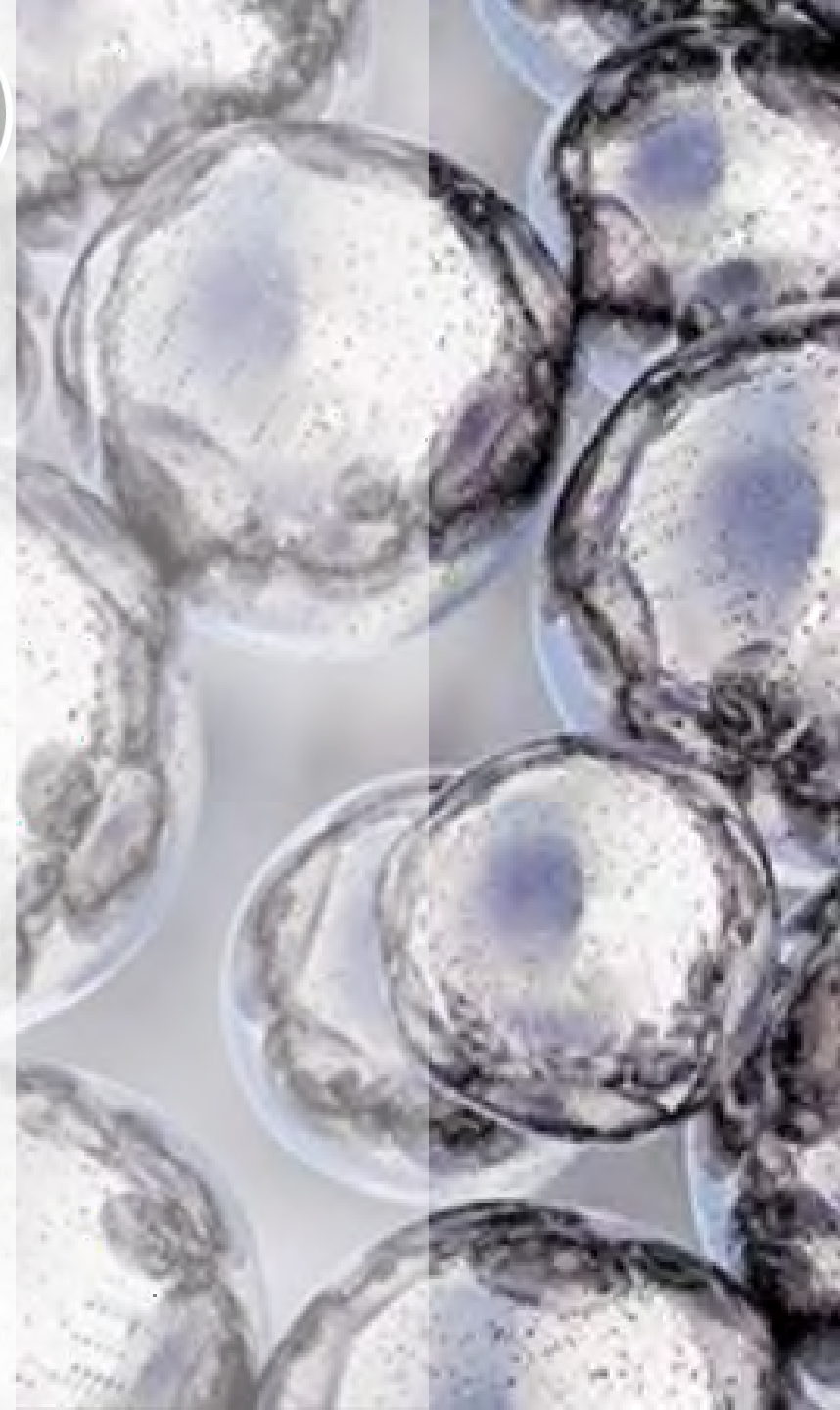
The Impact of Modified Nanoparticles on Oil Recovery
Osama Ahmed, EGPC

Tailored Nanoparticles-based Fluid for Production Enhancement (NanoClear®)
Abdelrahman El-Diasty, TenEx Technologies

Long-term prevention of deposition materials and a long-lasting wetting resistance to heavy hydrocarbon (Case Study in Ras Budran Field; SUCO-GOS)
Hatem Eldawy, SUCO



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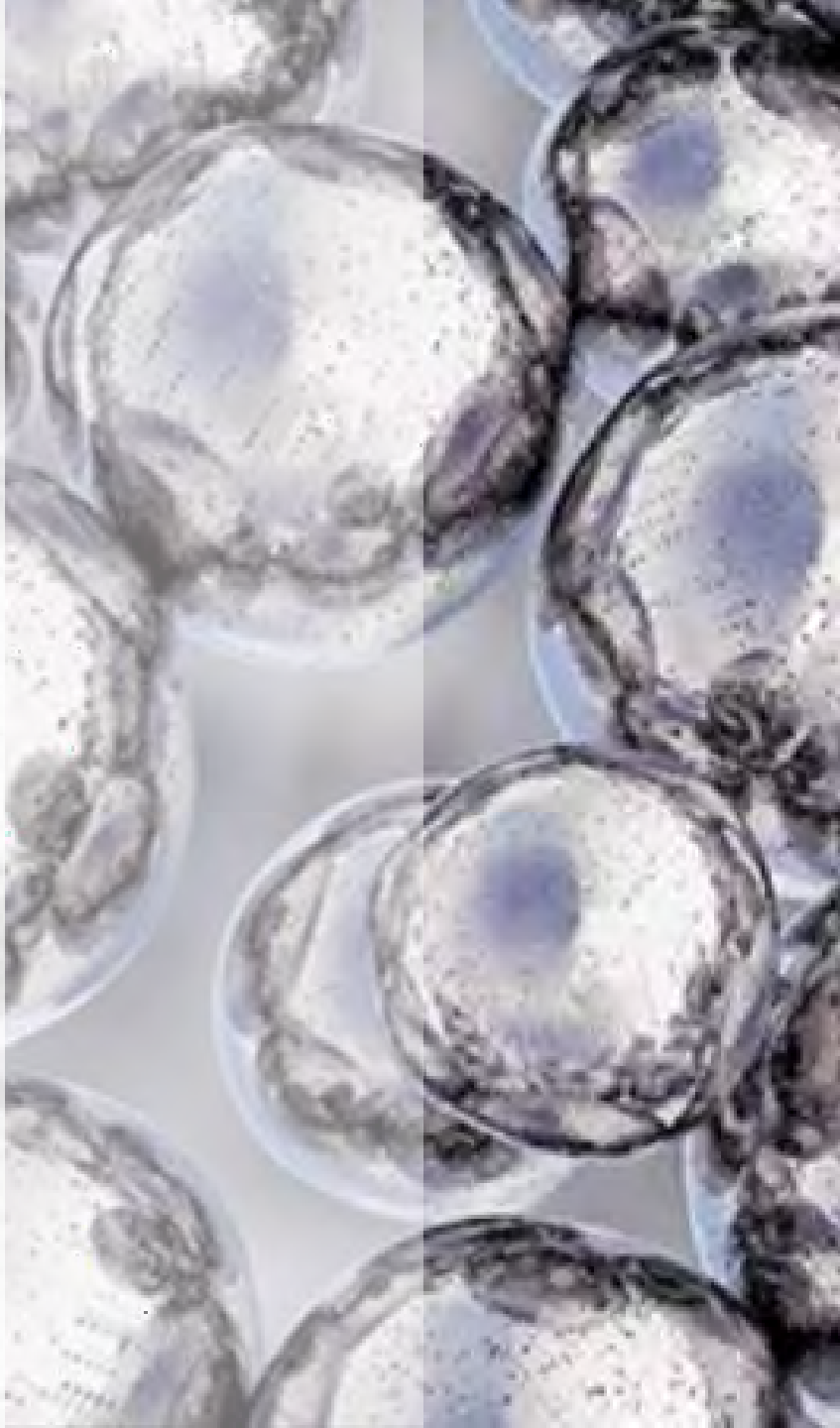
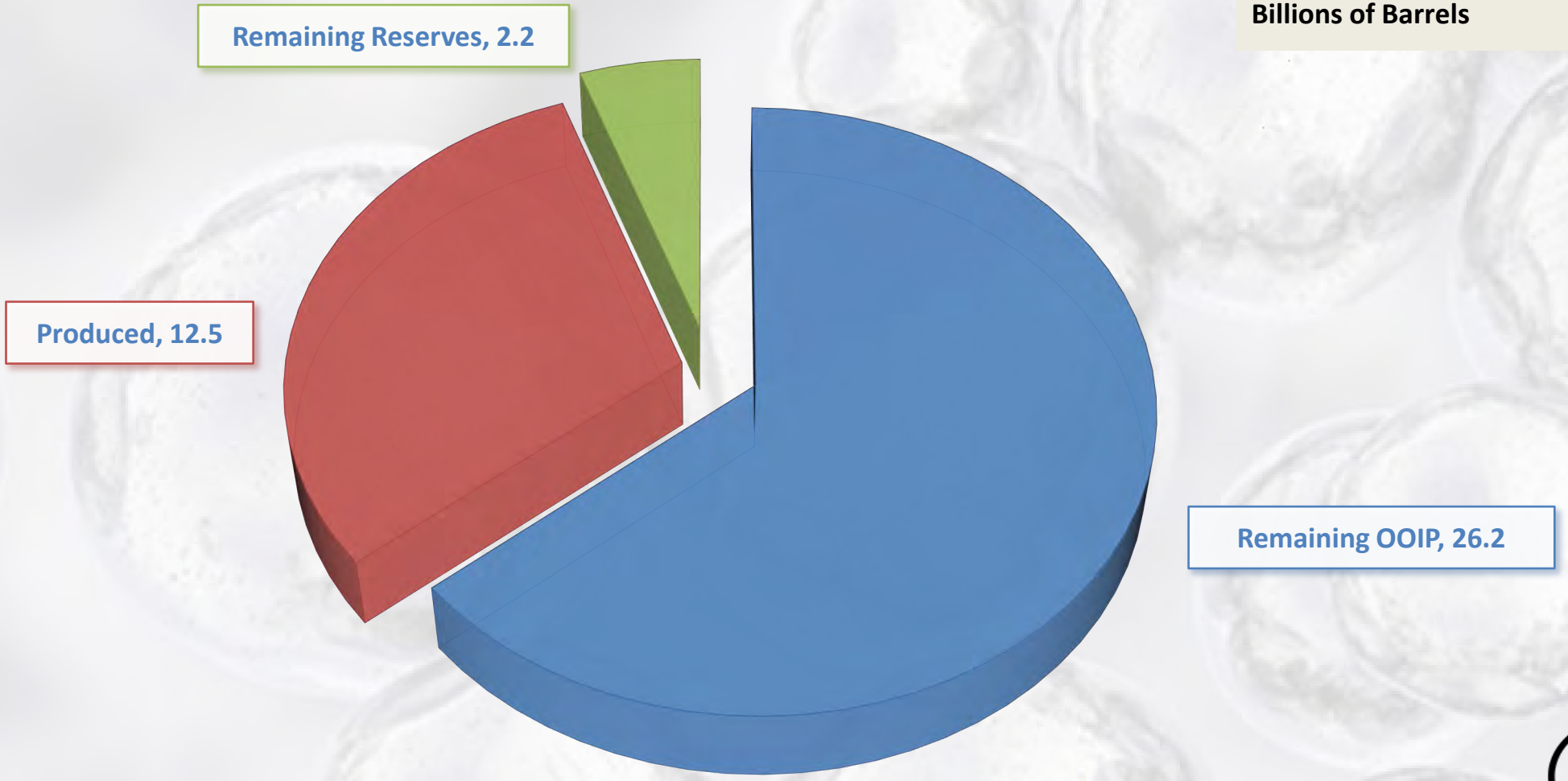


Egypt Oil Reserves Balance

Billions of Barrels



OOIP= 40.9 Billions

EGPC

Can we add more recoverable reserves?

- Increase Exploration Activities to add more resources.
- Increase Recovery Factor.
- Produce the hard oils.

EGPC

Nanotechnology Statistics

An evaluation of modified silica nanoparticles efficiency in enhancing oil recovery of light and intermediate oil reservoirs:

- Results showed that the interfacial tension reduces dramatically in the presence of nanoparticles for both light and intermediate oil.

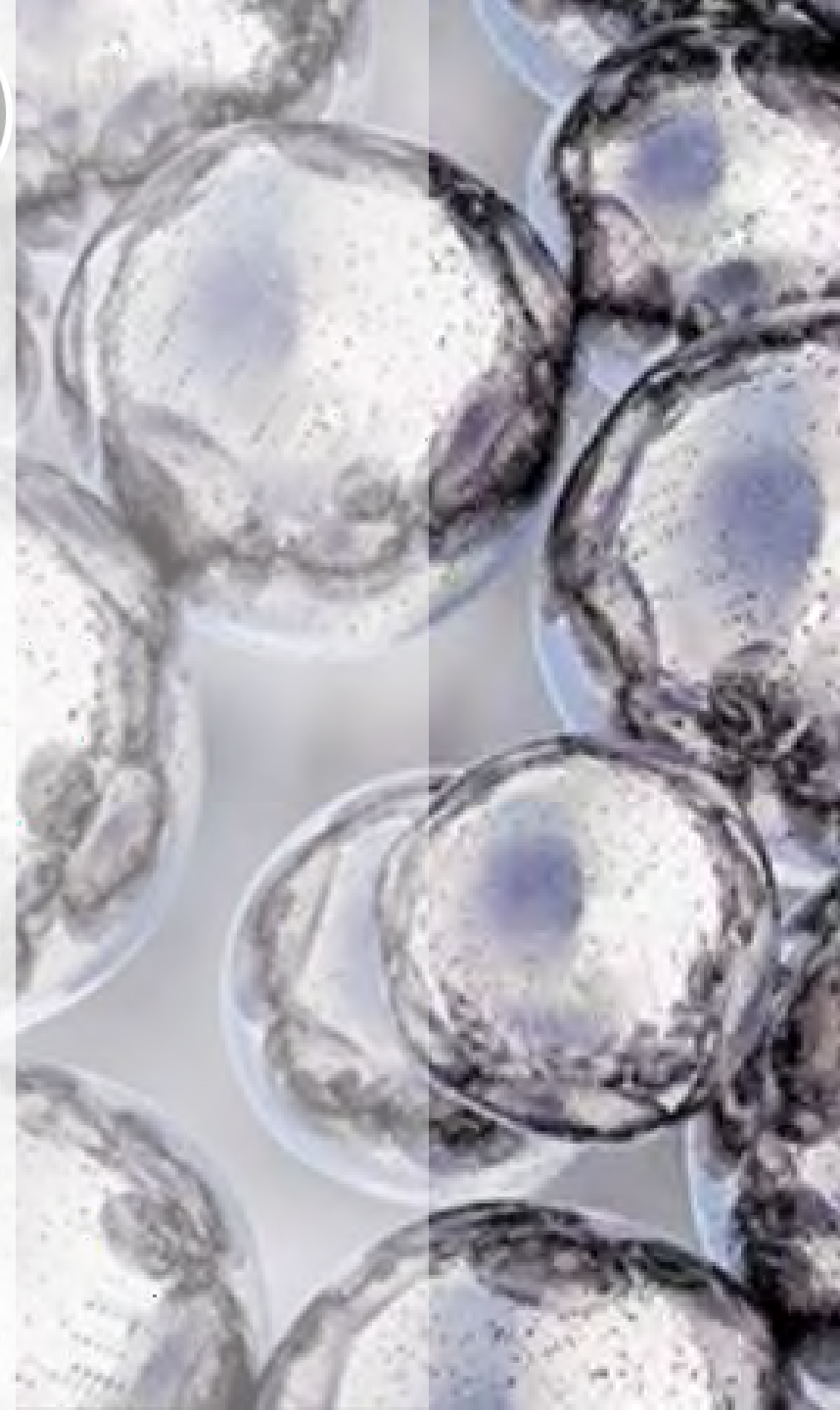
Silica Nano fluid flooding for enhanced oil recovery in reservoir rocks:

- The ultimate recovery of OOIP increased by 13.28% when using tertiary flooding of silica Nano fluid compared to the recovery achieved by water flooding alone.
- Silica Nano fluid flooding is a potential tertiary enhanced oil recovery method after water flooding has ceased.

EGPC

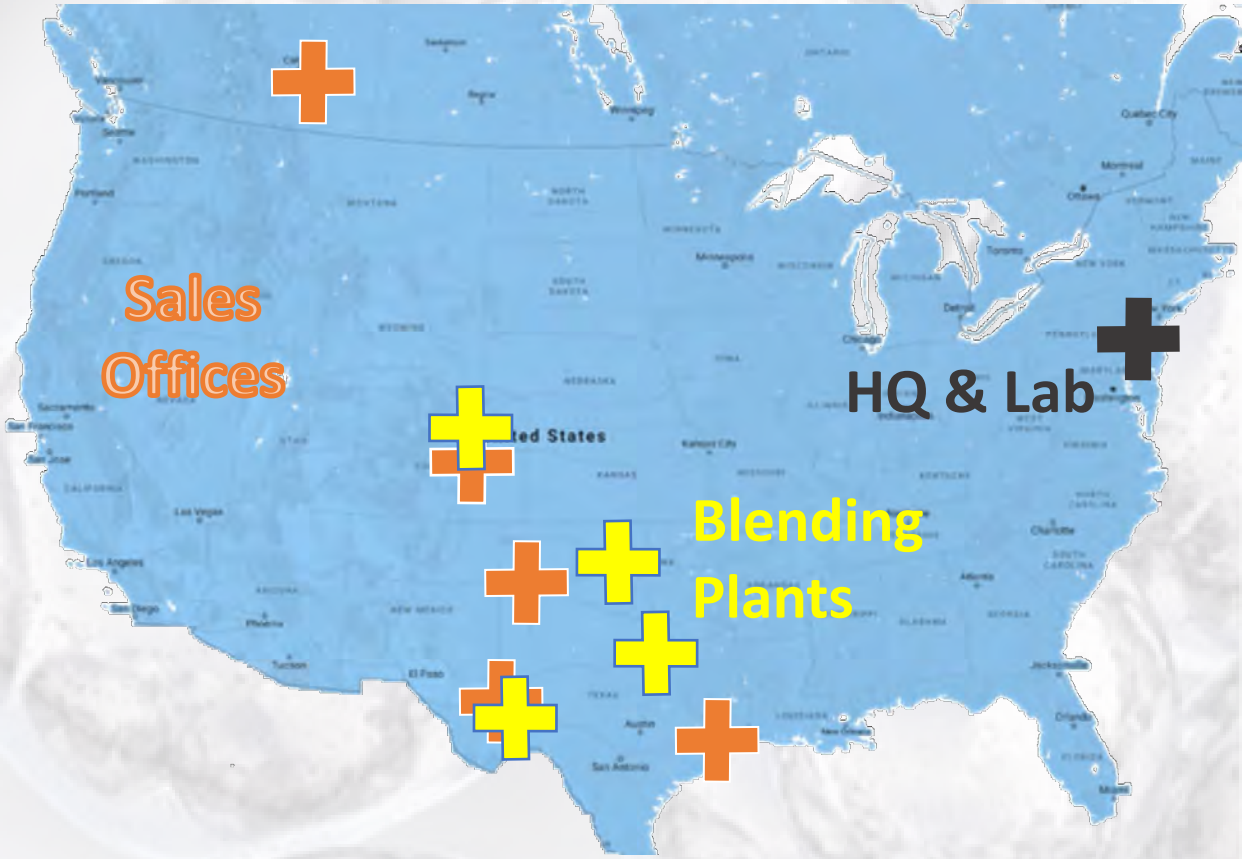
Tailored Nanoparticles-based Fluid for Production Enhancement (NanoClear®)

Abdelrahman El-Diasty, TenEx Technologies



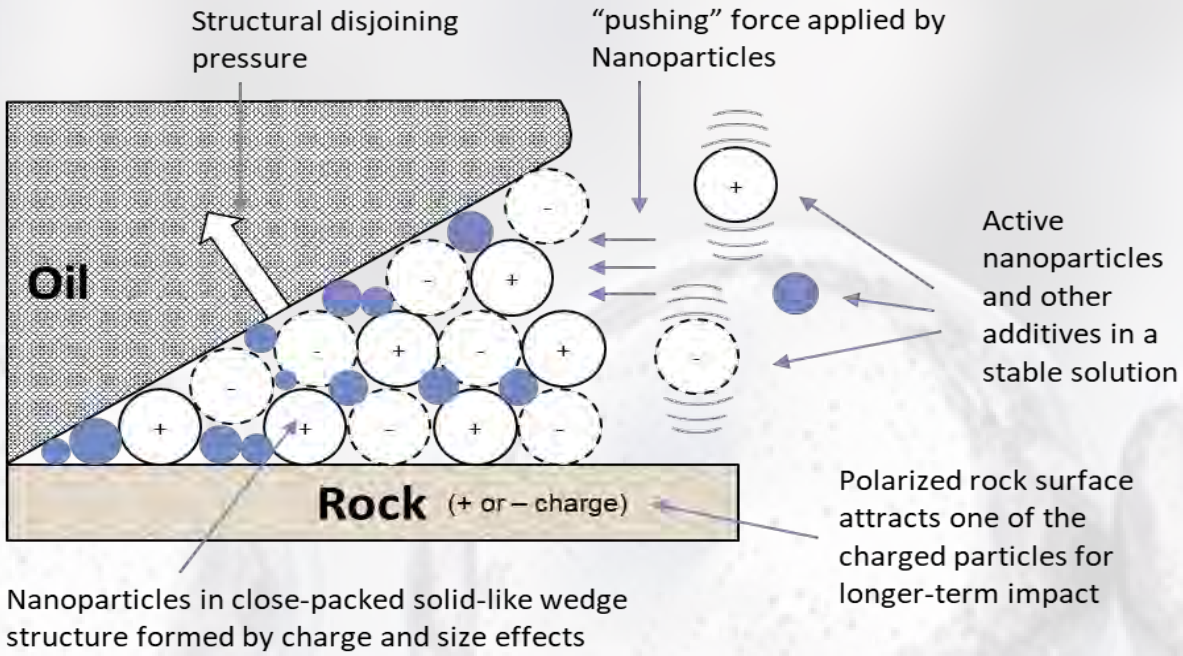
About TenEx

- **TenEx Technologies, LLC** was founded in 2016 with R&D HQ in Philadelphia and sales operations in Houston, Midland, and Denver.
- We develop a Nanotechnology-based portfolio of products tailored for oil production enhancement for existing wells and new completions.
- Our first product, NanoClear®, is a patented nanoparticle solution that has been used to treat over 300 wells in U.S. and Canada since its introduction in 2017.

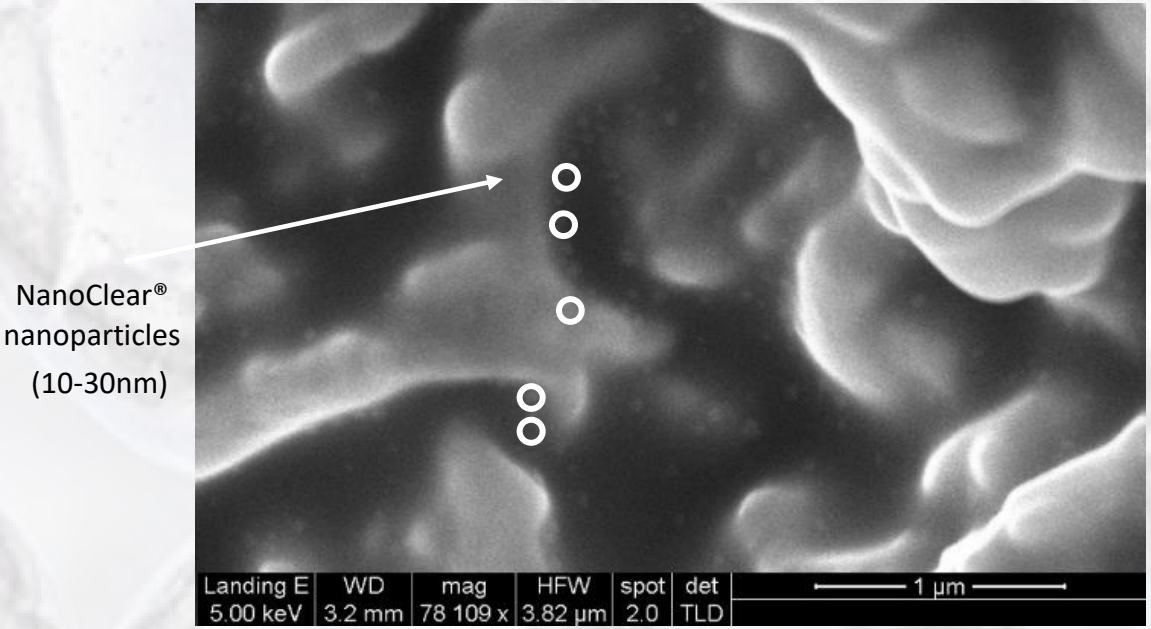


NanoCLEAR® MicroHOLD® NoHIT® SandBOND™

What is NanoClear®? - How Does NanoClear® Work?



NanoClear® takes effect through the use of disjoining force created from Brownian Motion and electrostatic repulsion between the nanoparticles



NanoClear® injected through core in core flood equipment & then core magnified under Scanning Electron Microscope (SEM)

NanoClear® particles shown in the small spaces of the core, "coating" the rock surface to alter wettability from oil wet to water wet

NanoClear® FD: Formation Damage Treatment (Brown Fields)

Removal of formation damage materials

- Natural materials: Paraffin, Asphaltene

Long-term prevention of deposition materials

- Alters wettability (oil wet to water wet)
- Improves permeability over baseline performance by providing a long-lasting wetting resistance to heavy hydrocarbon

Enhances Oil Recovery

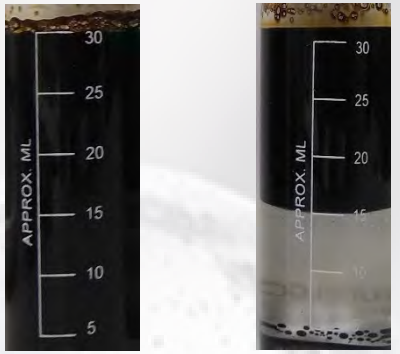
- Enhances oil recovery via wettability alteration
- Reduces water production

NanoClear® FD: Field Operations

1. **Inject NanoClear® into the pay zone(s) at any pump rate**
   - Simultaneously inject NanoClear® FD with water
   - No need to remove pumps or equipment – can pump into tubing or casing
2. **Shut-in the well for a few hours to allow NanoClear® FD to:**
   - Remove formation damage (asphaltene, paraffin, etc.)
   - Reduce surface energy (inhibits build up of asphaltene, paraffin, etc.)
   - Alter wettability to water wet
3. **Resume normal well production**

**Fresh water preferred but can discuss using produced water*

NanoCLEAR® Outperforms in Key Lab Testing



w/o NanoCLEAR®

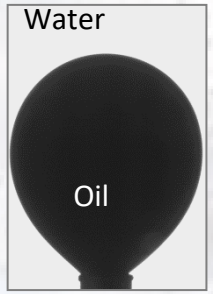
w NanoCLEAR®

De-Emulsification

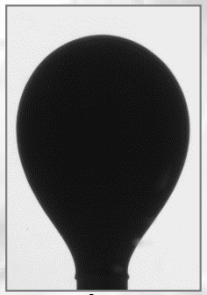
Before Treatment

After Treatment

Spontaneous Imbibition



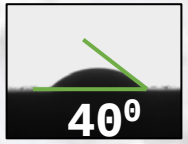
w/o NC



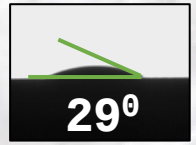
w/ NC

91% lower IFT

Interfacial Tension (IFT)



w/ Nanosurf.



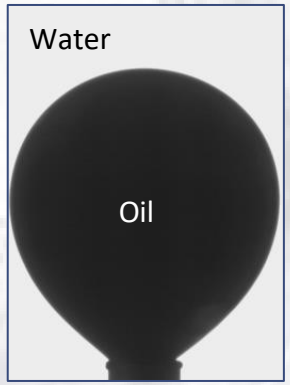
w/ Nanoclear®

Contact Angle

Wettability Alteration: Interfacial Testing (IFT)

- IFT plays a critical role in multi-phase flow in porous media, particularly for water-oil systems.
- The lower the IFT, the more efficient the two-phase fluid flow.
- **NanoClear® significantly reduces IFT:**

The interfacial tension between oil droplet (black) and surrounding water (white) decreases when the aqueous phase contains NanoClear®



Without NanoClear®
IFT = 18.09 mN/m

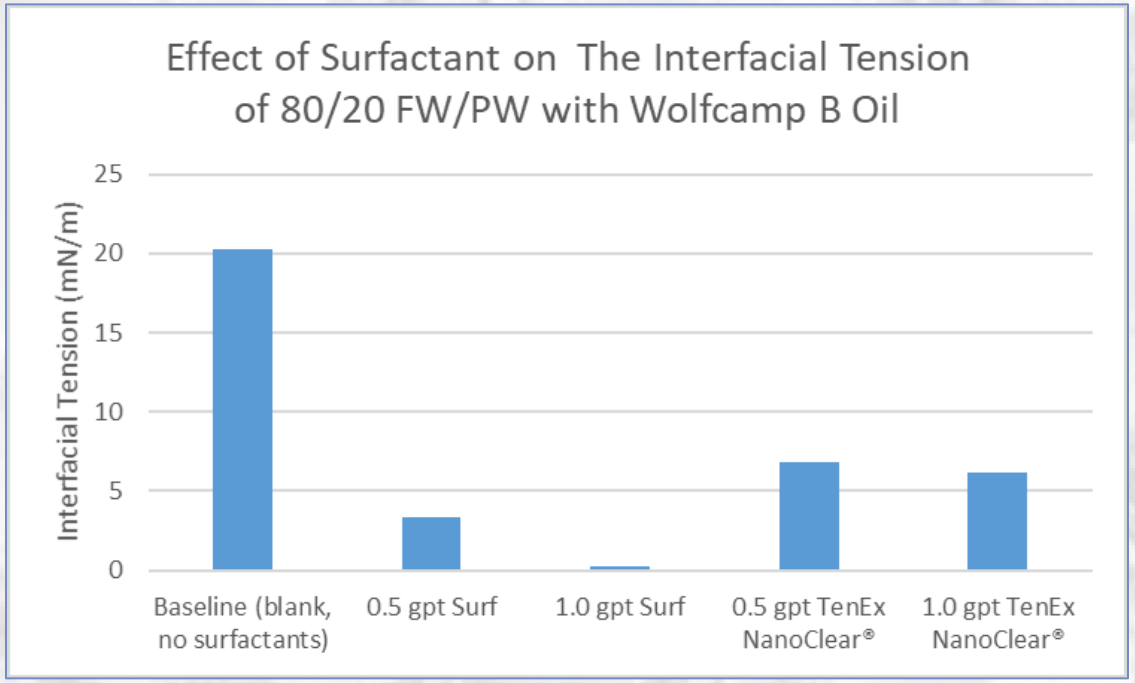
With NanoClear®
IFT = 1.61 mN/m
91% IFT reduction

(left: oil in water; right: oil in water + NanoClear®)

NanoClear® reduced IFT significantly indicating improved capability to help oil migration in porous media

Wettability Alteration: NanoClear vs Surfactants

- NanoClear® delivered a 70% reduction in IFT compared to a base fluid.
- While it does not provide as strong an impact as a premium surfactant, NanoClear® substantially reduces IFT.
- And because NanoClear® persists in the well longer than a surfactant, it provides IFT reduction for a much longer period of time.



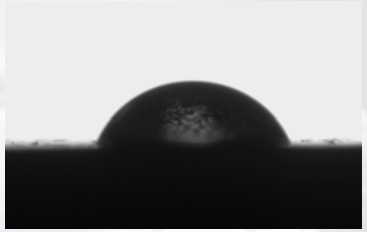
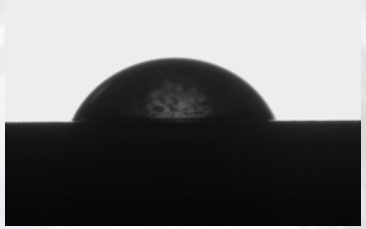
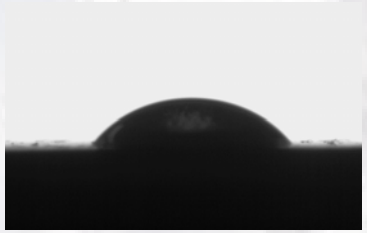
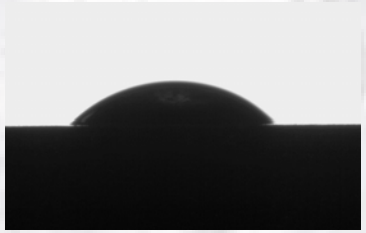
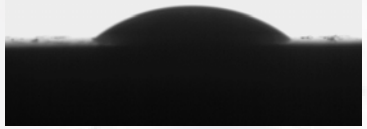
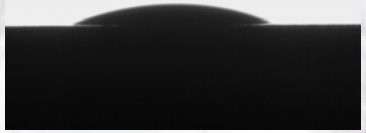
PREMIER OILFIELD GROUP
US LABORATORIES

TenEx customer retained Premier Oilfield Group to perform selected tests of NanoClear®

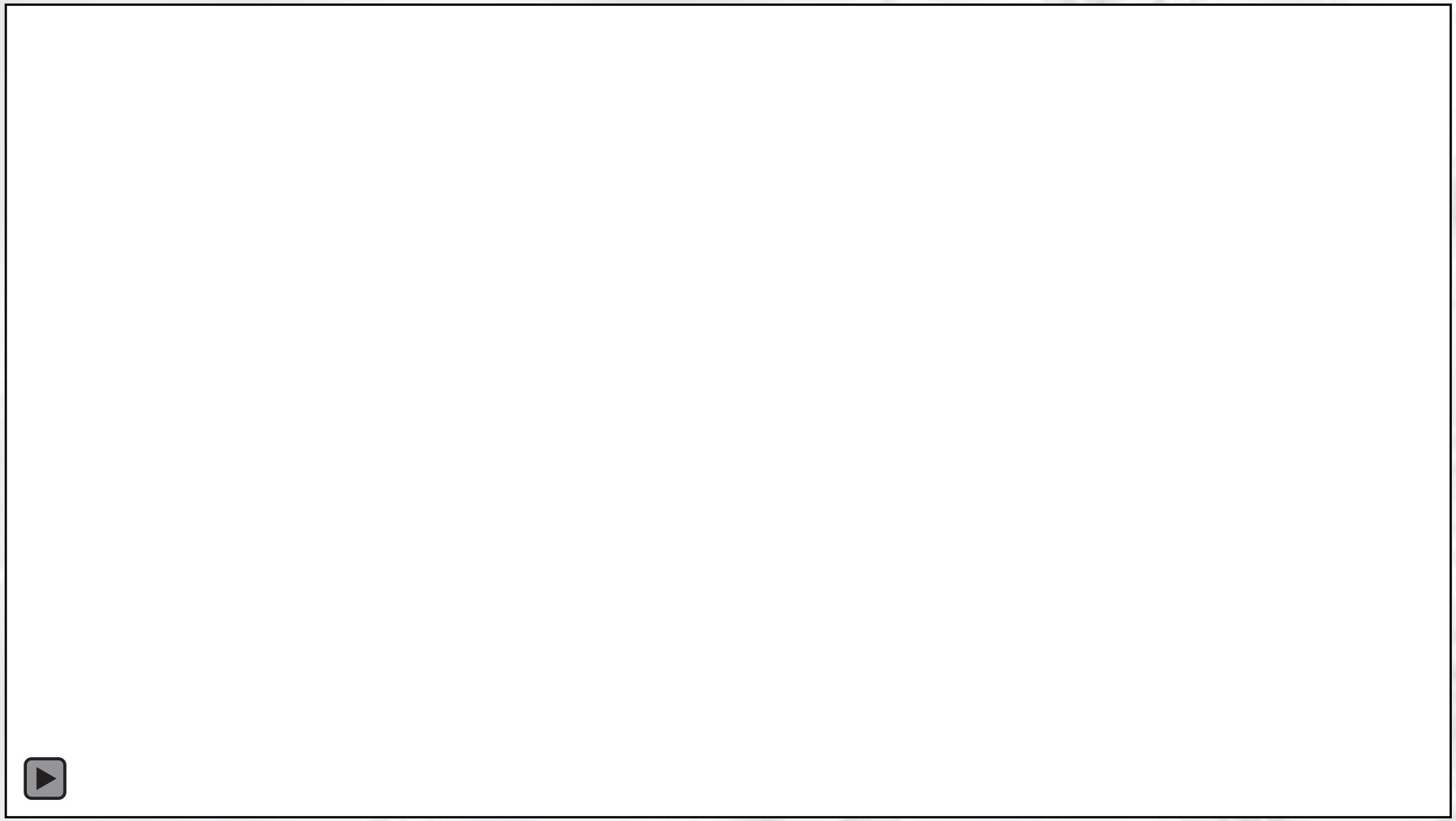
TENEX

Wettability Alteration: NanoClear vs Surfactants

Results on Oil Coated Rock

	Pretreated with Surfactant	Pretreated with NanoClear®
Time: 0.2 min	 Contact Angle: 76°	 Contact Angle: 67°
Time: 10 min	 Contact Angle: 58°	 Contact Angle: 48°
Time: 20 min	 Contact Angle: 40°	 Contact Angle: 29°

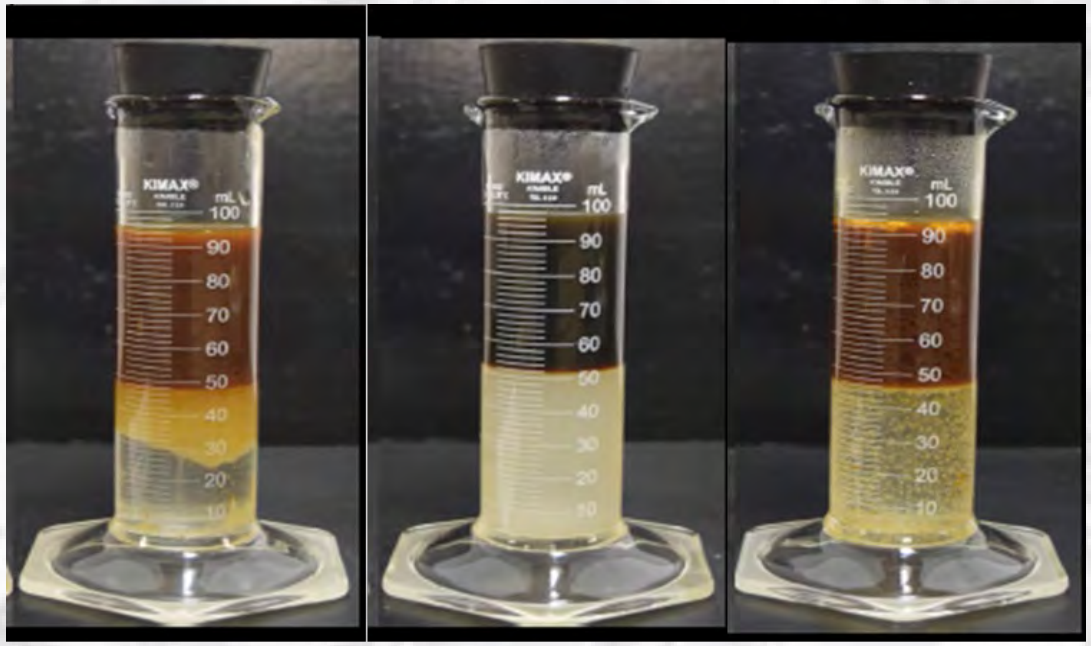
Wettability Alteration: NanoClear vs Surfactants



Wettability Alteration: NanoClear vs Surfactants

De-Emulsification Testing

- The de-emulsification characteristics of NanoClear® and a premium surfactant were compared using the following test parameters:
  - Water: 80% fresh, 20% produced
  - Water/Oil ratio: 50/50
  - Timeframe: 60 min.
- As can be visibly seen, NanoClear® provided substantial de-emulsification effects compared to an untreated sample, and visibly comparable effects to that of a surfactant.



Untreated | Surfactant @ 1 gpt | NanoClear® @ 1 gpt

PREMIER OILFIELD GROUP
US LABORATORIES

TenEx customer retained Premier Oilfield Group to perform selected tests of NanoClear®

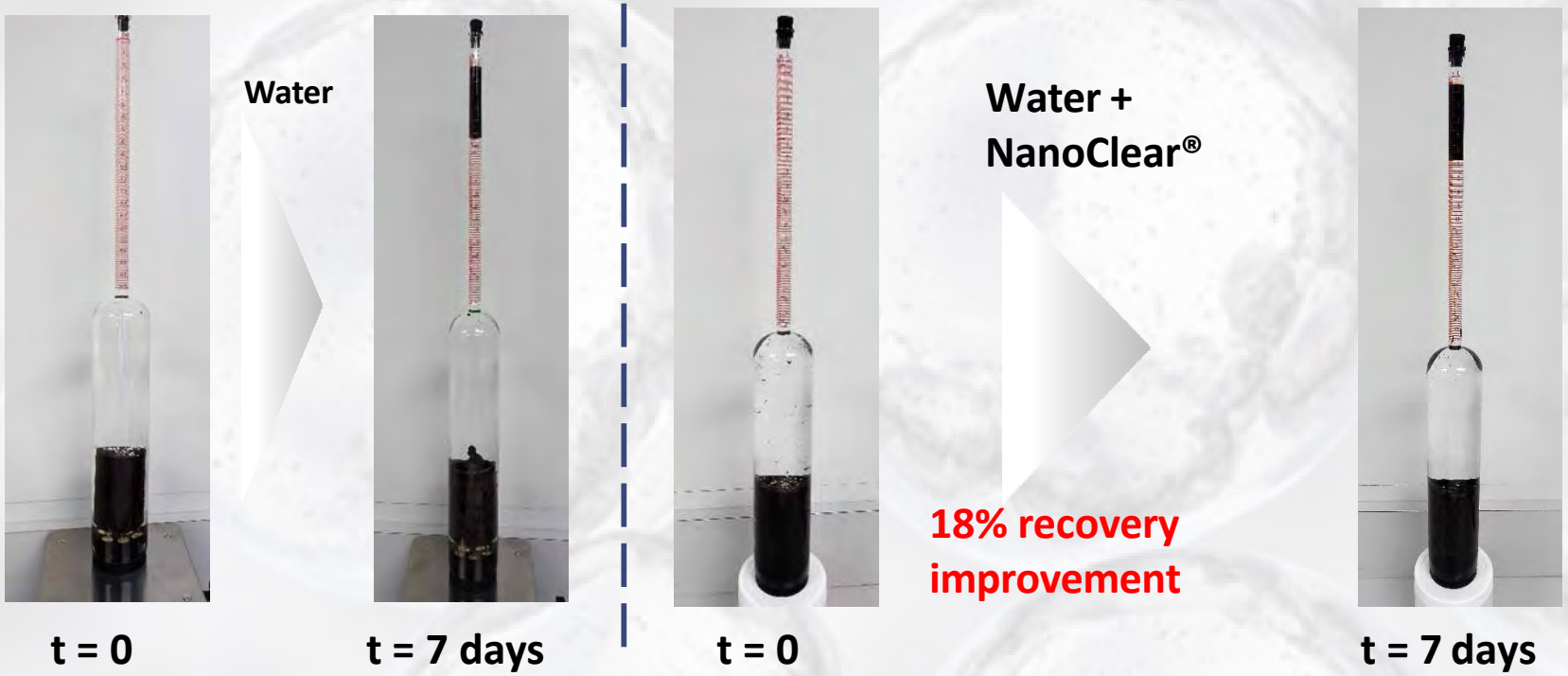
TENEX

Static Bottle Test; Heavy Oil - 12 API, Viscosity is > 1000 cp

NanoClear®: Spontaneous Imbibition with Amott Cell

Static Imbibition Testing:
An oil-saturated core sample is placed in water. The expelled oil volume is monitored and oil recovery determined.

- Berea Sandstone
- Texas Crude
- Room conditions
- 7 Days

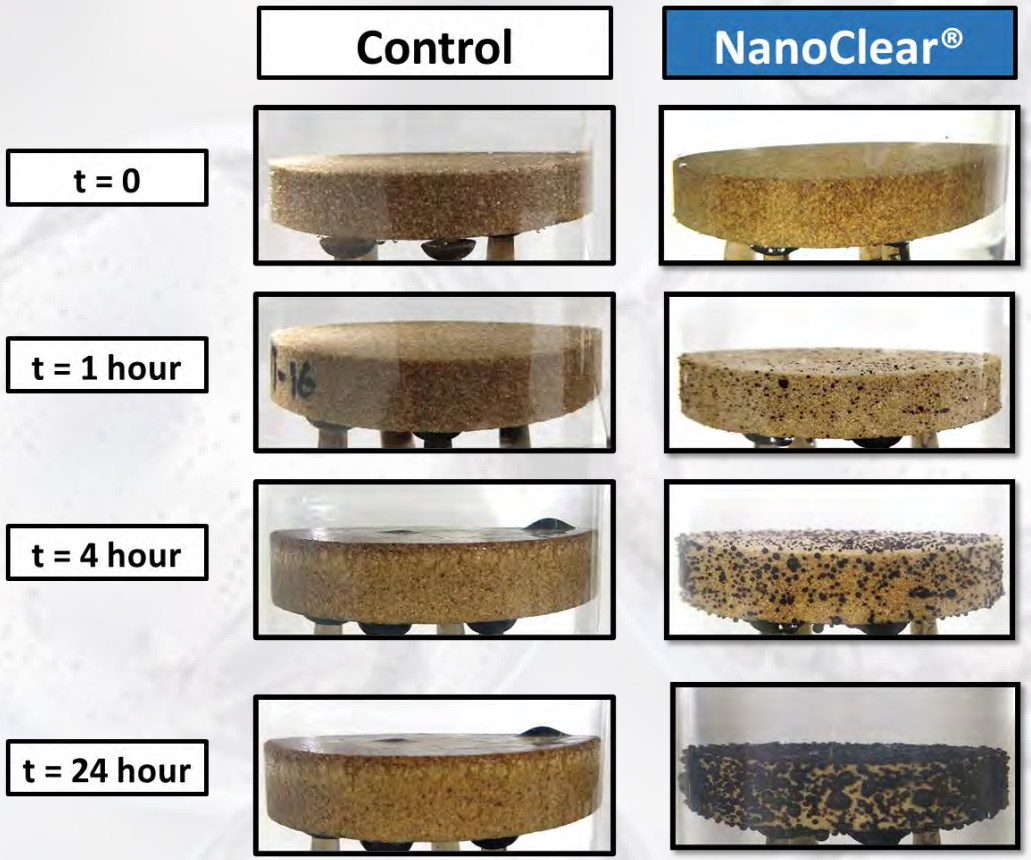


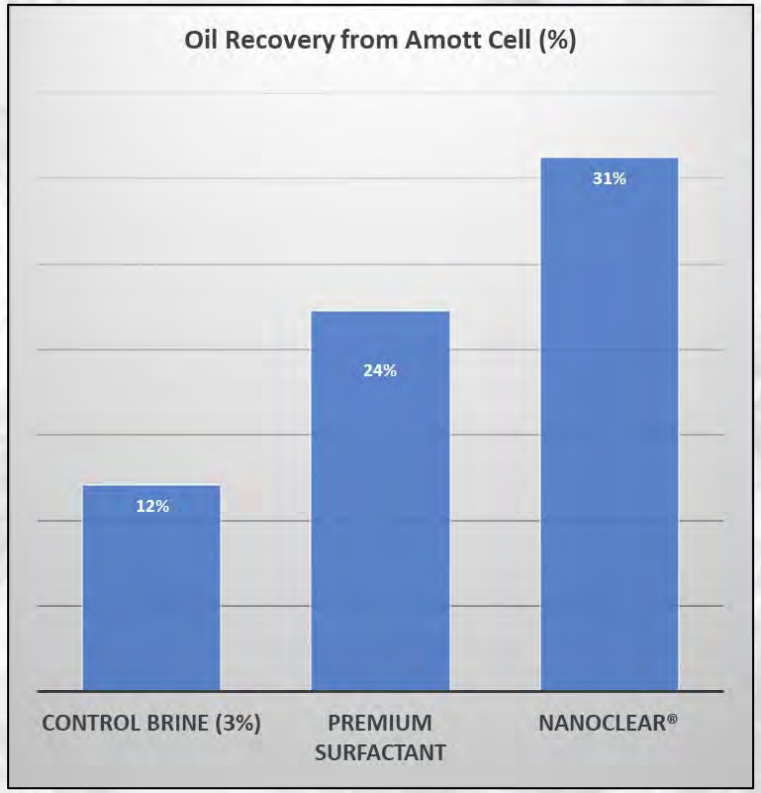
NanoClear® has improved imbibition performance by expelling more oil from the core

Lab Results – Amott Cell Test

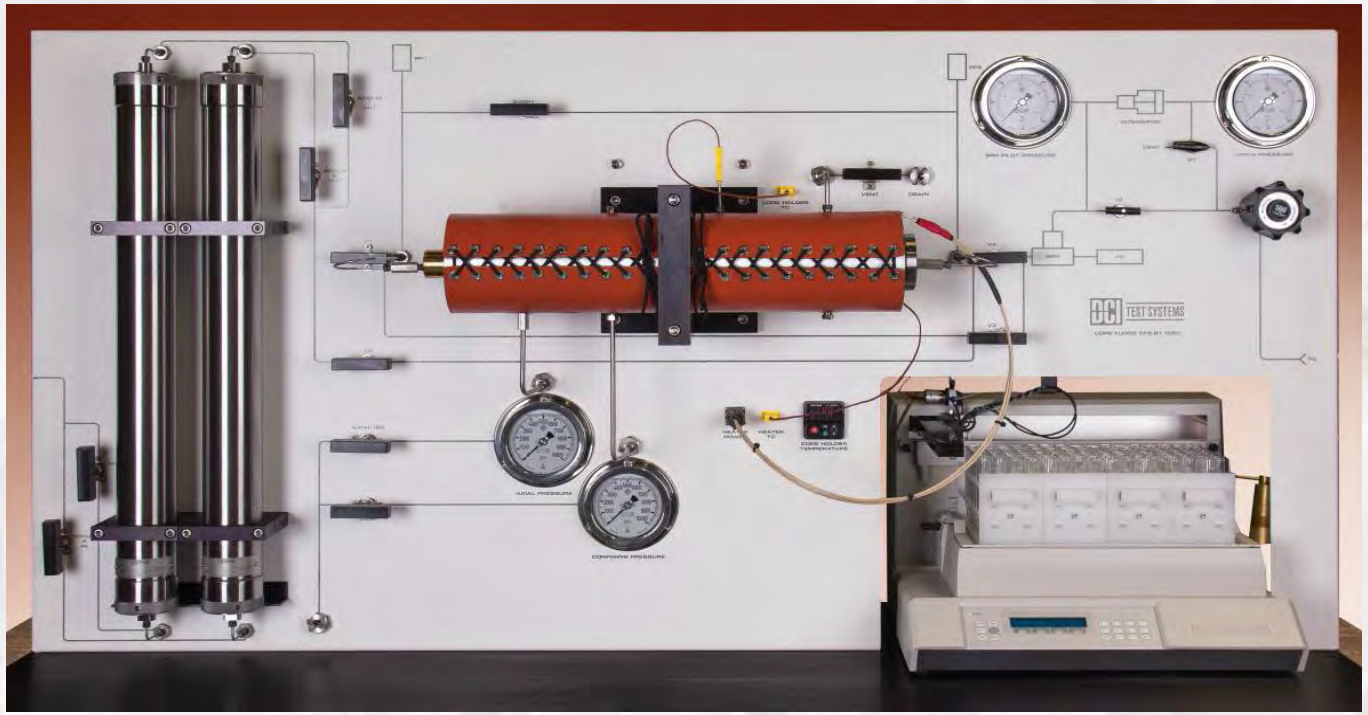
Spontaneous Imbibition Procedure
1. Saturate core with crude oil using vacuum pump for 24 hours. 2. Place core in Amott cell and soak with control/NanoClear®. 3. Observe oil production as a function of time.

Test Conditions	
Pressure	14.7 psi (1 bar)
Temperature	70°F (21°C)
Core	Berea Sandstone
Crude Oil	West Texas Oil
Control	3% KCl
NanoClear® Dosage	1 gpt



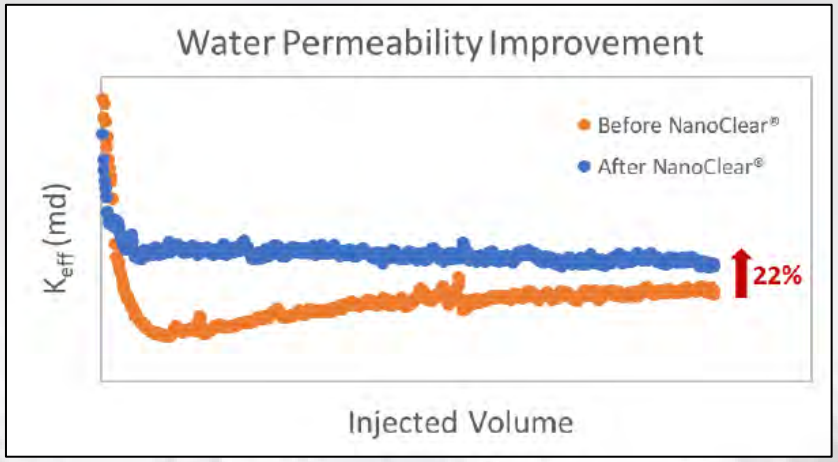


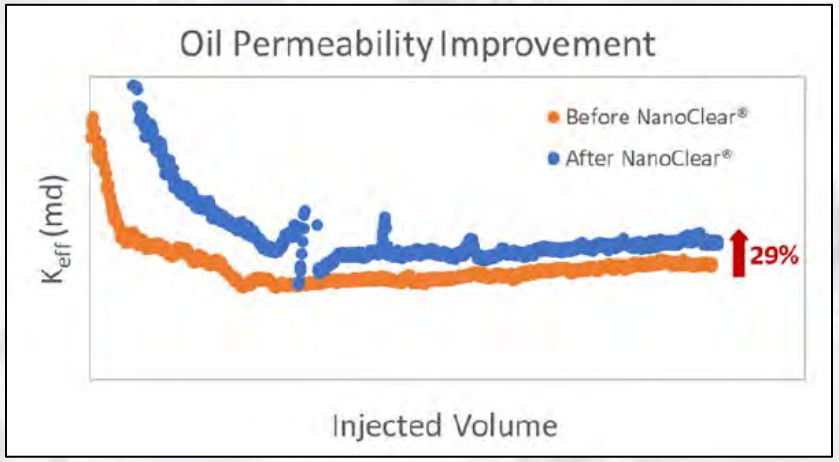
Core Flood Testing – Asphaltene Deposition

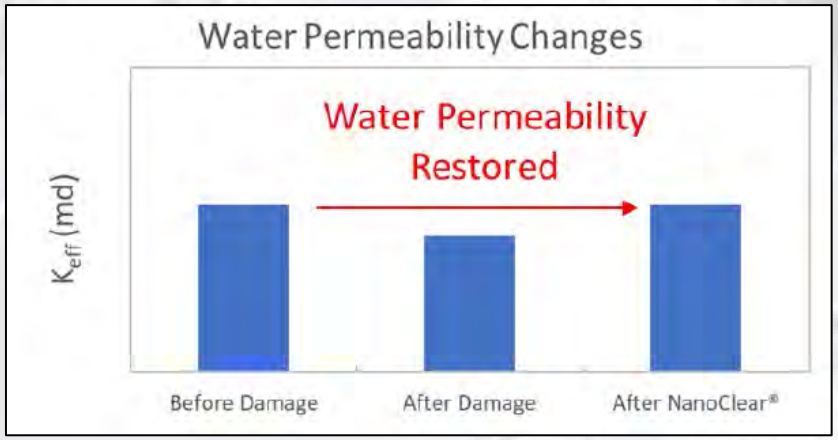


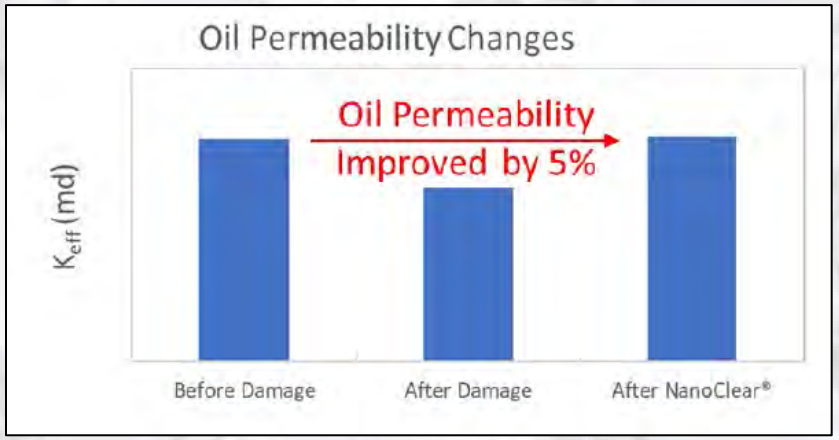
- Core Flooding test simulated reservoir oil/brine saturation and induced asphaltene damage in order to evaluate the effectiveness of NanoClear® treatment in removing formation damage
- Initial conditions were selected based on a medium-depth, mid-life flowing well with pressure of 1000 psi and temperature of 80 °C.
- Continuous measurements collected on the change in permeability and pressure.
  - Stage 1: Saturate core with Texas Crude Oil (with >2% asphaltene content)
  - Stage 2: Induce damage (asphaltene deposition)
  - Stage 3: NanoClear® treatment applied

Lab Results – Coreflood Test (Organic Damage Removal)

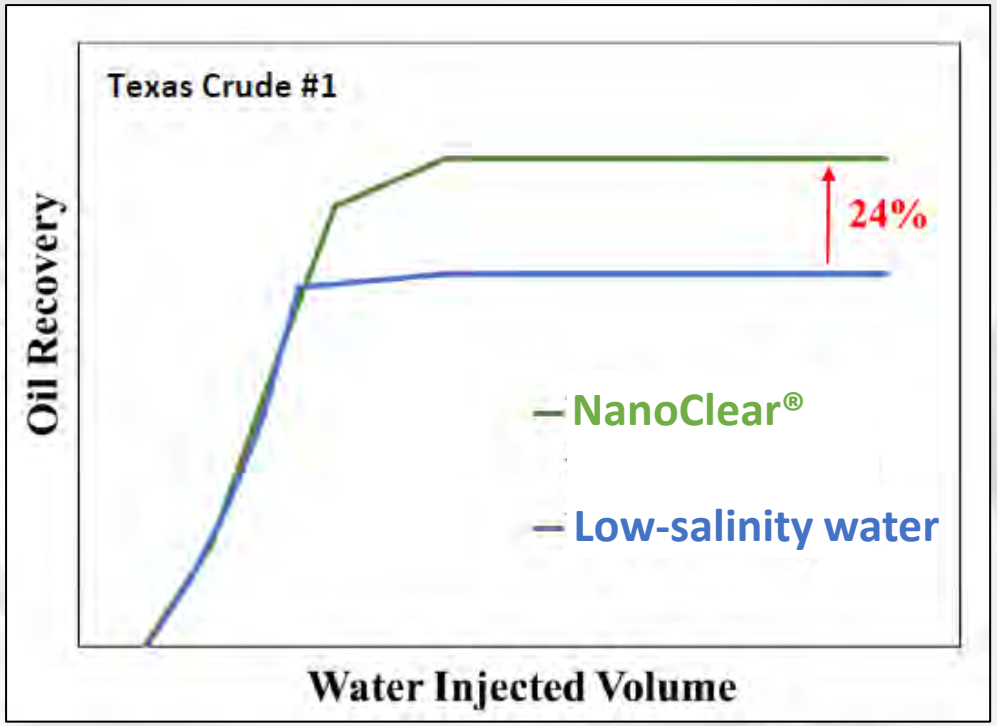




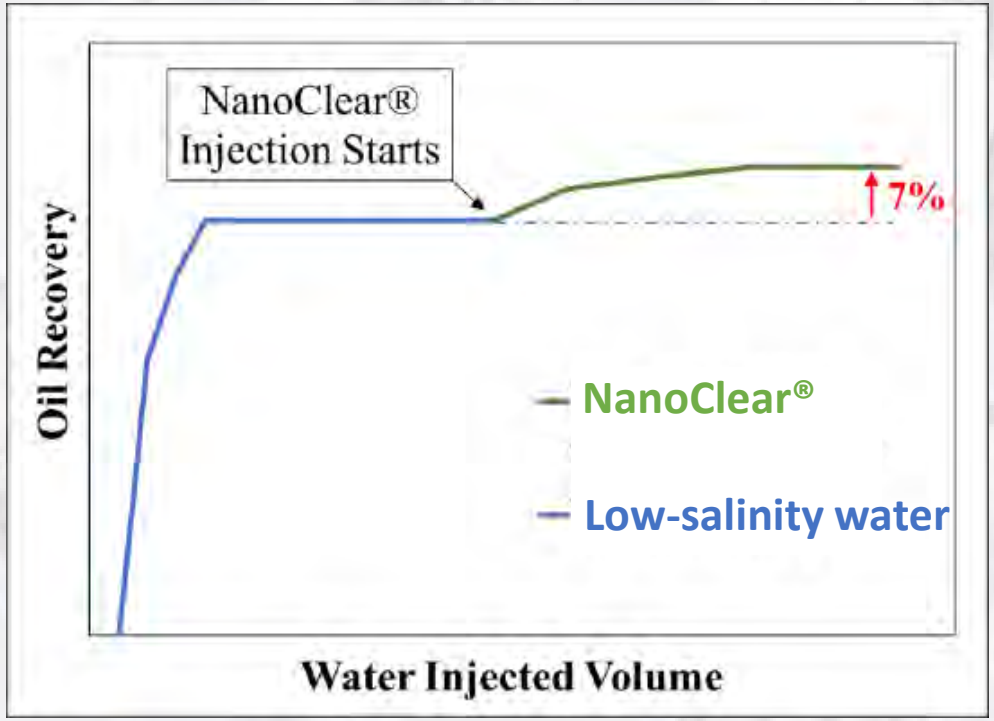




Lab Results – Coreflood Test (EOR)



Secondary Oil Recovery Mode



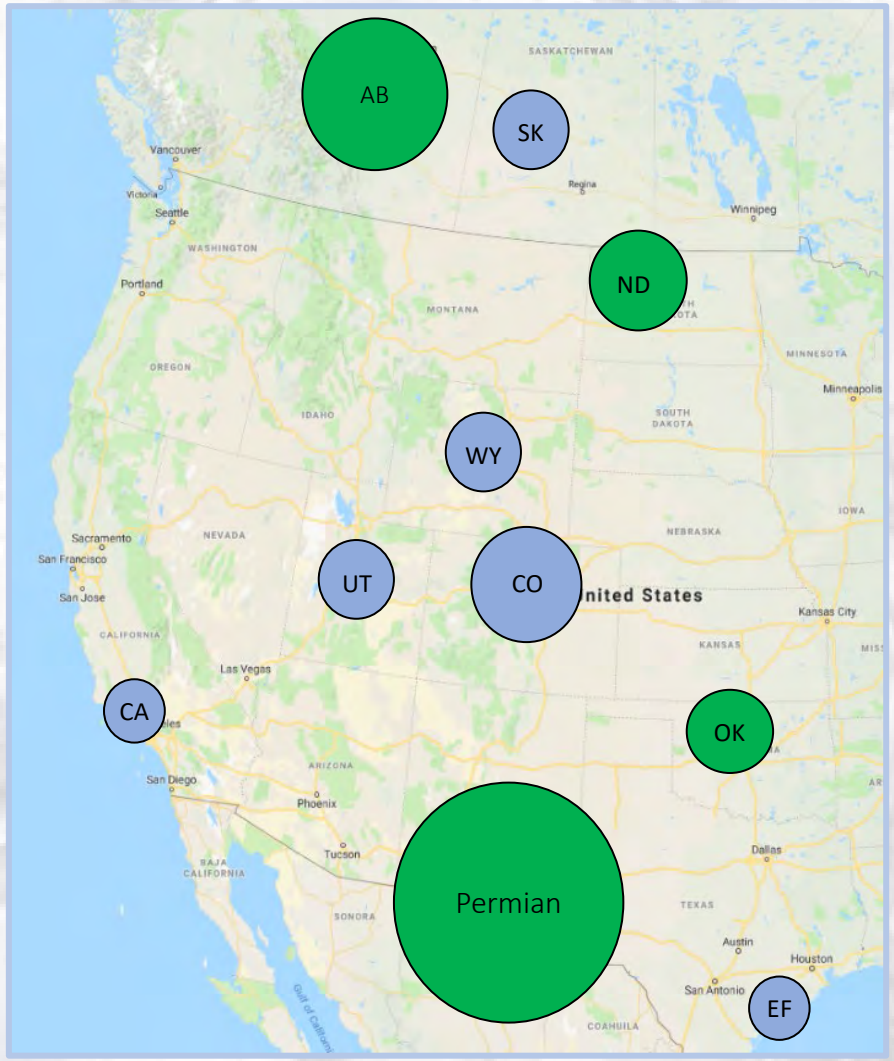
Tertiary Oil Recovery Mode

NanoClear® FD: Benefits

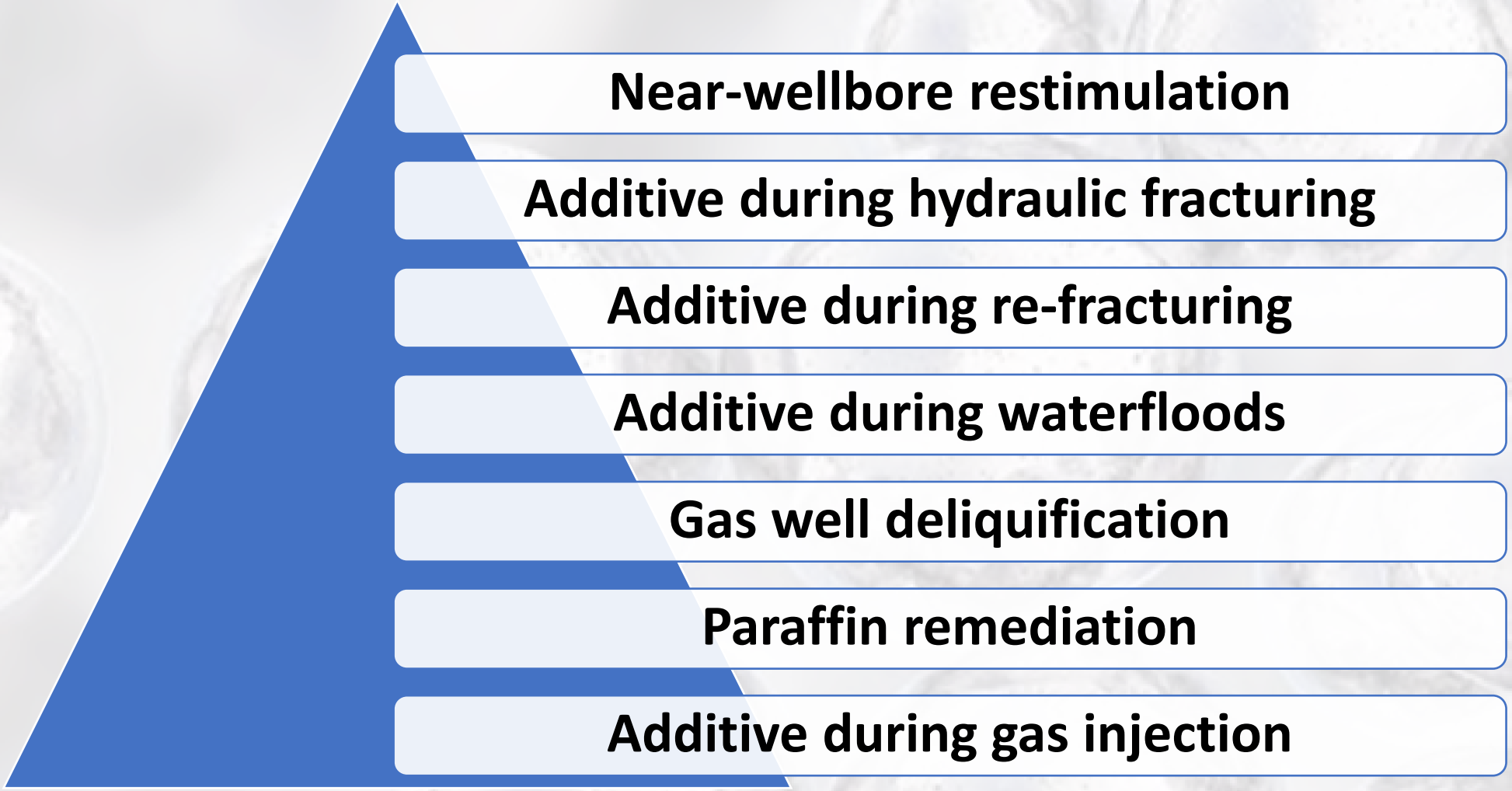
- Cost effective treatment which reduces frequency of treatment vs. other high-performance oil field chemicals
- Proven treatment in field across various formations
- No capital investment
- Simple & quick operations
- Low labor intensity
- Environmentally-friendly materials and fluids
- Seamlessly fit into standard oilfield processes: doesn't require special onsite operations
- Tested in the lab under a physical reservoir simulator to reduce operational uncertainties

NanoCLEAR® Field History

- First well treated in Nov. 2017
- Hundreds of wells treated to date
- Multiple E&P's are continuously pumping NanoCLEAR®
  - Additive to common hydraulic fracturing fluids
  - Stimulation applications (a stand-alone stimulation treatment or as an additive to acids)



Applications for NanoCLEAR®



Summary of NanoClear® FD Wells Treated to Date

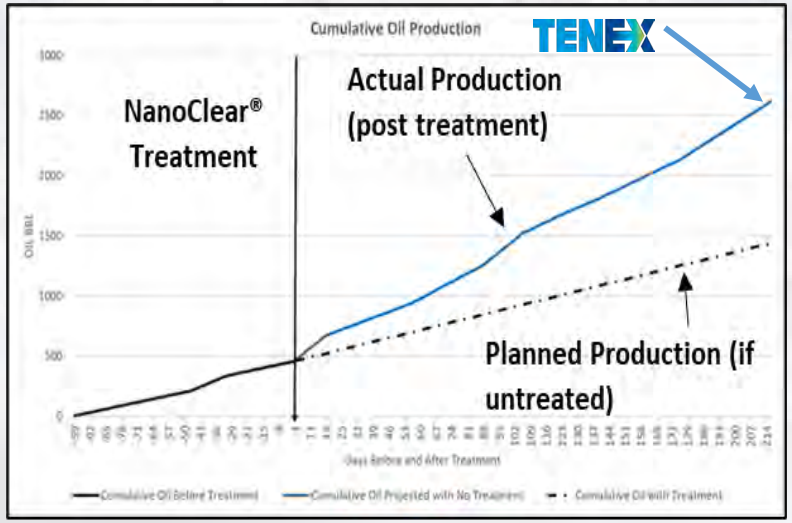
- Treated ~300 wells to date in the WCSB, Williston & Deep basins in Canada and the Permian, DJ, Delaware & Midcon in the US with APIs of 19-45 in various formations
- Trial results show increase in total fluids production (removal of formation damage), increase in oil production & reduction in water cut demonstrating wettability alteration
- 99% successful with water cuts between 10-90%; 97% success rate overall
- Average daily oil production increase is ~20-50% lasting 180 days+
- All case study clients have either ordered additional FD wells, ordered NanoClear® CEC for new fracs, or have confirmed plans for additional trials
- Treated successfully both vertical and horizontal wells

See case studies for more information

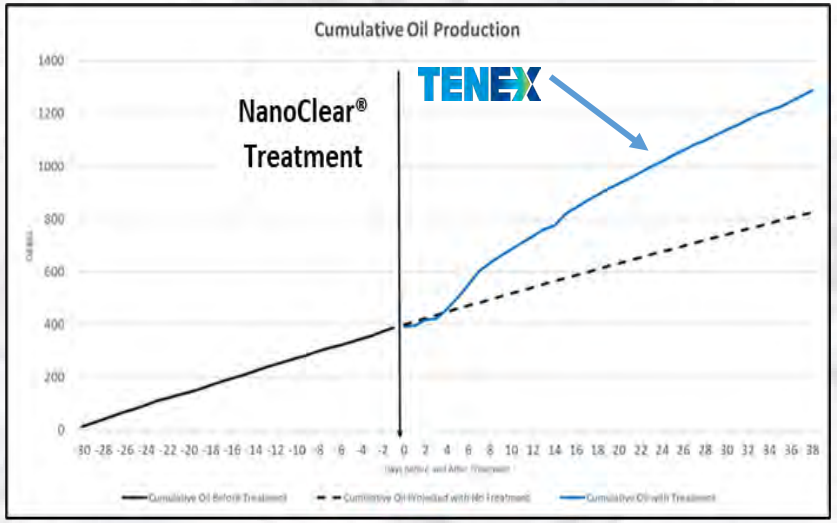
Multi-Basin Restim: Case Studies

APPARENT CROSS-BASIN APPLICABILITY	Well 1	Well 2	Well 3
Basin	Permian, TX	Uinta, UT	Deep Basin, AB
Formation	Spraberry/Wolfcamp	Multiple	Glauconite
Rock Type	Shale + Sand/Limestone	Sandstone & Carbonate	Sandstone
Well Type	Vertical	Vertical	Horizontal
Porosity	10%	10%	10%
Oil API	40°	32°	26°
TVD/MD	10,750 ft	6,020 ft	6,312 ft / 11,237 ft
NanoClear® Qty	1,380 gals	1,110 gals	1,380 gals

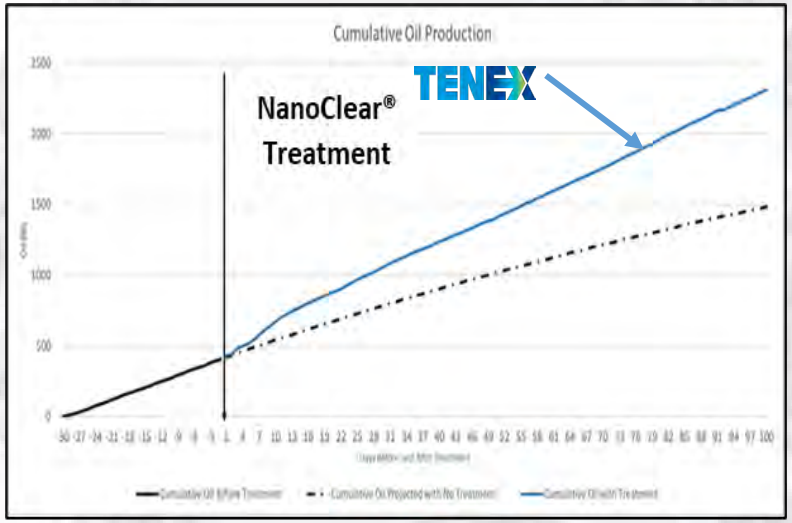
TREATMENT RESULTS	Well 1		Well 2		Well 3	
	Pre	Post	Pre	Post	Pre	Post
Measurement Period	107 days	237 days	30 days	38 days	30 days	100 days
Avg Oil Production	14 bbl/day	19 bbl/day	13 bbl/day	24 bbl/day	14 bbl/day	19 bbl/day
% Avg Oil Increase		36%		85%		36%
Water Cut	71%	56%	37%	40%	26%	29%
Days to ROI		71 days		27 days		38 days



Well 1

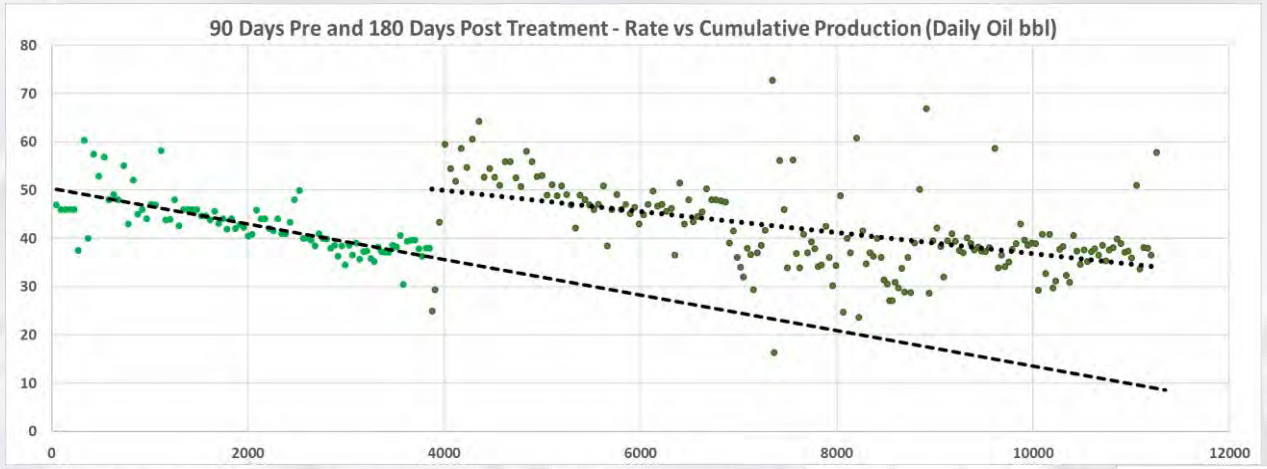


Well 2

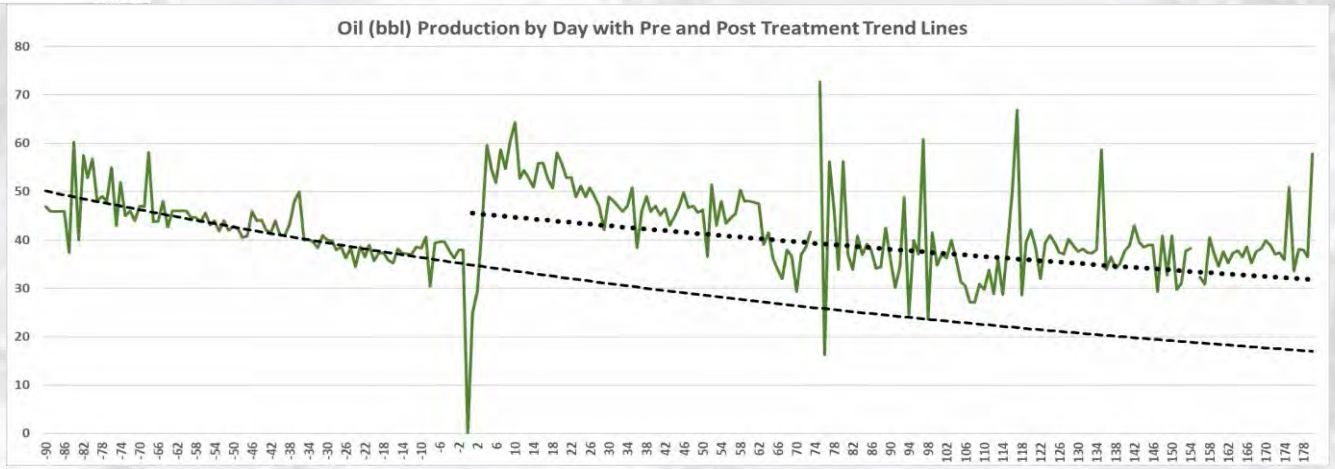


Well 3

NanoClear® FD Treatment Results: Texas / Permian / Vertical Well

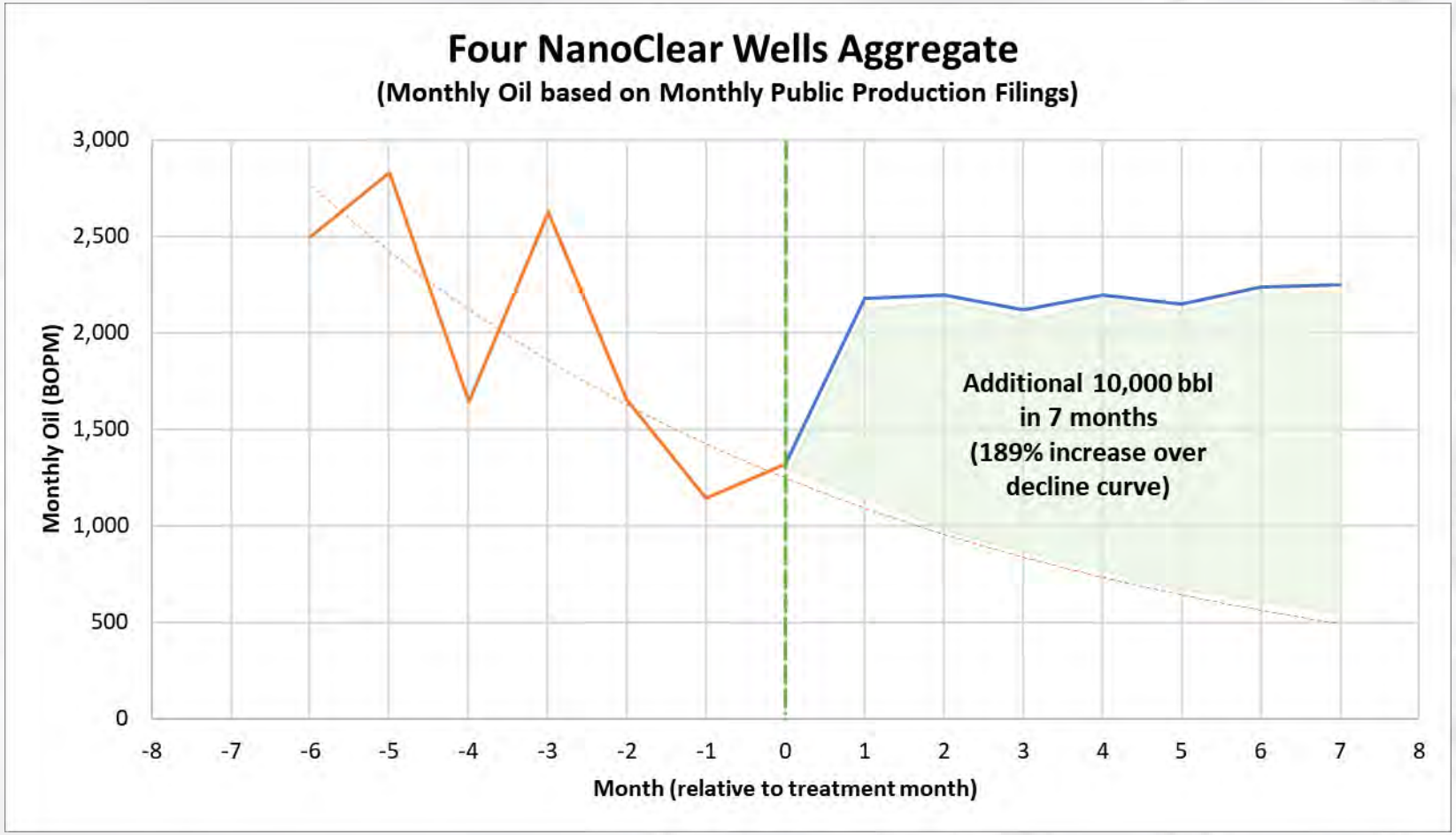


Key Results after 180 Days of Treatment (in bbl)	
Avg. Oil Expected with Trendline	24.9
Actual Oil Avg.	41.6
% Improvement	67%
Cumulative Oil Gained to Date	3006



After treatment with NanoClear®, the oil production decline curve & rate vs. cumulative production trend lines shifted up significantly and are holding out 180 days

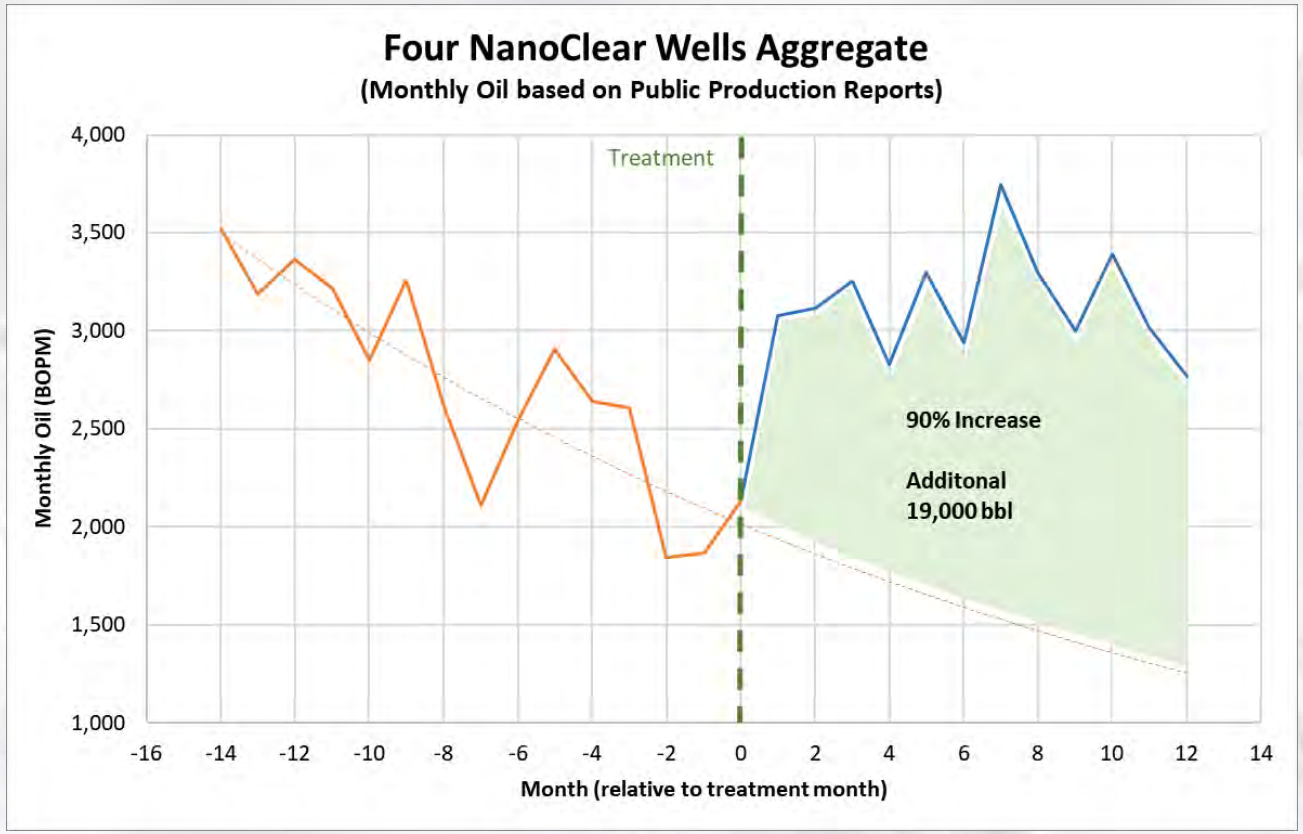
4 Re-Stim Wells – San Joaquin Basin

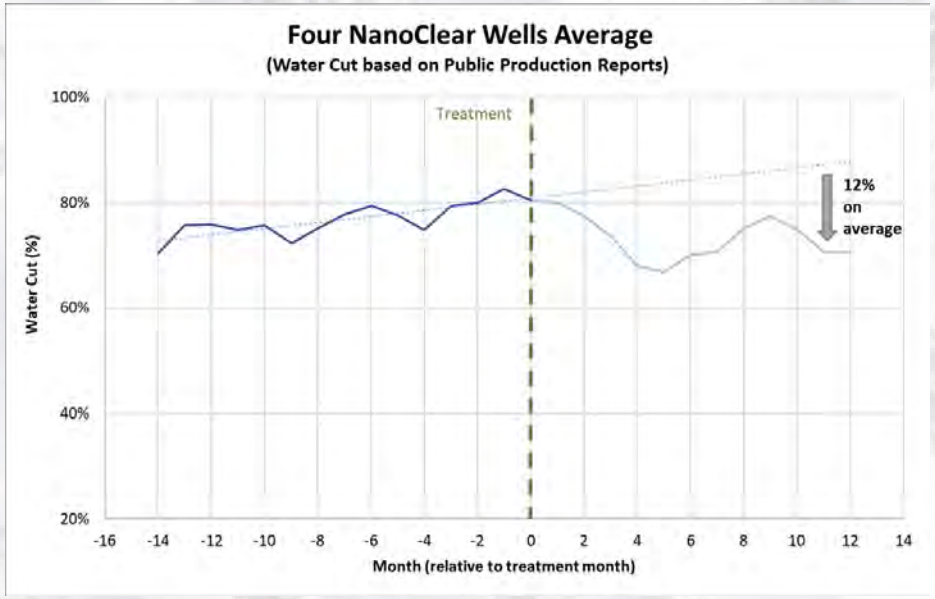


- 4 vertical wells
- 1 well was spot-treated at different intervals and had the best response

- Lithology: Sandstone and Shale
- Depth: 6,600-11,800 ft
- API: 28-30
- Viscosity: 3-44 cP at 70 F
- Artificial Lift: ESP, Sucker Rod, Jet Pump

4 Re-Stim wells – Avalon/Delaware





- Lithology: Carbonate
- Depth: 3,500-5,000 ft
- API: 35
- Artificial Lift: Sucker Rod

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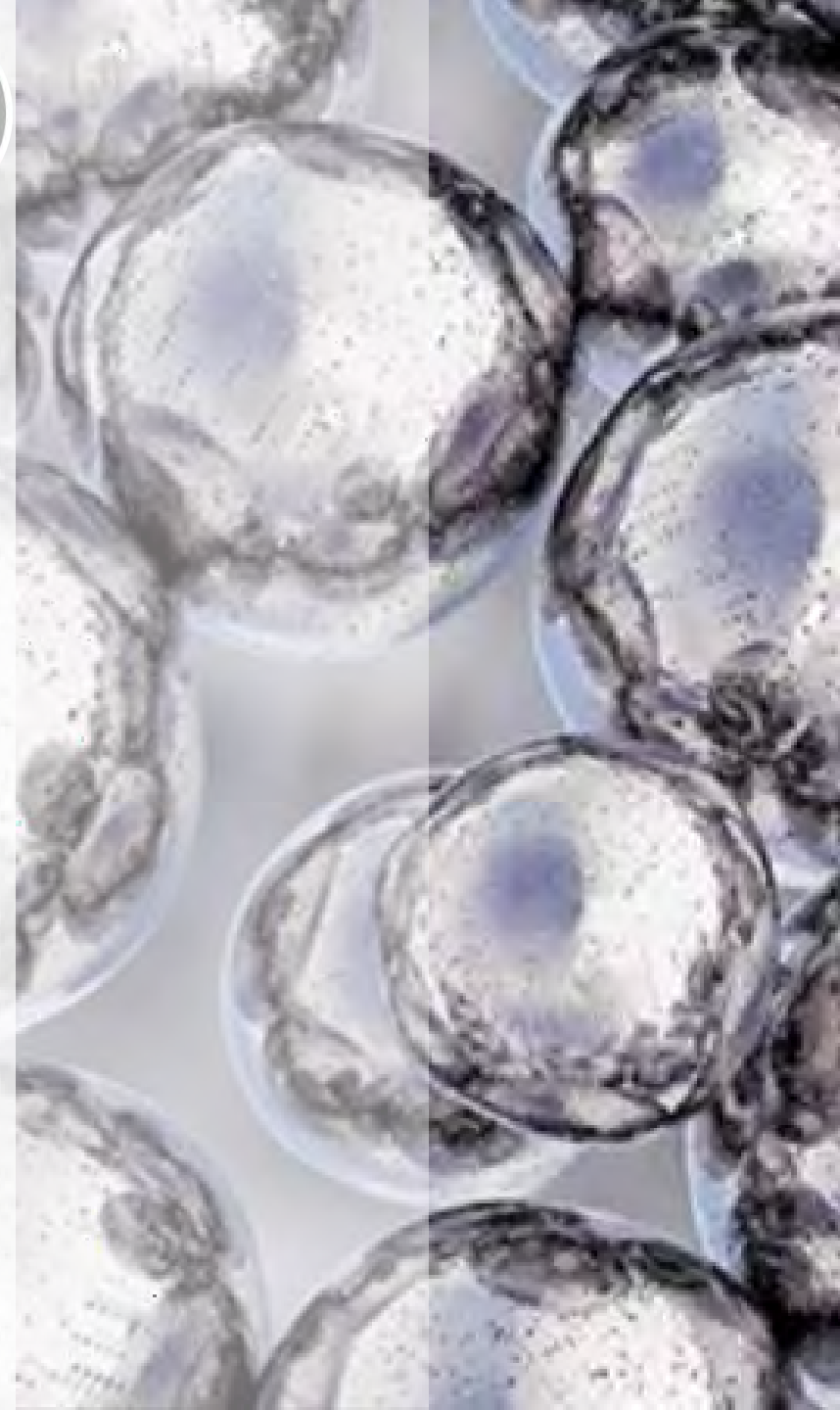
aeldiasty@tenextechnologies.com

Long-term prevention of deposition materials and a long-lasting wetting resistance to heavy hydrocarbon

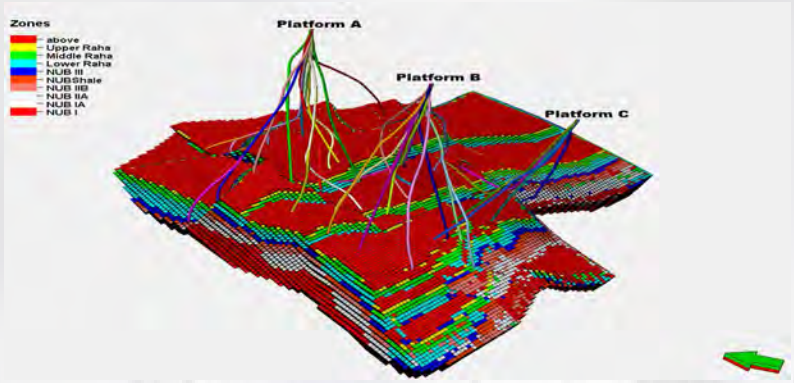
Case Study in Ras Budran Field; SUCO-GOS

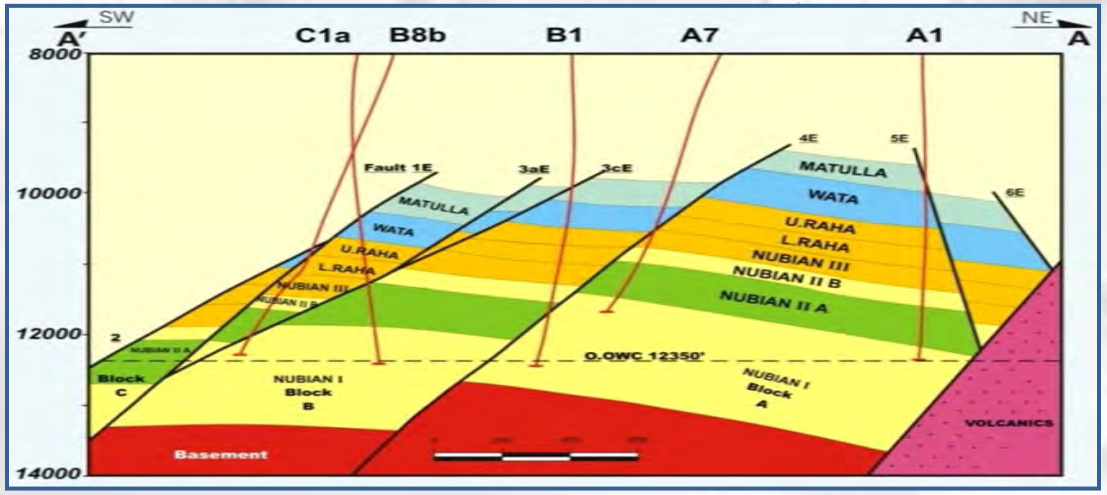
Hatem Eldawy, SUCO



Ras Budran Subsurface Overview

Reservoir Units
Matulla
Upper Raha
Middle Raha
Lower Raha
Unit III
Lower Unit III
Unit UIIB
Unit UIIA
Unit IA
Unit I





General Information

Location: North Belayim offshore Area
Discovery: **1978**
1st production: February 1983
Offshore Facilities: 3 Offshore Platforms (A, B, C)
STOIIP: 830 MMstb
Cum. Production: 294 MMstb
Recovery Factor: ~35%

Reservoir Data

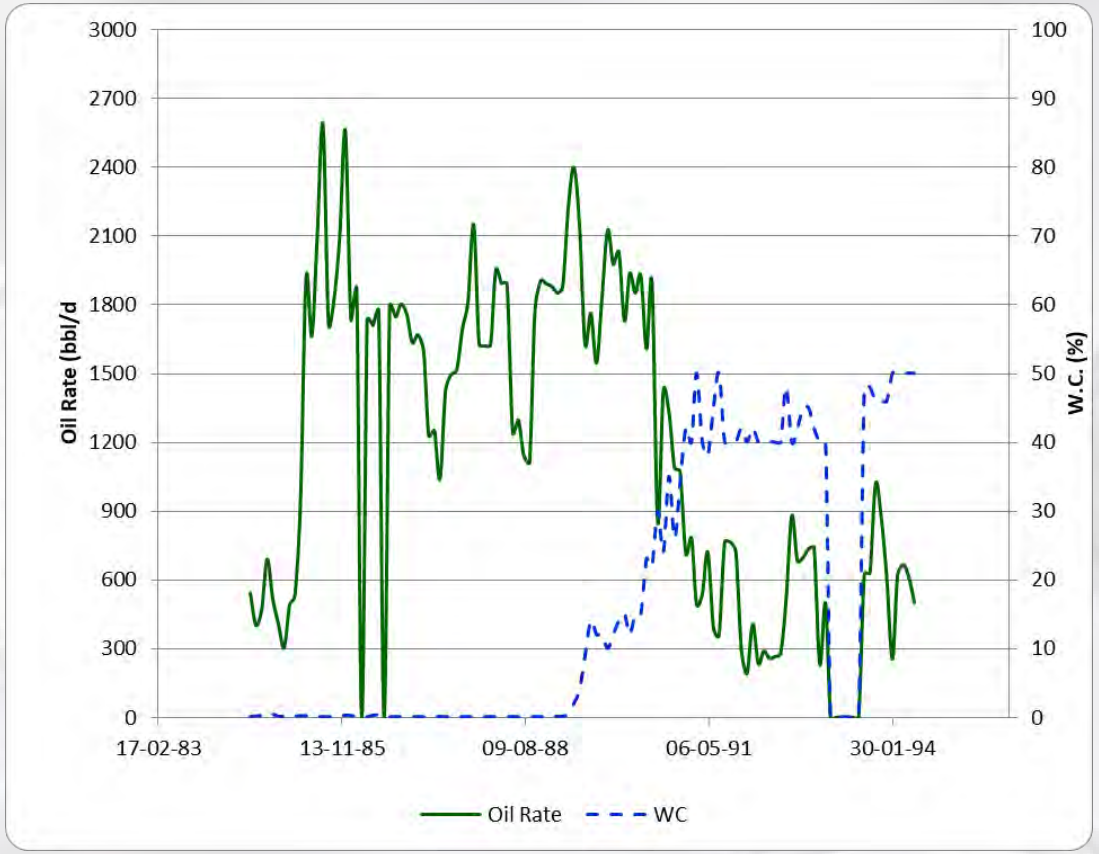
Reservoir Formation: Nubia, Raha, Matulla.
Formation Type: Sandstone, &Carbonate.
Formation depth: ~9500 ft
Reservoir thickness: ~ 2100 ft
Permeability: 40 - 340mD
Porosity: 9 - 15%
Oil Gravity (API):19 – 26

Historical Background of Unit I producers

	Well Name	Completion Type		Last Production			Isolation Date	Cum. Oil
		Cased Hole	Open Hole	Gross BPD	WC (%)	Oil Rate BOPD		MMSTB
Block "A"	A4	X		1300	50	650	Jun-94	**3.63**
	A5	X		250	15	213	Feb-90	0.96
	A7		X	1800	70	540	Jun-89	2.38
	B3	X		400	0.6	398	May-85	0.27
	B7		X	1000	80	200	Jan-90	1.94
	B9		X	1400	85	210	Sep-95	**8.9**
Total Cum Oil Production								**18.08**

	Well Name	Completion Type		Last Production			Isolation Date	Cum. Oil
		Cased Hole	Open Hole	Gross BPD	WC (%)	Oil Rate BOPD		MMSTB
Block "B"	B4		X	3000	10	2700	Mar-84	
	C1		X	1800	50	900	Sep-87	1.34
	C1a		X	750	98	15	Jun-94	
Total Cum Oil								**1.34**

UI Best Producer – RB-A4



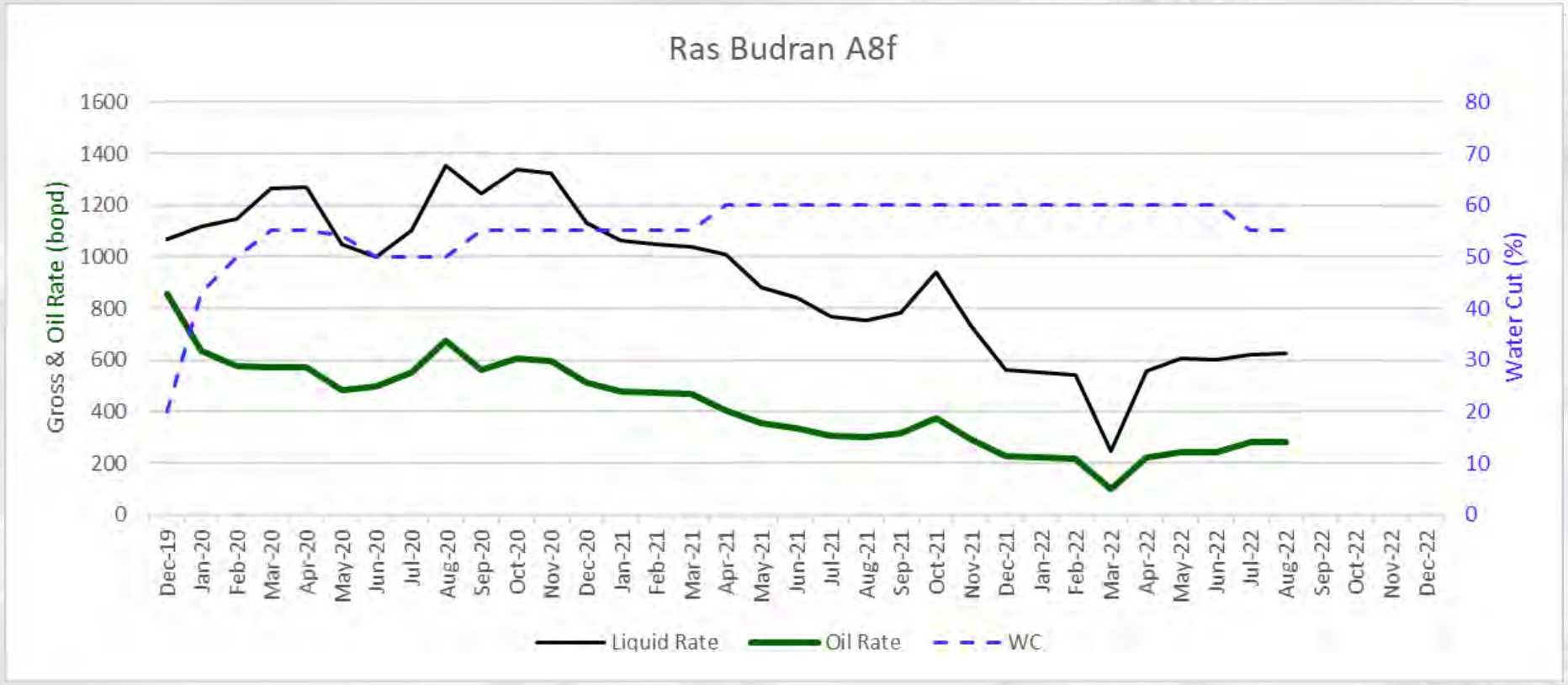
Total Field production from unit I from 1984 to 1995 was only 19 MMstb

The recovery factor for this unit less than 8%

Its reduced permeability values (i.e. K ranges from 20-120 MD)

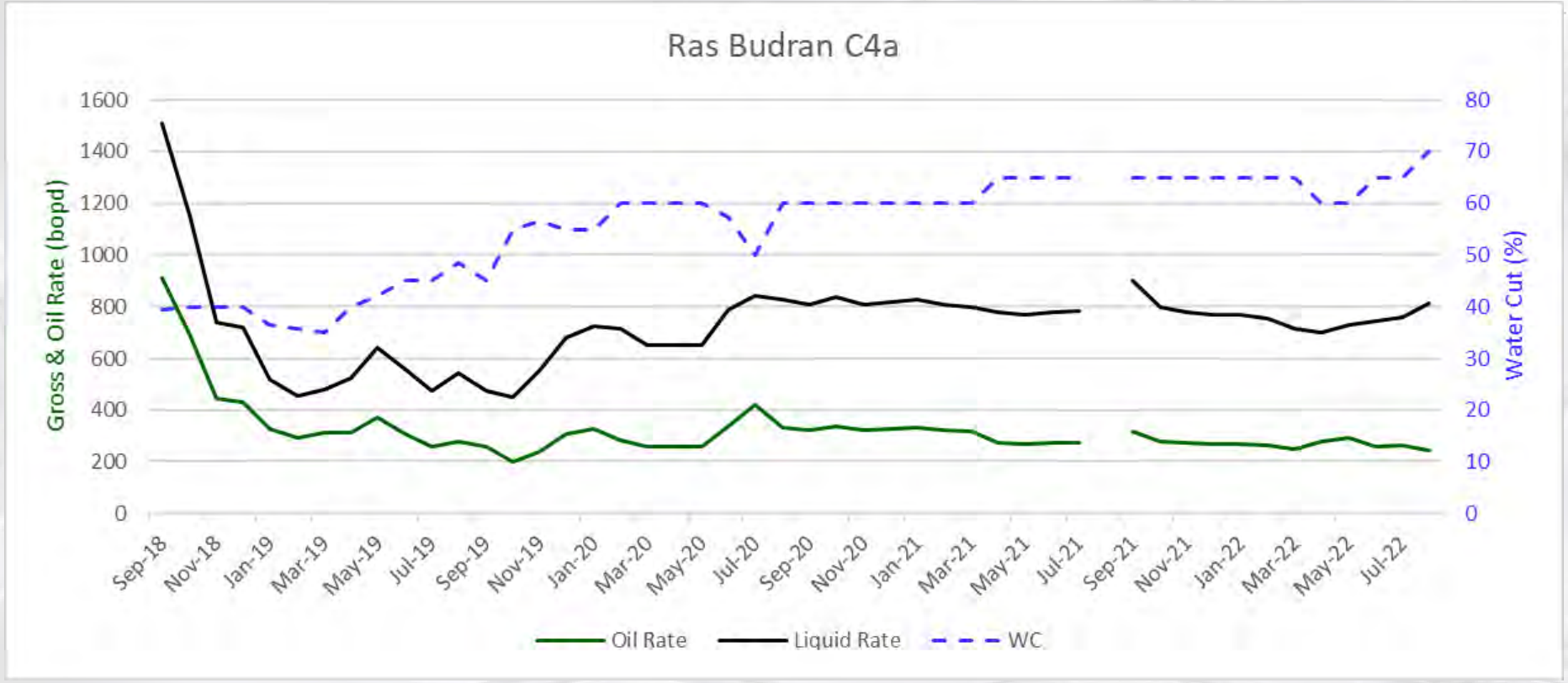
There was no production from this unit during the period from 1995 to 2018

RB-A8f– First Commercial Producer in UI



Cumulative Oil Production 0.4 MMSTB

RB-C4a– First Commercial Producer in IIA



Cumulative Oil Production 0.45 MMSTB