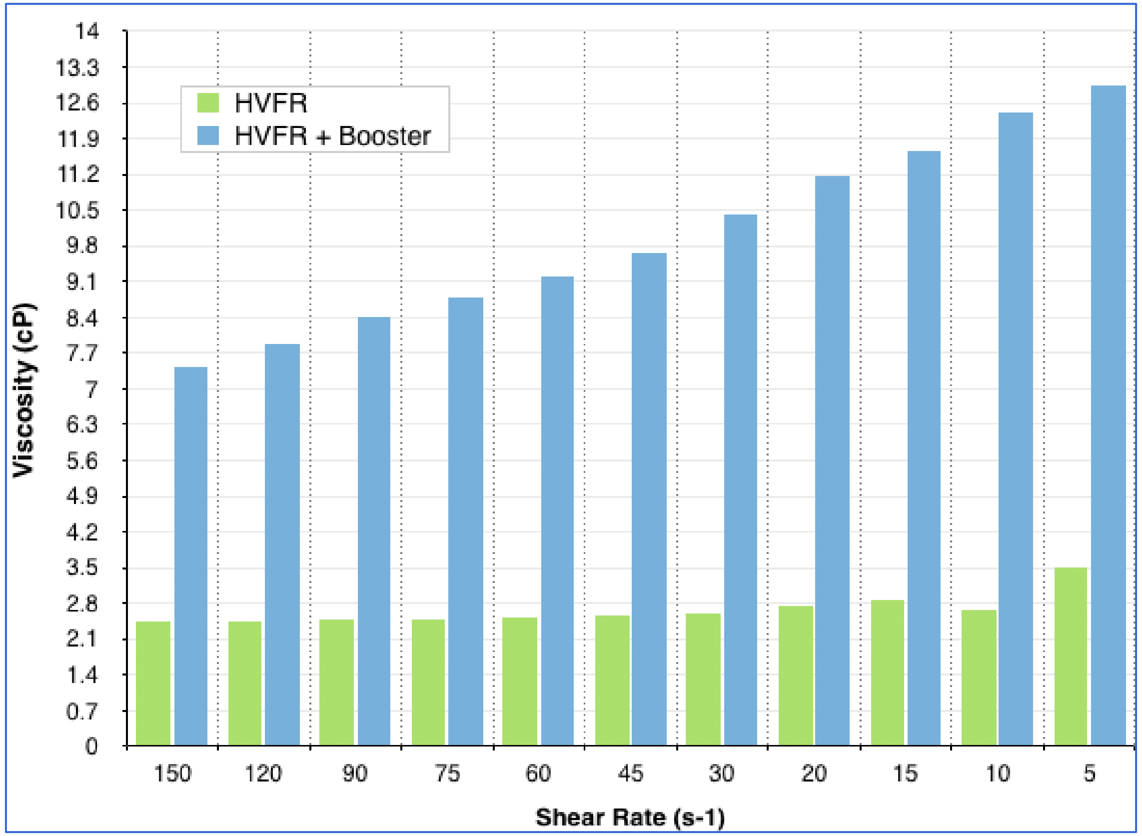
Friction Reduction with Field Produced Water



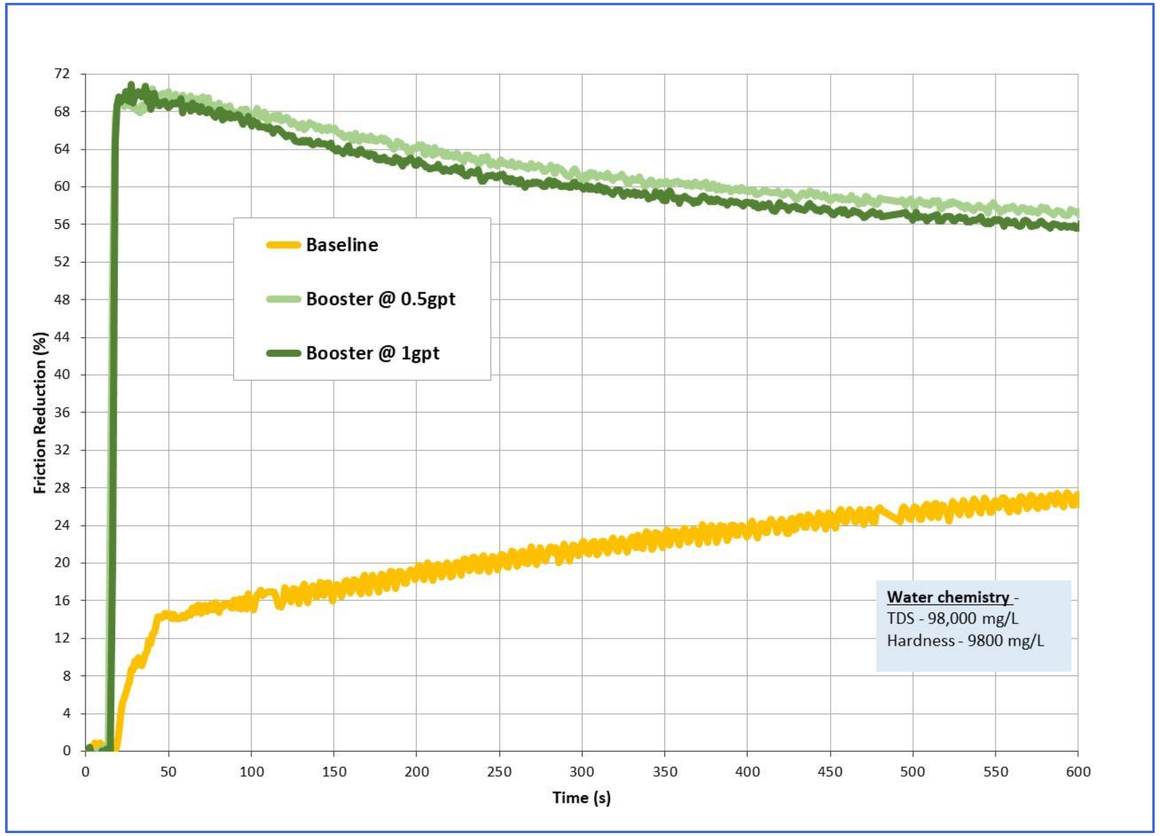


FR Boosters – A Sacrificial Surfactant

VFR at 4gpt, Booster at 1 gpt



FR at 0.5 gpt, Booster at 0.5 and 1 gpt



SPE-195199

Summary from SPE-195199

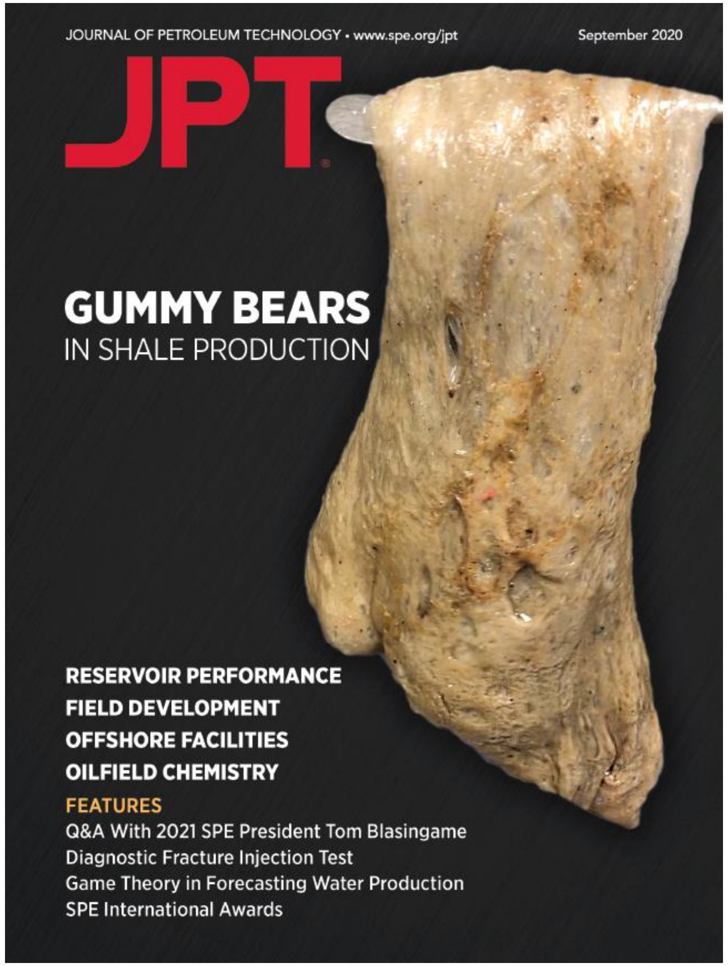
- Overall, iron was found to have the most detrimental effect on FR performance
- Total dissolved solids (TDS) values by themselves are not a complete indicator of fluid performance. The overall composition of ions is critical to FR performance
- FR Boosters show positive results on the friction reduction and viscosity development of VFR fluids

Impact of Iron – Preventing Gummy Bears

UrTEC 2487
Performance of Friction Reducers in Iron-Rich Environments
2020

Nathan Peregoy, Pele Okullo and Bruce Darlington, Ovintiv Inc.
Suchandra Hazra, Mark Van Domelen and Wayne Cutrer, Downhole Chemical Solutions

Impact of Iron – Preventing Gummy Bears

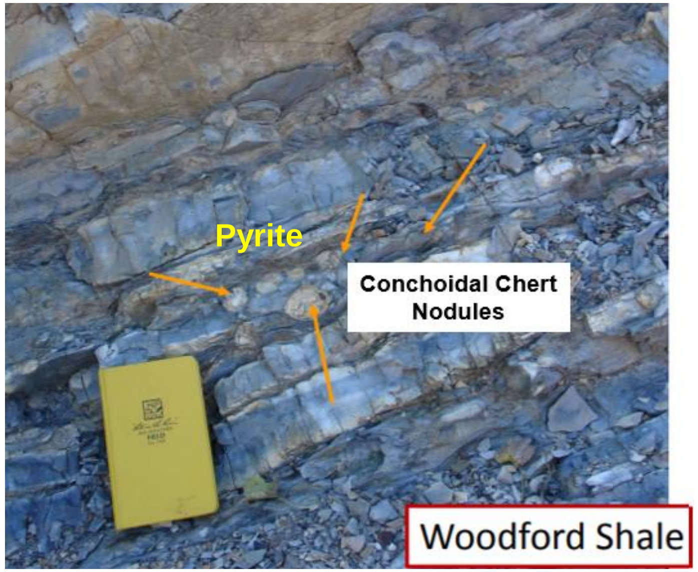


Sources of Iron in Frac Operations

Source Water

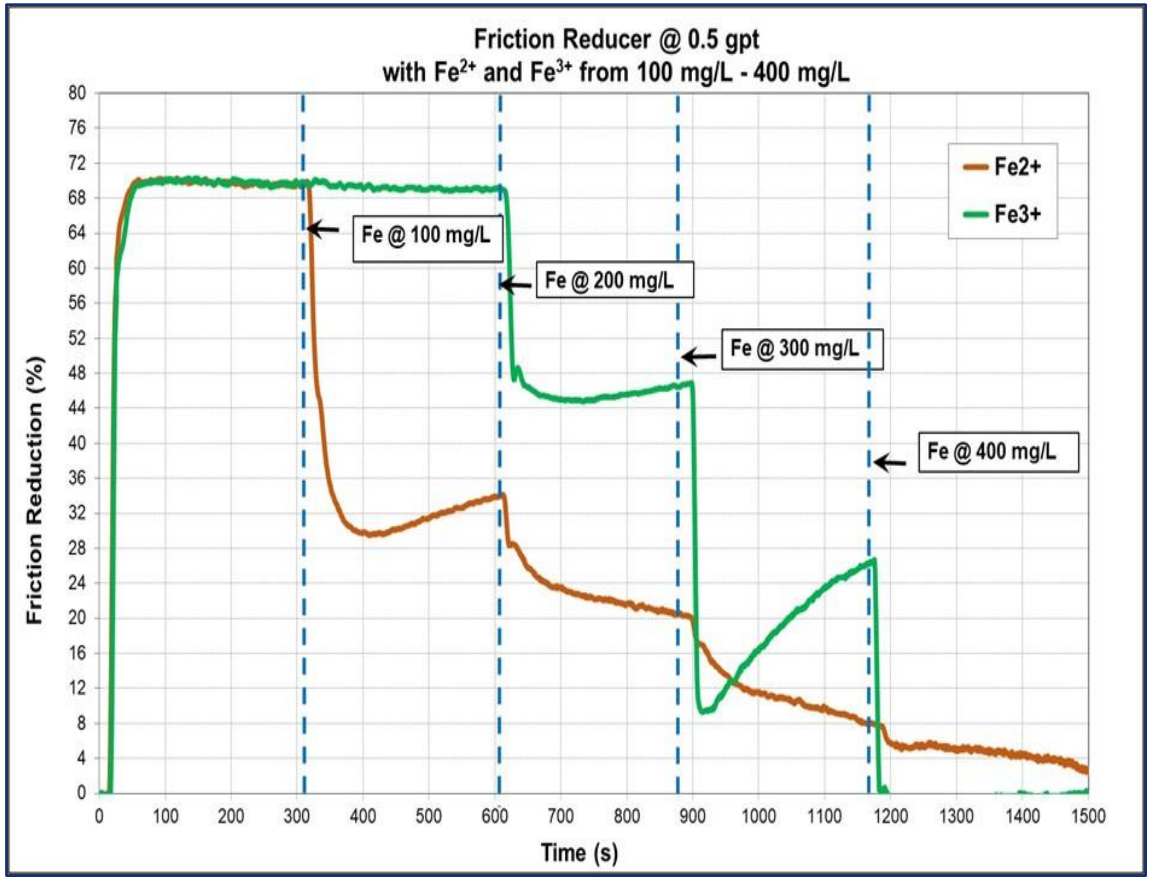
Tubulars

Formation



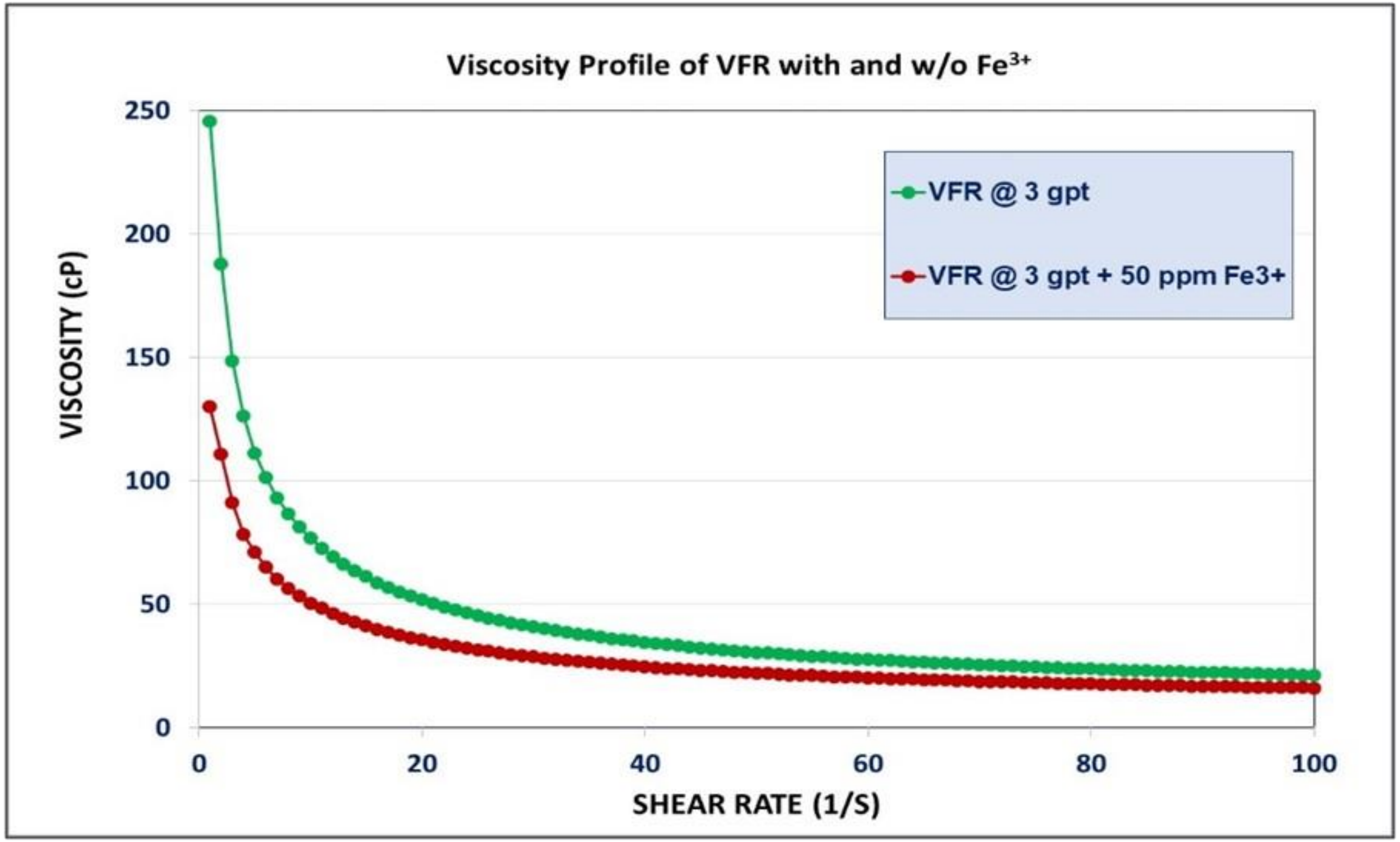
Iron Interactions with Friction Reducers

1. **Impairment of Friction Reducing Properties**



Iron Interactions with Friction Reducers

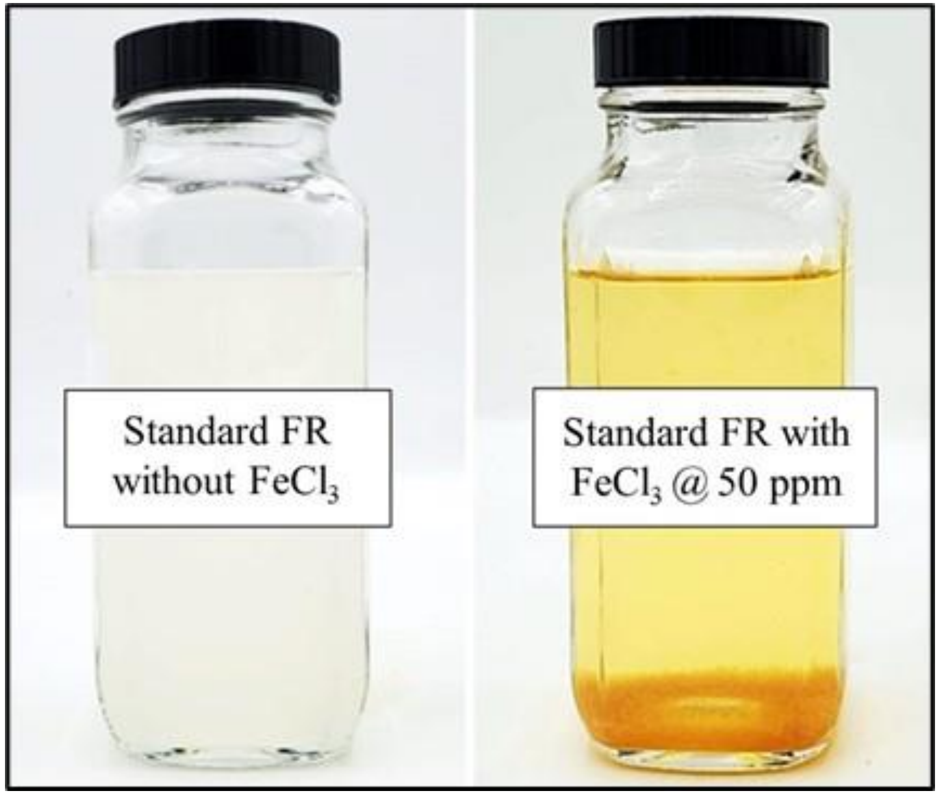
2. Loss of Viscosity with Viscosifying Friction Reducers (VFR)



Iron Interactions with Friction Reducers

3. Formation of Accumulations (aka “Gummy Bears”)

Standard industry FR added to water with and without $FeCl_3$



Iron Interactions with Friction Reducers

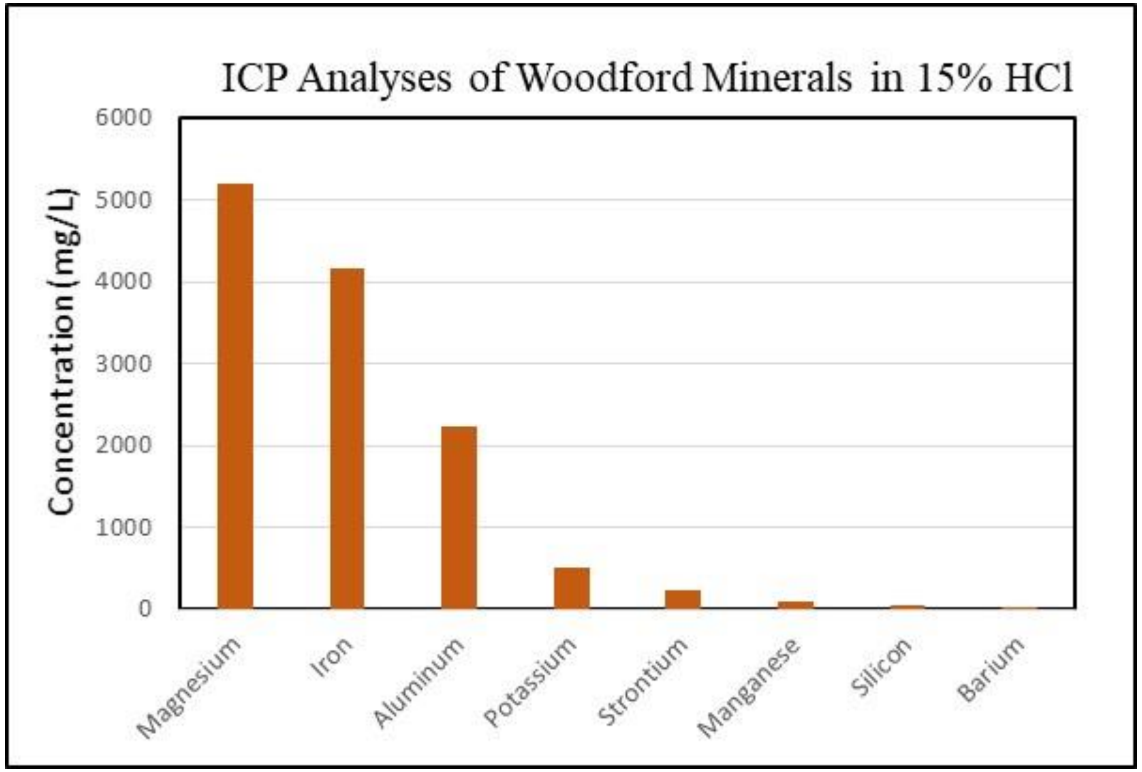
3. Formation of Accumulations (aka “Gummy Bears”)

Accumulations taken from Woodford wells in Oklahoma following slickwater fracs

Prevention and Mitigation Approaches

1. **Limit Use of Acid Spearheads**

Acid spearheads can release different elements into solutions, causing issues with FRs



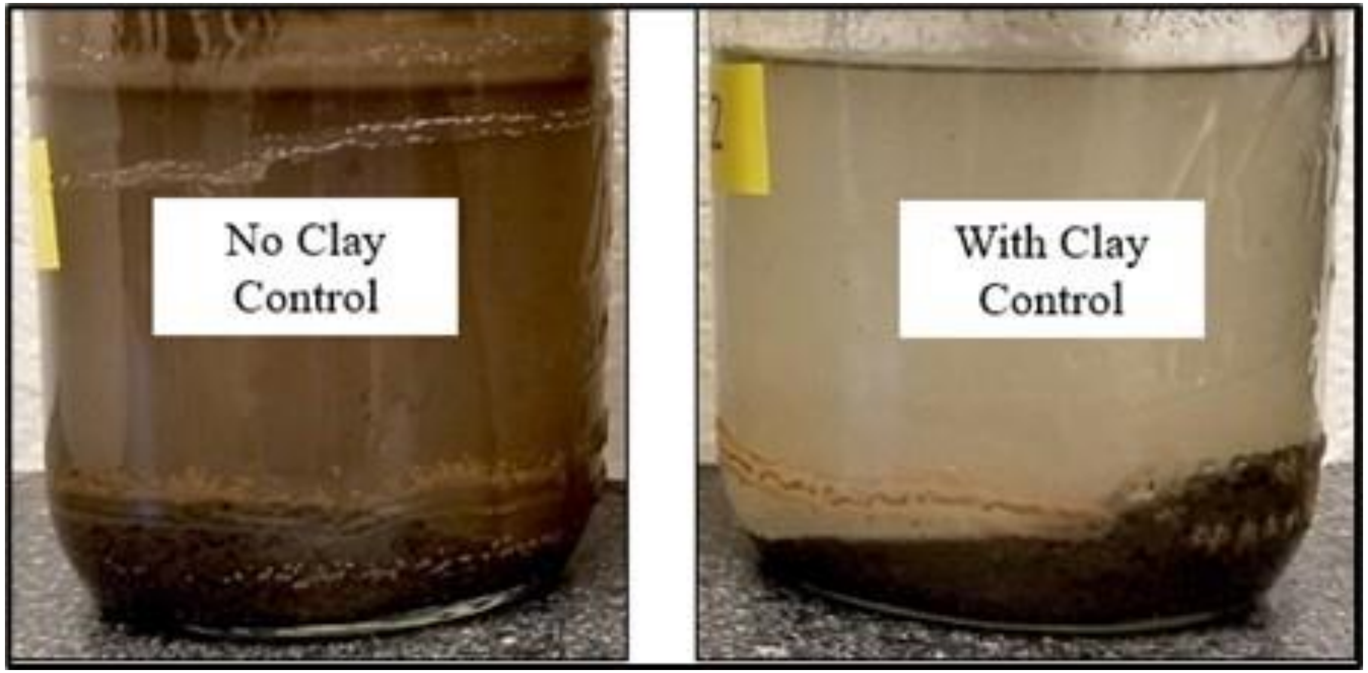
Prevention and Mitigation Approaches

2. Use of Clay Control

Clay control minimizes the release and movement of illites

	Woodford
Quartz(%)	67.0
Calcite, syn(%)	0.0
Feldspar(%)	10.0
Pyrite(%)	2.0
Total Non Clay	79.0
Smectite (%)	0.0
Illite (%)	17.0
Chlorite IIb-4(%)	1.0
Kaolinite-1A(%)	3.0
Total Clay	21.0

Example of XRD from Woodford

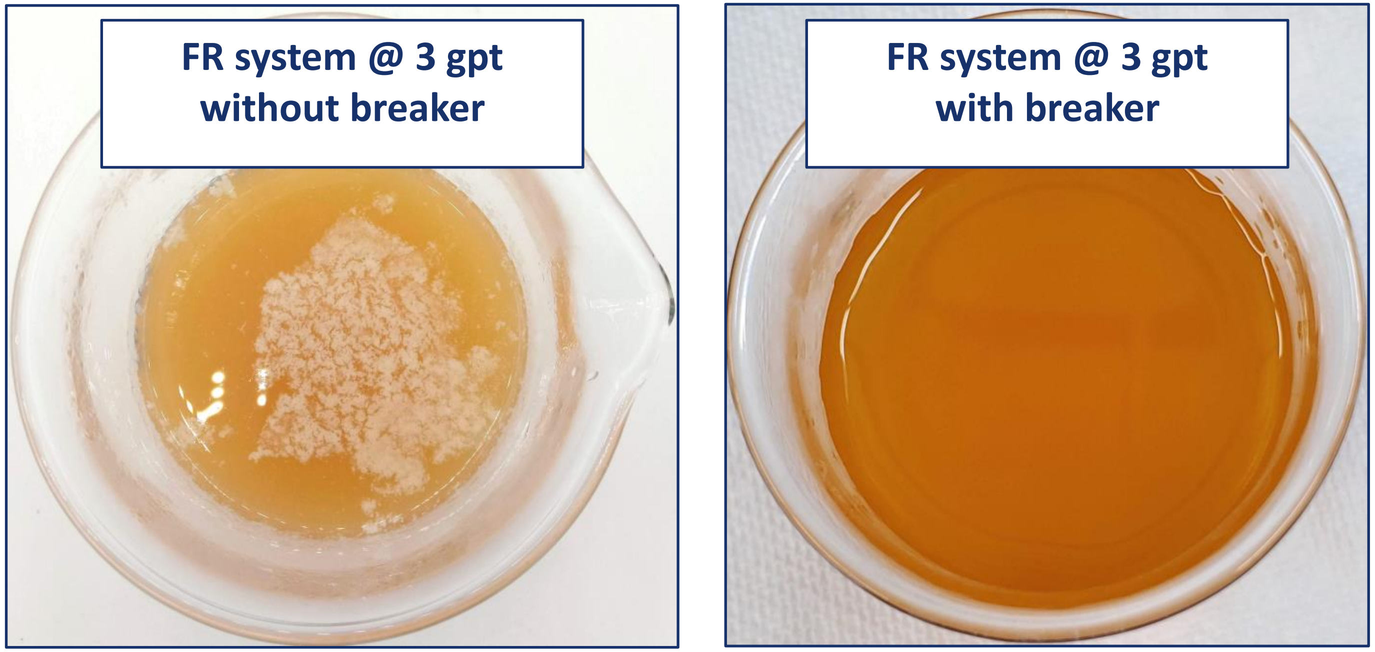


Samples before and after Hot Roll testing with Woodford cuttings

Prevention and Mitigation Approaches

3. Use of Polymer Breaker

- ❑ Reduces viscosity of VFR system
- ❑ Degrades polymer accumulations before they become problematic



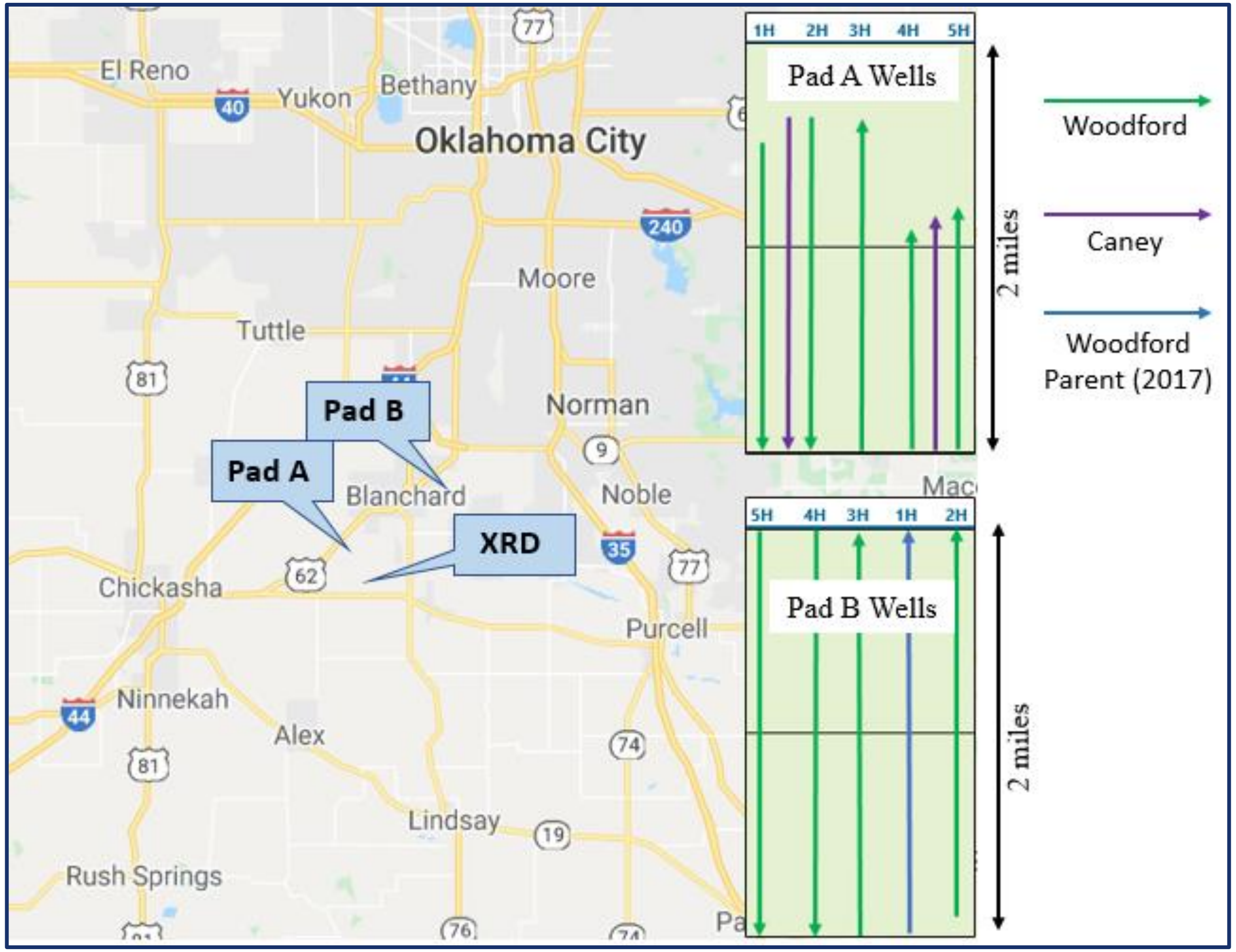
FR mixed in produced water with and without breaker

Case History – Woodford Completions

I. Eastern Grady and Western McClain counties in Oklahoma

II. Pad A
- 5 Woodford + 2 Caney wells
- All wells completed in 2019

III. Pad B
- 5 Woodford wells
- Parent well completed in 2017
- Other 4 wells completed in 2020 using new technique

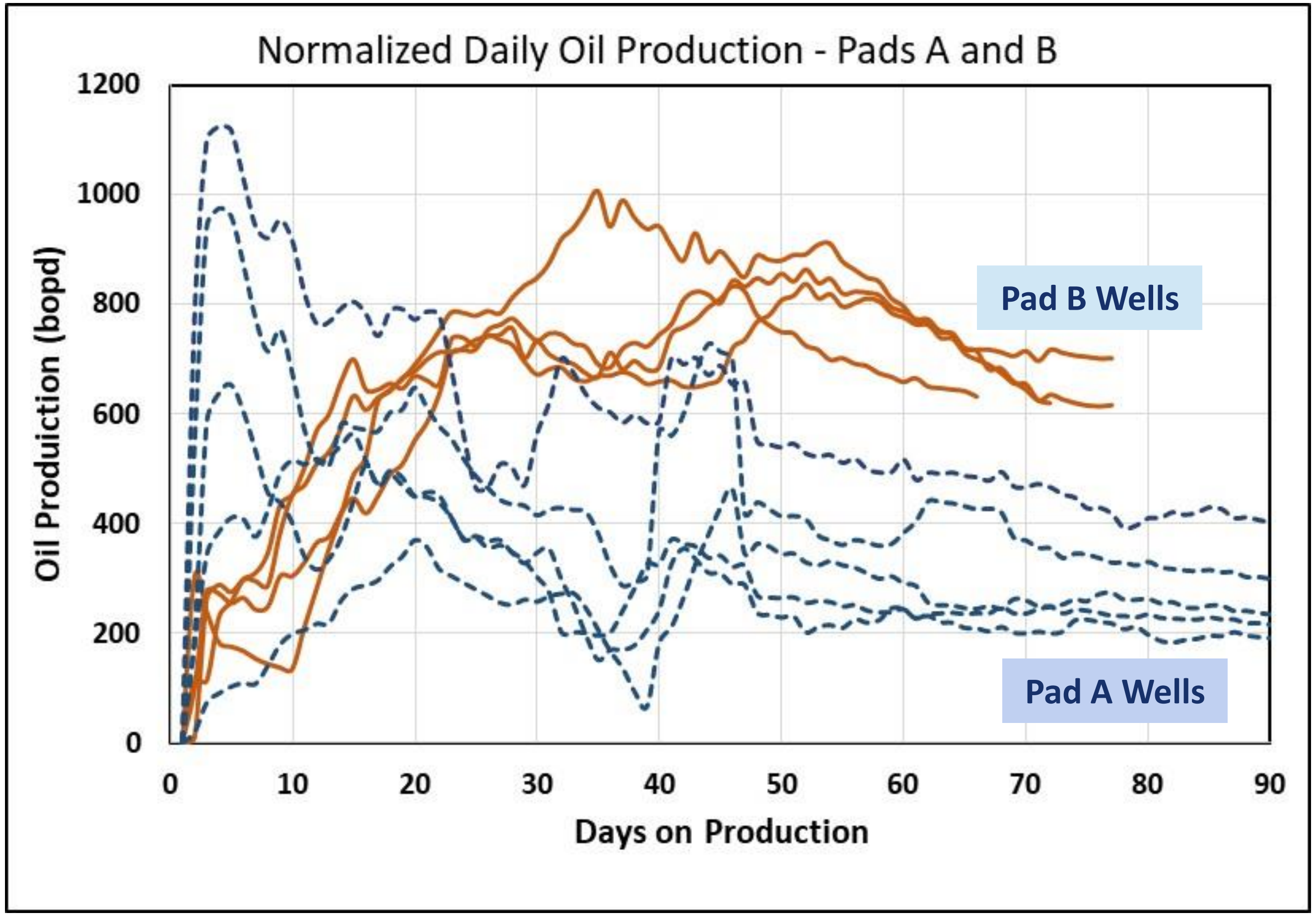


Production Comparisons – Pad A vs. Pad B

- Production rates normalized to lateral lengths

- After 60 days
  - Ave Prod Pad A = 335 bopd
  - Ave Prod Pad B = 750 bopd

- Similar well performance is being observed on other Woodford wells



Proppant Transport

SPE 196073
An In-Depth Study of Proppant Transport and Placement with Various Fracturing Fluids
2019

Don Anshutz, Terry Lowrey, Michelle Stribling, PropTester Inc.
Pat Wildt, Wildt Consulting

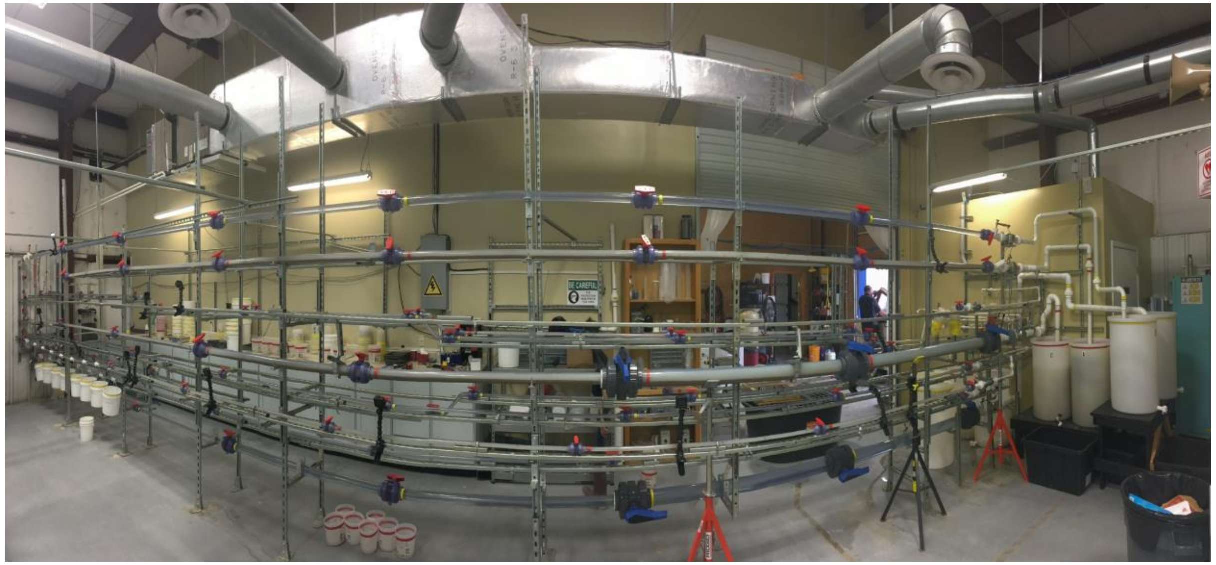
Consortium Member List

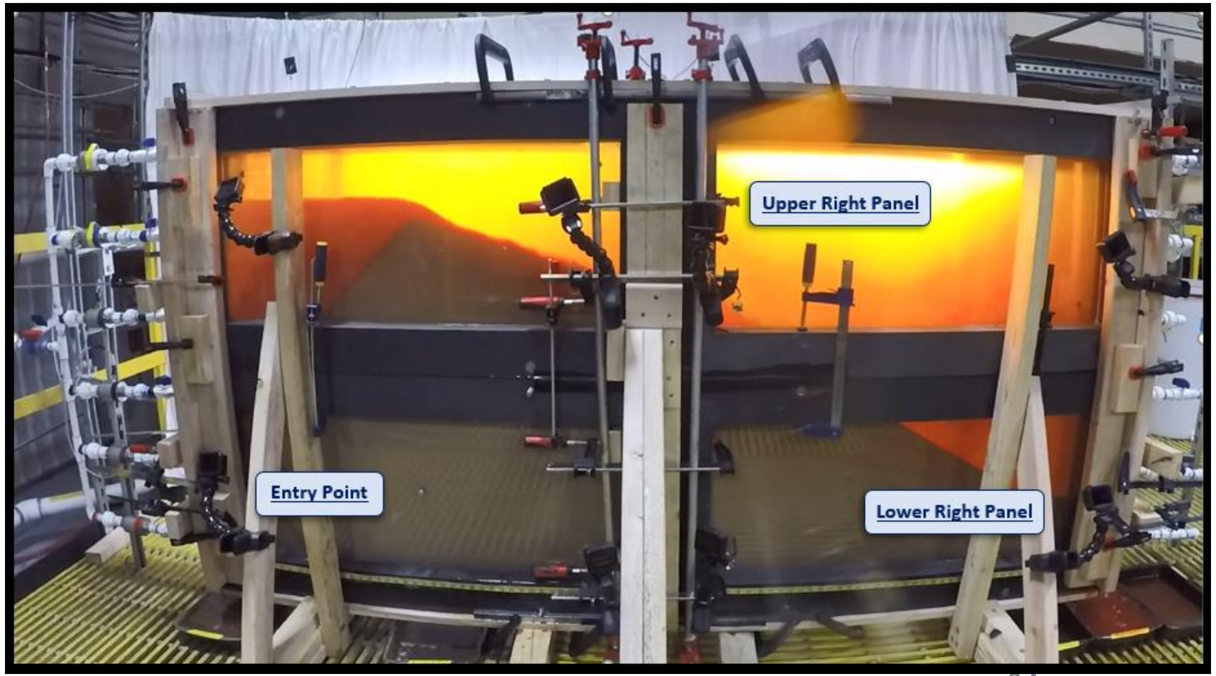
- Anadarko Petroleum
- Atlas Sand
- Aramco Services
- AquaSmart Services
- CalFrac Well Services
- Chevron Corporation
- Covia Corporation
- Diagnostic Stimulation Optimization
- Downhole Chemical Solutions
- ExxonMobil
- Lewis Energy
- Liberty Oilfield Services
- Marathon Oil
- Parsley Energy
- Pattison Sand Company
- PfP Technology
- Pioneer Natural Resources
- Saint Gobain Proppants
- Sierra Frac Sand
- SIL industries
- SNF Holdings
- Sun Drilling
- Superior Silica Sand

Consortium Objectives

Study how proppant moves, settles and banks through pipe flow and an open slot at various shear rates with differing viscous and elastic fluids.

Proppant	Fluids
• 40/70 Sand • 100 Mesh Sand	• Fresh Water • Slickwater • HVFR (2.5, 4 and 6 gpt) • Linear Guar • Crosslinked Guar

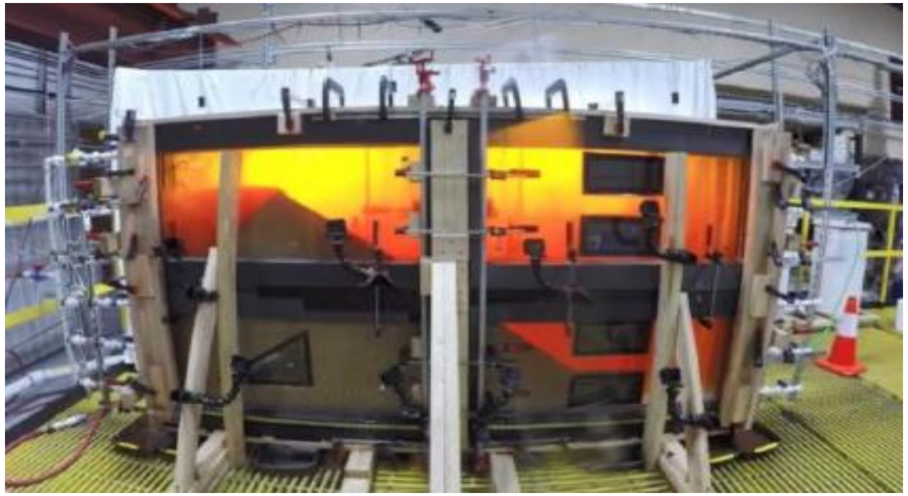




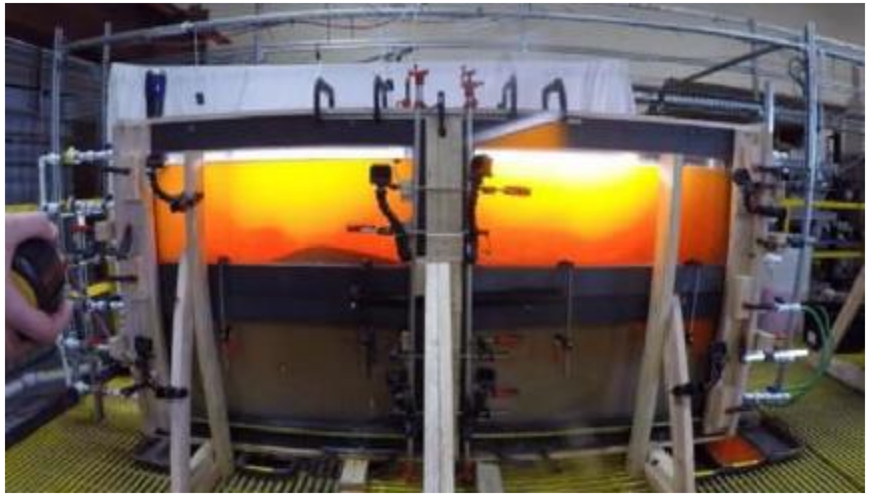
SPE 196073

Proppant Distribution Various VFR Concentrations

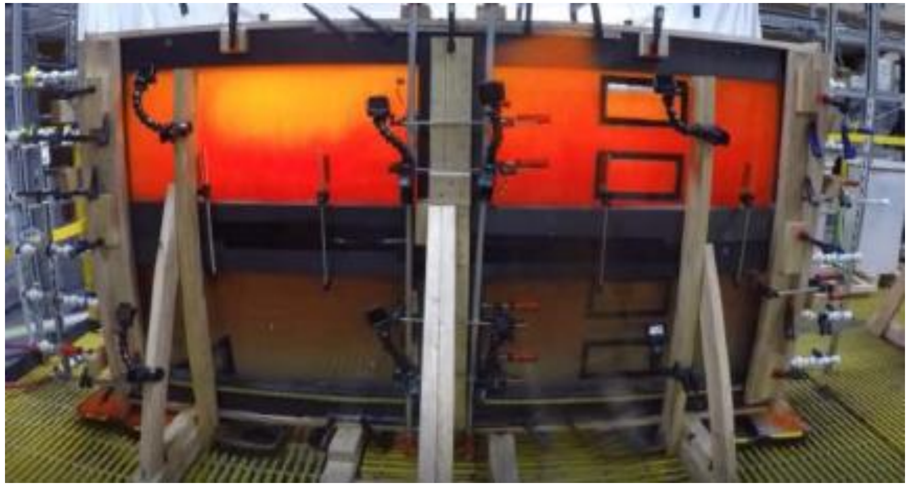
0.5 gpt "Slickwater"



2.5 gpt VFR

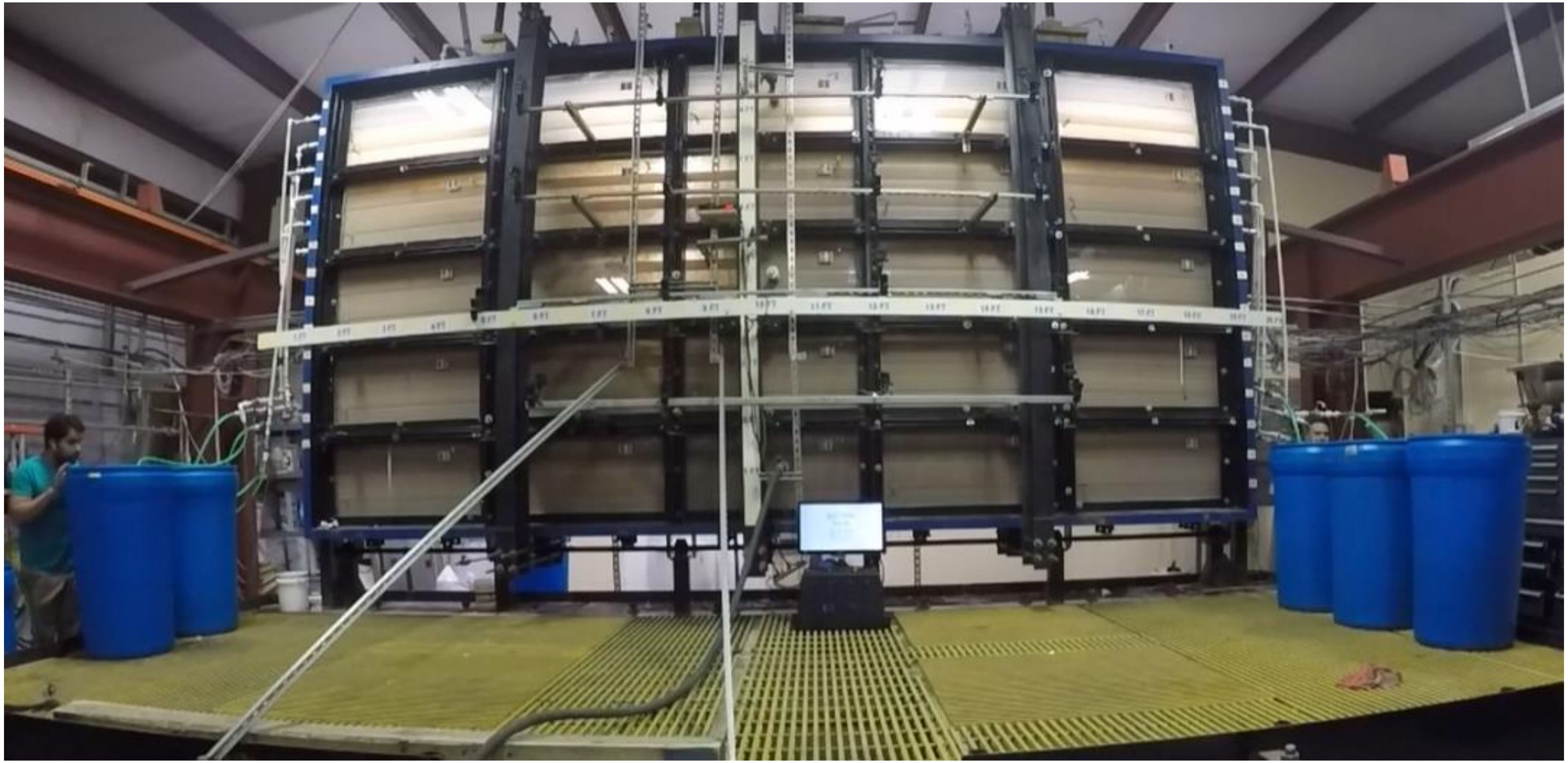


4 gpt VFR



6 gpt VFR

10’ x 20’ Test Cell for 2021 Consortium



Dry Powder Delivery

SPE 204176
Dry Powder Deliver of Friction Reducers: A Step Change in Slickwater Fracturing
2021

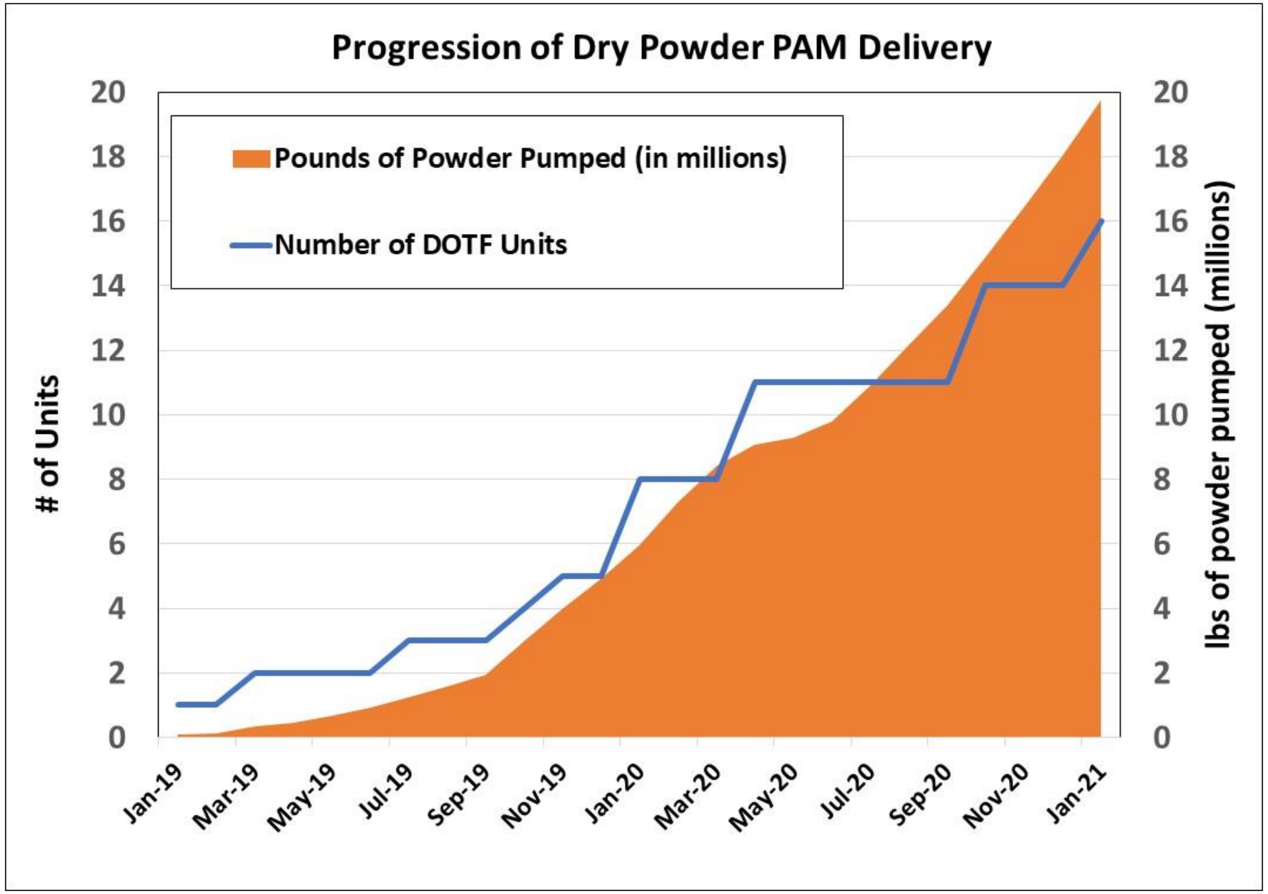
John Blevins, Hibernia Resources
Mark Van Domelen, Zach West, Jason Rall and Drake Wakefield, Downhole Chemical Solutions

Advantages of Powder Delivery

- 75% reduction in chemical volumes brought location
- Cost Reduction
- Elimination of FR “refill” truck traffic
- Elimination of mineral oils used in liquid FRs
- One pneumatic transport can supply 50-100 frac stages
- For International Operations – significantly reduced shipping costs

Dry Powder Usage History

- Currently 16 units in DCS fleet
- Began in early 2019 with first unit
- 20MM lbs of powder delivered since startup

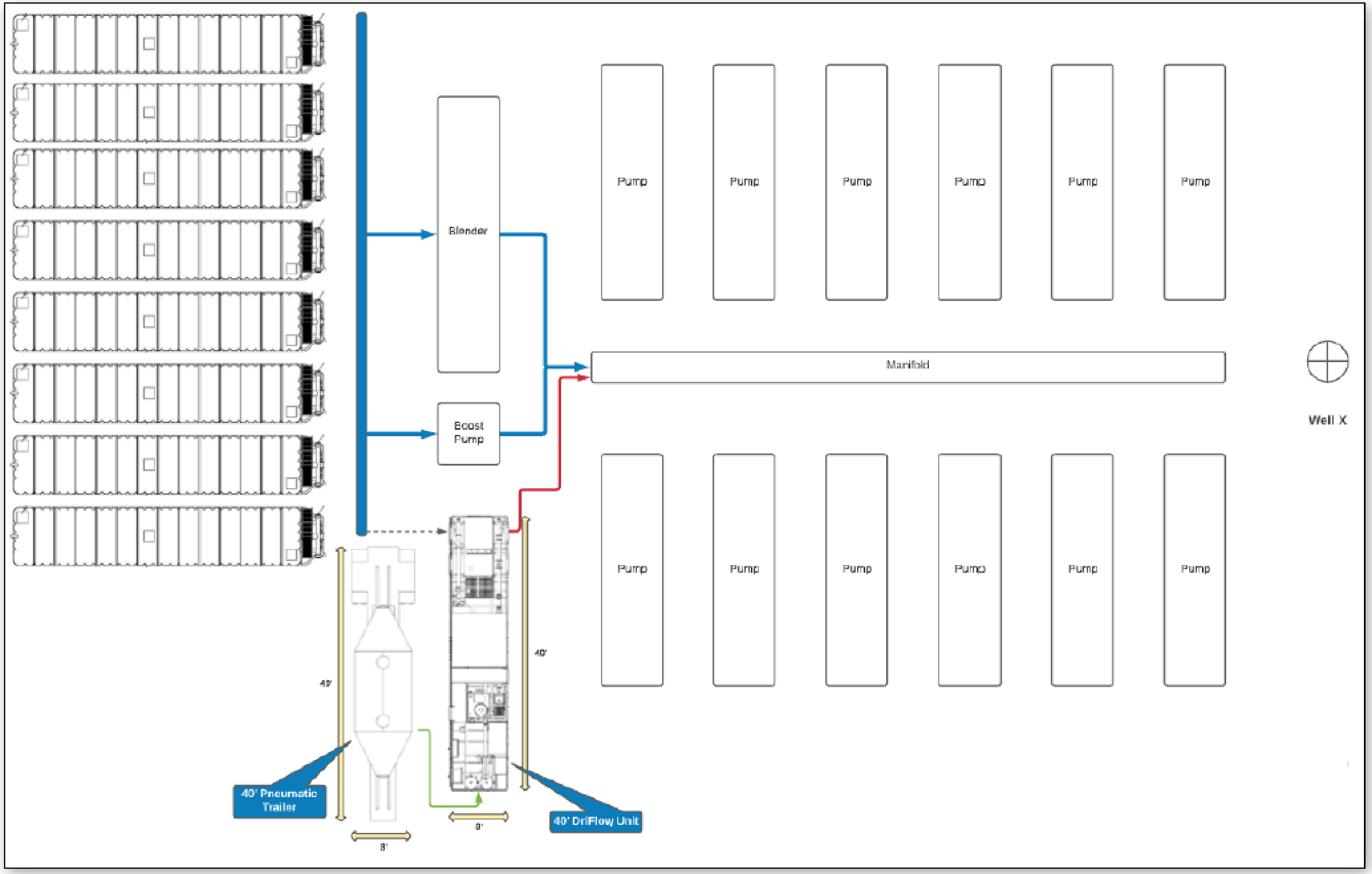


“Dry On The Fly” System

- Suction/Discharge Manifold
- Powder Mixing System
- Chemical Additive Pumps
- Air Handling
- Dual-Screw Powder Feed Mechanism

SPE 204176

“Dry On The Fly” Wellsite Layout



Cost Analysis Example (Two Wells from Same Pad)

Well #1			
Stage	Liquid FR Used?	Dry FR Used?	Total FR Cost
1	x		$1,844
2	x		$3,975
3	x		$4,208
4	x		$3,657
5	x		$3,275
6	x		$3,244
7	x		$3,074
8	x		$3,540
9	x		$2,820
10	x		$3,551
11	x		$3,138
12	x		$3,021
13	x		$3,678
14	x		$3,000
15	x		$3,159
16	x	x	$3,733
17	x	x	$2,796
18		x	$2,108
19		x	$3,403
20		x	$2,811
21	x	x	$3,610
22		x	$2,299
23		x	$2,670
24		x	$2,150
25		x	$1,964
26		x	$1,905
27	x		$2,767
28		x	$1,967
29		x	$1,791
30		x	$1,955
31		x	$2,054
32		x	$1,845

Ave. Cost
Liquid FR =
$3381/stage

Ave. Cost
Dry FR =
$2352/stage

Savings 30%

Well #2			
Stage	Liquid FR Used?	Dry FR Used?	Total FR Cost
1	x		$1,346
2	x		$4,685
3	x		$5,851
4	x		$4,855
5	x		$5,798
6	x		$5,639
7	x		$5,120
8	x		$5,448
9	x		$5,745
10	x		$5,427
11	x		$6,275
12	x		$5,660
13	x		$5,501
14	x		$5,321
15	x	x	$4,769
16		x	$4,524
17		x	$3,122
18		x	$3,884
19		x	$3,436
20		x	$3,349
21	x	x	$4,287
22		x	$3,232
23		x	$3,232
24		x	$3,669
25		x	$3,875
26		x	$3,992
27	x		$4,812
28		x	$3,669
29		x	$3,585
30		x	$3,672
31		x	$2,482
32		x	$2,198

Ave. Cost
Liquid FR =
$5486/stage

Ave. Cost
Dry FR =
$3461/stage

Savings 37%

Carbon Reduction with Dry Powder FR

Webinars

Assumptions

- *22.5 lb CO_2 released per gallon diesel (EPA Guidance)*
- *Typical emulsion contains about 40% oil, which is 86% carbon*

Data from 5 recent pads

	Powder Pumped	Number of Dry Deliveries	Number of Liquid Deliveries	Distance Traveled (Powder)	Distance Travelled (Liquid)	CO2 Reduction (lbs)	Carbon Reduction (lbs)
Eagleford	127,065	4	10	3,080	7,700	20,790	145,701
Delaware	142,471	4	11	976	2,684	7,686	163,367
Permian	43,996	2	6	228	684	2,052	80,124
Haynesville	90,612	3	7	2,640	6,160	15,840	103,902
Haynesville	239,564	6	18	4,692	14,076	42,228	274,700

SPE International

Case History – Vaca Muerta, Argentina

SPE 204171
Early Applications of Viscosifying Friction Reducers For Hydraulic Fracturing Operations in The Vaca Muerta Formation, Argentina
2021

Roberto Sentinelli, Leandro Moreno and Marcelo Pellicer, Pan American Energy
Mark Van Domelen, Downhole Chemical Solutions

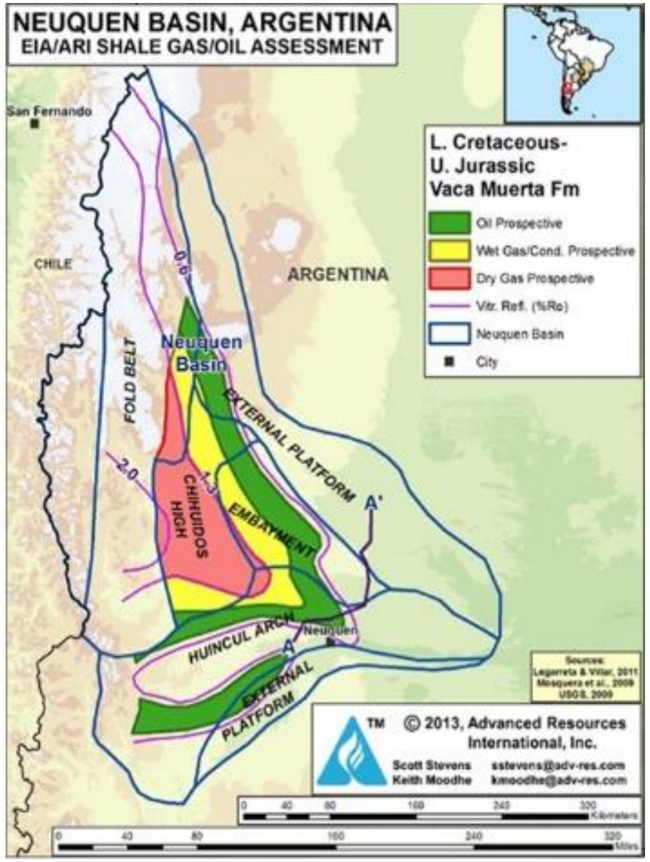
The Vaca Muerta

I. One of the largest shale plays in the world, with over 900 MM bbls (110 MM m3) proven reserves

II. Pay thickness from 100-300 m with high reservoir pressures

III. Reservoir hydrocarbons include oil, wet gas and condensate, and dry gas

III. Keys to Success
  - Infrastructure development
  - Cost reduction
  - Technology application

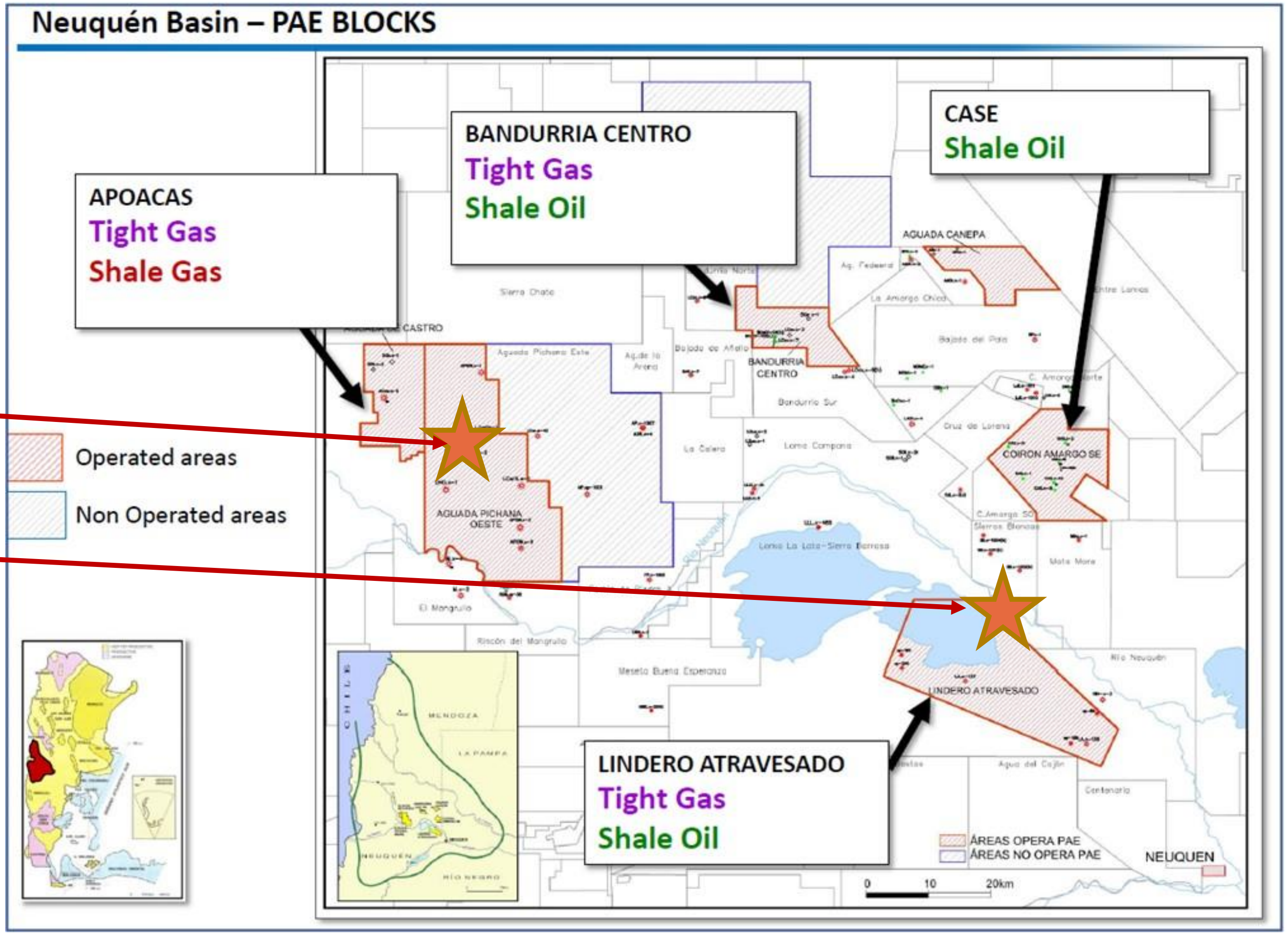


Area of Operations

I. Pan American Energy (PAE) operates 4 blocks in the Neuquen Basin in western Argentina

II. Field trial took place in the Aguada Pichana block

III. 5 well development phase project took place in the Lindero Atravesado block



The Field Trial – 27 Stages in HZ Well

Pump Schedule – Summary

Maximum Pump Rate	**90 bpm**	**14.3 m^3/min**
Maximum Sand Conc.	**5 ppa**	**600 kg/m^3**
Total Fluid Volume	**457,500 gals**	**1732 m^3**
Total Sand Volume	**542,200 lbs**	**246,454 kg**

Pump Schedule – Aguada Pichana

Stage	Rate (bbl/min)	Fluid Type	Fluid Volume (gals)	Sand Conc. ppa	VFR Conc. (gal/Mgal)	Total Sand (lb)	Sand Type
PDP	11	VFR			0.5		
Acid	4	15% HCL					
Acid Flush	4	VFR			0.5		
SDRT	90	VFR			0.5		
Shut.in	0	--					
Pad	90	VFR	35,000		0.5		
0.25 PPA	90	VFR	41,000	0.25	0.5	10,250	Arena malla 100
0.50 PPA	90	VFR	41,000	0.50	0.5	20,500	Arena malla 100
0.75 PPA	90	VFR	41,000	0.75	0.5	30,750	Arena malla 100
1.00 PPA	90	VFR	41,000	1.00	0.5	41,000	Arena malla 100
1.00 PPA	90	VFR	41,000	1.00	0.5	41,000	Arena Natural 40/70
1.25 PPA	90	VFR	41,000	1.25	0.5	51,250	Arena Natural 40/70
1.50 PPA	90	VFR	41,000	1.50	1.5	61,500	Arena Natural 40/70
1.70 PPA	90	VFR	41,000	1.70	2.0	69,700	Arena Natural 40/70
2.00 PPA	90	VFR	18,000	2.00	2.0	36,000	Arena Natural 40/70
2.00 PPA	90	VFR	18,000	2.00	2.0	36,000	Arena Natural 30/70
2.50 PPA	90	VFR	14,000	2.50	3.0	35,000	Arena Natural 30/70
2.75 PPA	90	VFR	9,000	2.75	3.0	24,750	Arena Natural 30/70
3.00 PPA	90	VFR	5,500	3.00	3.0	16,500	Arena Natural 30/70
3.50 PPA	90	VFR	4,000	3.50	4.0	14,000	Arena Natural 30/70
4.00 PPA	90	VFR	4,000	4.00	4.0	16,000	Arena Natural 30/70
4.50 PPA	90	VFR	4,000	4.50	5.0	18,000	Arena Natural 30/70
5.00 PPA	90	VFR	4,000	5.00	5.0	20,000	Arena Natural 30/70
Flush	90	VFR	14,000		0.5		
Total			457,500			542,200	

The Field Trial – Summary

- All 27 stages place with no issues or screenouts
- Compared to Offset Well…
  - Surface treating pressures was 3,500 psi lower
  - HHP required was 7,000 HHP lower
  - Hydration unit was not required
- Concentrations and volumes of the VFR were reduced as experienced was gained
- Cost reduction of 32% was realized

Field Development Case History (5 wells)

I. Lindero Atravesado Block

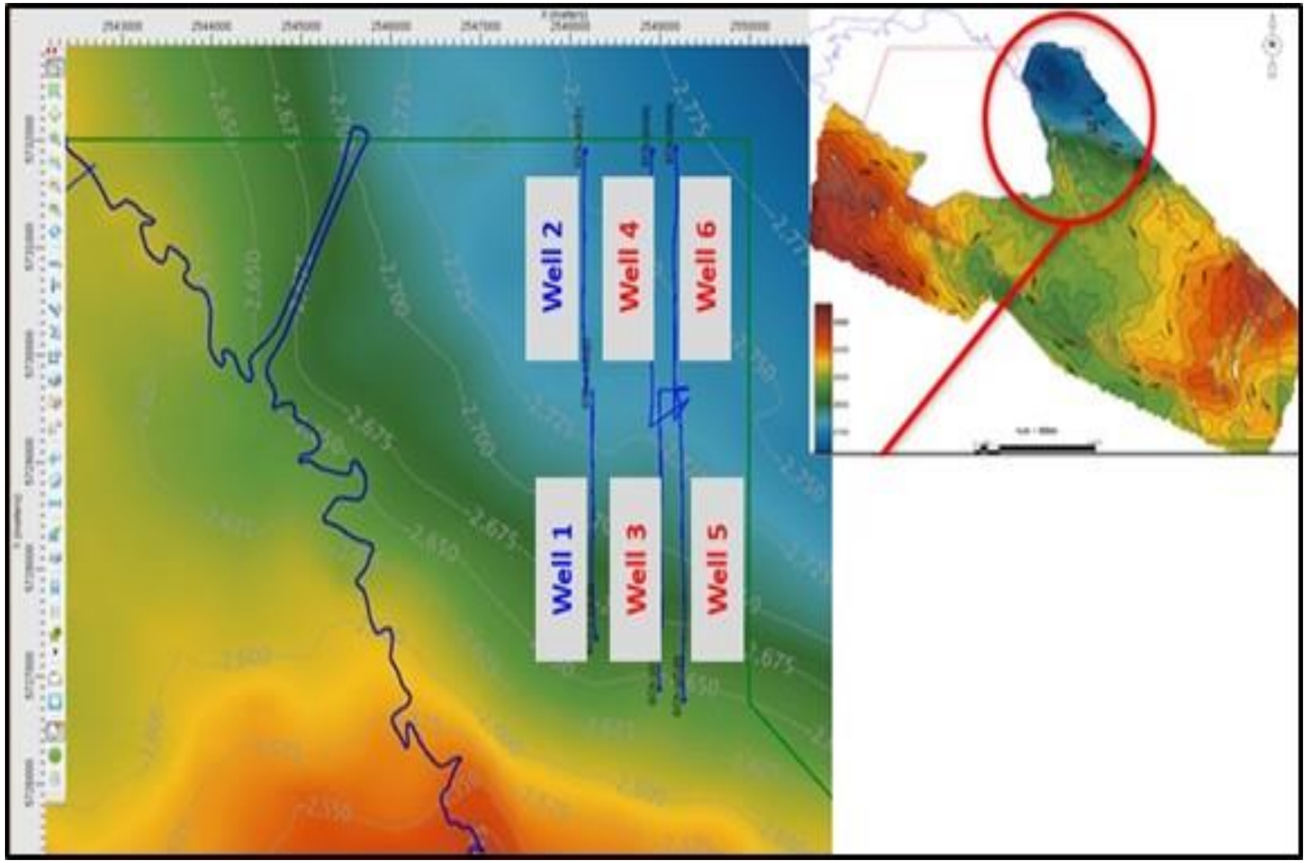
II. 5 wells in same landing zone (well 6 in different zone)

III. Wells 1-2 ➔ Hybrid Fluid

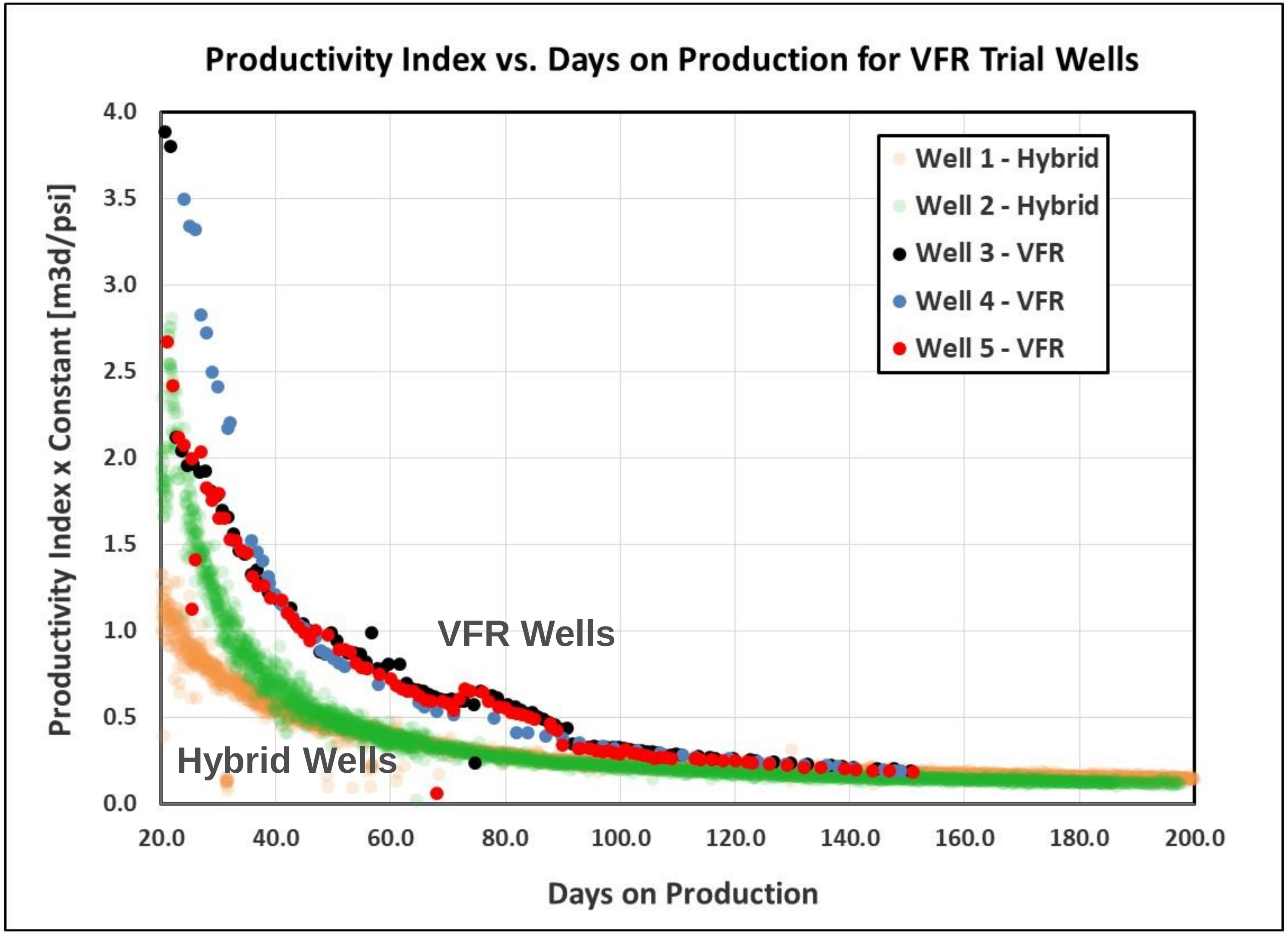
IV. Wells 3-6 ➔ VFR Fluid

V. Same fluid and proppant volumes

VI. Hybrid wells completed about 4 months prior to VFR wells



Field Development Case History (5 wells)



Summary of SPE 204171

I. To date, 19 wells have been completed with VFR system

II. Fracturing operations have been simplified

- Fewer chemicals on location
- No hydration unit
- Lower HHP requirements

III. Fluid system costs have been reduced by > 30%

IV. Positive production results have been observed

V. VFR fluid system was successfully implemented in the Vaca Muerta, and can be applied to other unconventional plays

Relevant Publications

URTeC 5249 "High Viscosity Friction Reducer Testing, Trialing, and Workflow: A Permian Basin Case Study" **2021**

SPE 204176 "Dry Powder Deliver of Friction Reducers: A Step Change in Slickwater Fracturing" **2021**

SPE 204171 "Early Applications of Viscosifying Friction Reducers for Hydraulic Fracturing Operations in the Vaca Muerta Formation, Argentina" **2021**

IPTC-20112 "Application of High Viscous Friction Reducers in Saudi Unconventional Reservoirs" **2020**

URTec 2487 "Performance of Friction Reducers in Iron-Rich Environments" **2020**

SPE-195199 "Correlating the Performance of Friction Reducers with Source Water Chemistry" **2019**

Relevant Publications (Cont'd)

SPE-196073 "An In-Depth Study of Proppant Transport and Placement with Various Fracturing Fluids" **2019**

SPE 189893 "Case Studies of High Viscosity Friction Reducers HVFR in the STACK Play" **2018**

SPE-185084 "Applications of Viscosity-Building Friction Reducers as Fracturing Fluids" **2017**

SPE-179154 "High Concentration Polyacrylamide-Based Friction Reducer Used as a Direct Substitute for Guar-Based Borate Crosslinked Fluid in Fracturing Operations" **2017**

SPE-179146 "Dry Polyacrylamide Friction Reducer: Not Just for Slick Water" **2016**

Thank You for Attending!

Q&A