MULTIFUNCTIONAL CHEMICAL REMEDIATION STRATEGIES FOR WELLS IMPACTED BY FRAC HITS: FIELD APPLICATIONS AND PERFORMANCE OUTCOMES

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ABSTRACT

Fracture-driven interactions (FDIs), commonly known as frac hits, are becoming an increasing concern as hydraulic fracturing operations intensify in mature basins. These interactions can introduce foreign solids, crosslinked gels, and the formation of fines into existing wellbores, significantly impairing well productivity. Traditional mechanical clean-outs, while effective, are costly and may not fully restore well performance. This paper presents a series of field case studies highlighting the application of advanced chemical remediation strategies designed to address these complex challenges, providing operators with a cost-effective alternative to conventional methods.

Two novel chemical systems were developed to eliminate the need for solvent preflushes, utilizing multifunctional chemistries in combination with either fresh water or 15% NEFE HCl. Treatment designs targeted the dissolution of precipitated scales, removal of chemical residues, dispersion of fines, restoration of near-wellbore relative permeability, re-establishment of water-wet conditions, and reduction of capillary pressures to aid fluid recovery. Simple field deployment methods, such as bullheading, were selected for ease of execution and cost efficiency.

A comprehensive suite of laboratory tests, including dispersibility analysis, contact angle measurement, and fluid compatibility assessments, was conducted to validate the effectiveness of these multifunctional chemistries in mitigating frac hit damage. These tests provided critical insights into the interaction mechanisms and optimal treatment parameters for various damage profiles.

Field trials demonstrated consistent and sustained improvements in post-treatment performance, with some wells achieving production rates exceeding pre-frac hit baselines. Recovery outcomes ranged from 50% to over 100% relative to pre-hit decline curves, confirming the efficacy of the selected chemistries. Lessons learned from these deployments, including the importance of intervention timing and chemical compatibility, are also discussed.

This work introduces a novel chemical formulation that eliminates the need for traditional solvent preflushes, offering a more efficient and cost-effective approach to frac hit remediation. The integration of multifunctional chemistries with simple operational techniques provides a practical framework for operators seeking to maximize production recovery while minimizing downtime and extending asset life.

INTRODUCTION

Aggressive development of unconventional reservoirs has increased the frequency of frac hits, also known as fracturedriven interactions (FDIs), unintended hydraulic fracture communication between newly completed “child” wells and existing “parent” wells. These interactions occur when pressure, fluid, and solids from fracturing operations migrate through natural or induced fracture networks into offset producing wells (Rainbolt and Esco 2018). The phenomenon is well documented across shale basins including the Permian, Bakken, Eagle Ford, and Marcellus, most often in tight oil and gas plays where wells are drilled close together.

When a well is being fractured:

- High-pressure fluid creates fractures in the rock.
- Those fractures (or the pressure pulse) can connect with another well.
- The nearby well may experience:
    - Sudden pressure increase
    - Fluid influx (frac fluid or proppant)
    - Production damage or changes

Frac hits can severely impair parentwell performance by introducing foreign fluids and solid debris, creating multilayered organic–inorganic deposits (paraffin, FeS, $CaCO_3$), and altering nearwellbore flow characteristics. Traditional remediation strategies rely heavily on mechanical cleanouts and aromatic solvent washes such as xylene; however, these methods fail to address mixeddamage systems and suffer from miscibility limitations, rapid saturation, and redeposition tendencies (Morales et al. 2023; Morales and Davis 2024).

Mechanisms of Frac-Hit Damage

Frac hits typically induce one or more of the following damage mechanisms (Rainbolt and Esco 2018):

- Invasion of frac fluids: crosslinked gels, friction reducers, and residual polymers.
- Solid deposition: proppant migration, fines, paraffin, and inorganic scales.
- Altered wettability: transition from waterwet to oilwet conditions due to organic deposition.
- Reduced relative permeability: pore blockage by scale or paraffin coatings.
- Pressure and thermal shock effects: promoting precipitation and crystallization.

Frac Hit Impact

Frac hits can adversely affect both short-term well performance and long-term asset value by introducing a combination of mechanical, chemical, and reservoir-related damage mechanisms. High pressure interwell communication can disrupt normal production behavior, overload surface and downhole equipment, and alter near wellbore conditions. These impacts are often interconnected, with initial damage compounding over time if not properly mitigated, ultimately affecting recovery efficiency and field economics.

Key impacts associated with frac hits include:

- Loss of Production: Production declines commonly occur due to solids invasion, fluid incompatibility, scale formation, and near wellbore permeability impairment, all of which restrict hydrocarbon flow and delay cleanup.
- Artificial Lift Damage: Sudden pressure surges and solids laden fluids can damage electric submersible pumps (ESPs), accelerate wear in rod pump systems, and foul or stick gas lift valves, leading to increased downtime and intervention costs.
- Formation Damage: Frac hits may induce fines migration, polymer residue deposition, emulsion formation, and wettability alteration, reduce effective permeability and impair sustained reservoir productivity.
- Casing or Cement Integrity Issues: Elevated stresses and pressure transients can compromise well integrity through casing deformation, cement sheath debonding, or micro annulus formation, potentially undermining zonal isolation, and long term well reliability.
- Long Term EUR Reduction: When frac hit related damage is not adequately remediated, cumulative effects such as persistent productivity loss, increased

water or gas breakthrough, and repeated interventions can lead to a measurable reduction in estimated ultimate recovery (EUR).

Mitigation Strategy

- Temporarily shut in parent wells
- Pressure monitoring on offset wells.
- Use of diverters or modified frac designs
- Solid and scale management (important post-hit)
- Post-frac well cleanup and stimulation

Remediation/ Stimulation Clean-up Strategies After a Frac Hit

Chemical wellbore cleanup is the use of targeted chemical systems to:

- Remove solids, scales, and residue.
- Restore near wellbore permeability.
- Improve flow efficiency.
- Protect artificial lift and surface equipment.

It is not acidizing (though acids may be part of it). The goal is to remove damage without harming tubulars, cement, or the formation.

<u>Solids & Scale Remediation</u>

Extremely common post hit issues:-

- Proppant invasion
- Fines migration
- Iron sulfide particles.
- Scale precipitation:
    - Barium sulfate ($BaSO_4$)
    - Calcium carbonate ($CaCO_3$)
    - Iron scales (FeS, $FeCO_3$)

These restrict flow in the perforations, fractures, and near wellbore region, not the entire reservoir.

Solutions

- Chemical cleanouts (chelating agents, dispersants)
- Circulation or coiled tubing if severe
- Multifunction chemistries (scale + solids + iron)

Solids Removal and Dispersal

The primary objective of solids removal and dispersal treatments is to mobilize particulate matter within the wellbore and transport these solids to the surface. This process relies on blends of dispersants, surfactants, clay stabilizers, and high-performance wetting agents These systems work by breaking the attractive electrostatic forces between particles, reducing agglomeration, and keeping fines suspended for removal during flowback. By disrupting these interactions, the system keeps fines suspended throughout the cleanup process and prevents their redeposition during flowback. In long horizontals, these chemistries are critical to preventing redeposition and recurring solids production. A formulation that incorporates this multifunctionality and low adsorption of wetting agents to improve penetration into the invaded zone and maintain fluid mobility under harsh salinity and temperature conditions will enhance the clean-up process.

Scale Dissolution and Control

Frac hits frequently induce scale precipitation due to incompatible waters mixing between wells. This can result in carbonate scale, sulfate scale, iron scale, or mixed mineral deposits. Carbonate scale ($CaCO_3$) is typically treated using organic and inorganic acids or buffered acid systems that minimize corrosion while providing steady dissolution. For sulfate-based scales such as $BaSO_4$ and $SrSO_4$, which are far more insoluble, modern approaches rely on chelating agents that bind metal ions and lift scale without the risks associated with strong mineral acids. Iron management is a frequently overlooked yet essential component of effective well cleanup. Iron species can readily precipitate, plugging pore throats and restricting hydrocarbon flow. Without proper iron control, cleanup operations can unintentionally increase formation damage, reduce well productivity and impair long-term performance.

Currently, chemical wellbore cleanup removes frac induced solids, scale, polymers, and iron from the near wellbore region using tailored chemical systems, often restoring production faster and cheaper than mechanical intervention.

The field observed deposits frequently consist of mixed organic/inorganic layers. Aromatic solvents, surfactants, chelating agents, or acid systems by themselves alone cannot effectively dissolve such structures, especially when combining inorganic scale is coated with hydrocarbon deposits.

Emulsion Breaking and Wettability Restoration

Interwell communication often disrupts native wettability and produces stable oil–water emulsions. To counter this, current remediation strategies incorporate demulsifiers, surfactant packages, mutual solvents, and microemulsion systems designed to break tight emulsions, disperse trapped hydrocarbons, and restore water or oil wettability as required. Advanced surfactant-based systems help re-establish flow pathways by lowering interfacial tension and improving cleanup efficiency within the near-wellbore damage zone.

To meet this operational challenge, a **multifunctional chemical formulation** was developed to restore productivity through a single stage treatment capable of dissolving, dispersing, and wetting multiple damage types without the need for preflushes.

NOVEL APPROACH

Multifunctional Formulation Description

A notable shift in the industry is the growing use of multi-functional cleanup blends, capable of addressing solids, scale, iron, polymer residue, and emulsions simultaneously. These engineered chemical combinations reduce operational complexity and enable efficient treatments during downtime windows such as ESP pulls, pump replacements, or routine well intervention. Multi-functional systems are designed to reduce the need for staged treatments while providing deeper penetration and more comprehensive remediation of frac-hit damage.

A multifunctional formulation (MF) is a single-phase formulation developed for removing multi-skin damages present in the near-wellbore area. This formulation includes a combination of highly effective surfactants and a very robust solvent package. The synergy between the components allows it to act instantaneously, penetrating, breaking, reacting, and solubilizing solid build-up in producing and injection wells (Morales et al. 2023; Morales 2025). Product affinity to both the hydrocarbon and water phase allows it to be combined with acid to perform a one-step job to remove deposits of different natures. The formulation is thermally stable up to 350 °F allowing application under different system conditions. Some additional characteristics of the formulation include:

The multifunctional formulation utilizes a surfactant driven mechanism that acts primarily through diffusion to address the complex damage mechanisms associated with frac- hit events. When deployed alone or in combination with acid, the interaction between the formulation and invaded solids generates localized mixing energy that enhances penetration and accelerates cleanup within th-e near wellbore region. Acid synergy further promotes dissolution of frac- hit- related- inorganic deposits while improving the delivery efficiency of the surfactant system into damaged pore networks and fracture faces.

Due to its engineered multifunctionality, the formulation is effective at relatively low concentrations while simultaneously addressing multiple frac hit damage components. Unlike conventional -single purpose- chemistries, this system targets organic deposition, emulsified hydrocarbons, fines migration, and surface wettability alteration in a single treatment. Its ability to remove oily materials, including residual frac fluids, lubricants, emulsified hydrocarbons, and crude oil- components that adhere to rock and proppant surfaces, promotes a transition toward water wet conditions. This wettability restoration is critical for reducing capillary trapping, improving fluid mobility, and accelerating production recovery following frac- hit- events.

The formulation is specifically designed to address frac hit- induced solids invasion and fluid incompatibility challenges commonly observed- in parent wells. Its primary functions and associated benefits are summarized in Table 1.

This multifunctional formulation is specifically designed to address the challenges associated with drilling fluids in oil well production. Its primary functions include:

Table 1 Multifunctional Formulation Functions for Frac Hit Damage Remediation

Function	Description	Benefits in Frac Hit Environments
Water Wetting of Solids	Alters the wettability of frac invaded solids, proppant fines, and formation particles toward water wet	Enhances dispersion, minimizes capillary trapping, and improves hydrocarbon

	conditions.	flowback efficiency.
Dispersion of Particulates	Maintains fines, proppant debris, and mobilized solids in a dispersed state during cleanup.	Prevents resettling and pore throat plugging, reducing recurring solids production.
Deagglomeration of Solids	Breaks apart agglomerated fines and organic coated particles introduced during frac hits.	Facilitates effective transport of solids out of the wellbore and fracture network, improving cleanup completeness.

Multi-functional Formulation Performance

The developed formulation was engineered as a multifunctional cleanup chemistry to address the complex damage mechanisms commonly observed following frac hit events. Rather than targeting a single damage type, the formulation integrates several complementary chemical components to enable simultaneous remediation of organic, inorganic, and wettability related impairments under high temperature conditions.

Specifically, the formulation combines:

- **Surfactants**, designed to provide effective dispersion, wettability alteration, and ultralow interfacial tension (IFT) to enhance mobilization of trapped fluids and solids.
- A robust solvent package, selected for its ability to solubilize paraffin and asphaltene deposits without the limitations associated with conventional aromatic solvents.
- Acid compatibility enhancers, enabling full miscibility with 15% HCl and consistent delivery during combined organic–inorganic treatments.
- High thermal stability, maintaining chemical performance at temperatures up to 350°F, making the system suitable for high temperature unconventional reservoirs.

This multifunctional design allows the formulation to deliver multiple cleanup mechanisms in a single treatment, including:

1. Dissolution of paraffin and organic deposits.

2. Solubilization of iron sulfide (FeS) and calcium carbonate ($CaCO_3$) when deployed in combination with hydrochloric acid.
3. Reduction of interfacial tension into the 10^{-2} mN/m range, improving fluid mobilization.
4. Restoration of water wet conditions within the near wellbore region.
5. Dispersion of fine solids with inhibition of re-agglomeration during flowback.
6. Reduction of capillary pressure, resulting in improved cleanup efficiency and faster production recovery.

<u>LABORATORY EVALUATION</u>

Evaluation of organic deposit solubility, interfacial tension, contact angle measurement, acid compatibility, and an acid sludge test was conducted with this formulation and demonstrated the effectiveness in the removal of paraffin and scale deposits, and impact in well productivity.

Pumper's Test (Organic Solvency Performance)

To recreate the performance of formulation for soaking treatments, pumper's test was performed. This test consists of using produced water, crude oil, and solid paraffin. This test screens the products' ability to dissolve solid paraffin in the presence of water and oil to simulate a soaking job. During this test, the multi-functional formulation was tested in comparison to a traditional solvent system used for paraffin removal (see Fig 1).

(a) (b) (c) (d) (e)

Fig 1. Pumper's Test Performance Beginning of the Test (Time= 0hrs) with dosage of 100ppm

(a) (b) (c) (d) (e)

Fig 2. Pumper's Test Performance Results End of the Test (Time= 3 hrs) with dosage of 100ppm.

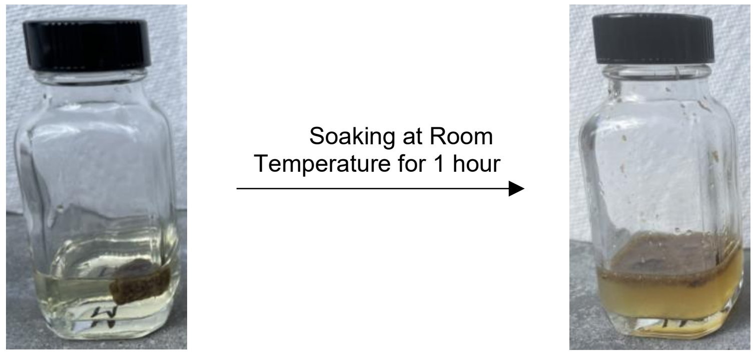
Testing results showed that the formulation was the best performing traditional solvents systems used in the oil and gas industry for paraffin removal treatments. The formulation removed around 35% of the attached paraffin at the 100ppm treatment rate.

Traditional solvent systems used in soaking jobs like xylene and combination products quickly achieve critical saturation, leading to solid particle re-aggregation, dropping out of solution, and re-depositing on the rock surface (Kelland, 2009). Re-deposition of organic deposits can also reverse the formation wettability from water- wet to oil- wet and affect the formation relative permeability (Leontaritis, 1994).

Organic Deposit Dispersancy

Cold Flask Test

Dissolution and dispersancy evaluation were performed using solid paraffin sample. Dispersancy results demonstrate the removal of organic deposits and restrictions to flow in the wellbore. As observed in Fig 3b, novel formulation effectively dissolves and disperses paraffin deposits (Fig 3a) utilizing neat formulation at room temperature in a 1-hour soaking period.



(a) (b)

Fig 3. Performance Evaluation of Multi-functional Formulation on Paraffin Deposits.

One-hour soak tests conducted at room temperature showed complete solubilization of paraffin chunks and formation of a fine, stable dispersion without particle balling. These results clearly differentiated the multifunctional formulation from solvent-only controls, which showed limited solubilization and visible residue persistence.

HighTemperature Flask Test (210°F)

Additional testing was performed to measure the formulation's ability to prevent the agglomeration of paraffin wax after it has been put in solution. It was shown that the multi-functional formulation successfully broke the paraffin into fine particles, with a distinct clean water phase. An unsuccessful product will allow paraffin deposits to ball-up and stick to the glass. The test temperature was 210°F utilizing paraffin and produced water field samples. It is shown in Fig 4 the performance of the formulation at a dosage of 500ppm.

At **500 ppm**, the formulation effectively prevented paraffin re-agglomeration, whereas the blank sample showed clear wax balling and adhesion.

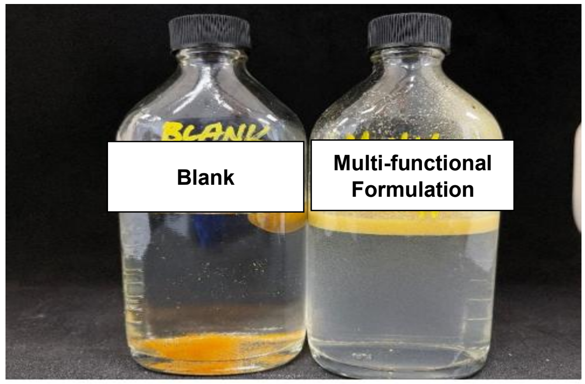


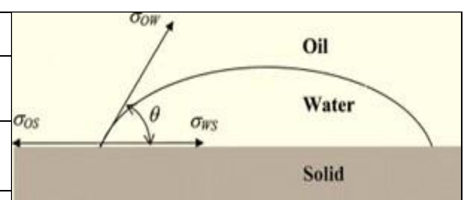
Fig 4. Paraffin Dispersancy Testing Performance with MF on Paraffin Deposits

Contact Angle Measurements

Contact angle measurements were conducted to evaluate the wettability behavior of the multifunctional formulation on a solid surface representative of inorganic wellbore materials. Wettability alteration is a critical mechanism for post-frac-hit remediation, as it directly influences capillary pressure, fluid mobility, and the efficiency of hydrocarbon cleanup in the near-wellbore region. Contact angle analysis provides a quantitative assessment of the interaction between the treatment fluid and the solid surface, enabling direct comparison of wetting behavior over time (Table 2).

Table 2 Wettability Profile vs Contact Angle measurement

Wettability	Contact Angle
Water Wet	0° to 70°
Neutrally Wet	~70° to ~100°
Oil wet	~100° to 180°



Measurements were performed using a Theta Flow Optical Tensiometer, employing both Sessile Drop and Pendant Drop techniques. A manual syringe fitted with a 30gauge needle was used to dispense the test fluid, while a hooked needle configuration was utilized for pendant drop formation. All tests were conducted on a clean glass slide to provide a smooth, inert, and reproducible substrate for evaluating surface wettability. The formulation was dispensed slowly until two drops were released, and image acquisition commenced immediately following deposition of the second drop to ensure consistent initial conditions.

Contact angle values were recorded at two time points: immediately after deposition (t = 0 s) and after a 10-second dwell period (t = 10 s). This approach allowed for assessment of both instantaneous wetting behavior and dynamic spreading characteristics. The sessile drop method was used to directly measure the solid–liquid contact angle, while the pendant drop method supported interfacial characterization and verification of fluid behavior during dispensing. Due to the strong wetting nature of the formulation, measurable contact angles were only observed at the initial time point, as the fluid rapidly spread across the glass surface.

Fig 5 summarizes the contact angle measurements obtained for Multiclean-2000. Initial contact angles at t = 0 s ranged from approximately 22°, indicating a strongly water-wet interaction upon contact. After 10 seconds, the formulation completely wetted the glass slide, resulting in contact angles too low to be reliably measured. This rapid transition to full wetting confirms the formulation's strong affinity for inorganic surfaces and its ability to promote water-wet conditions, which is essential for reducing capillary trapping and restoring effective flow pathways during post-treatment cleanup.

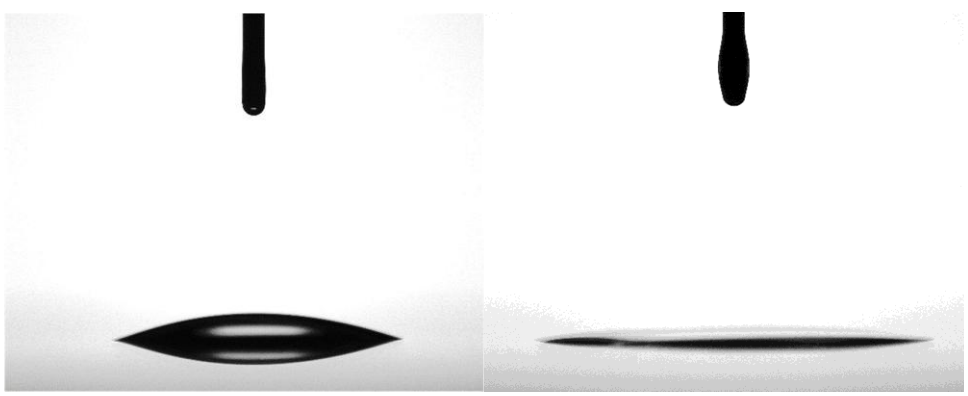


Figure 5. The initial contact angle (left, t = 0 s) and the stabilized contact angle (right, t = 10 s) of Multifunctional formulation on a glass slide.

For comparison, contact angle measurements were also conducted on a glass surface treated with xylene to evaluate its impact on surface wettability. The xylene-treated surface exhibited a contact angle of 94.6°, confirming the persistence of oil-wet conditions and limited wettability alteration. In contrast, treatment with the multifunctional formulation resulted in a contact angle of 0°, indicating complete wettability reversal to a strongly water-wet state. This pronounced difference highlights the formulation's superior ability to modify surface–fluid interactions, a critical factor for restoring hydrocarbon flow pathways, reducing capillary trapping, and enhancing post-treatment cleanup efficiency relative to conventional solvent systems.

Additional measurements were conducted to evaluate the potential change in wettability of the rock when it is in contact with the removal solution. The Modified ASTM D5946 protocol was used for this measurement. Contact angle measurements were performed using the Pendant Drop apparatus with a manual syringe and a 30-gauge needle. Below is detailed in the description of wettability in correlation with the measured contact angle.

To evaluate the wettability profile, two sets of tests were conducted:

- Carbonate and sandstone rock samples were used to evaluate the performance of the multifunctional formulation approach.
- Untreated Rock: A carbonate and a sandstone rock sample (1" diameter disc) was used without any treatment.
- Treated Rock: The same type of rock samples were treated with multifunctional formulation.
- Procedure Details:
  - The carbonate and sandstone rock samples were immersed in different brines for seven days to achieve rock-brine equilibrium.
  - The brines used were:
    - 30% NaCl
    - 30% (NaCl + $CaCl_2$)
    - 30% $CaCl_2$
    - 40% $CaCl_2$ (for Sandstone)
  - After equilibrium was reached, oil was slowly dispensed until a drop detached, at which point the recording started immediately. Results are presented in table 3 and table 4.

Table 3. Contact Angle Measurements: Carbonate Rock

System	Contact Angle (degrees) at 200°F / Interpretation
Untreated Carbonate Rock / 30% NaCl / Oil	104 ° Rock surface is weakly oil wet
Carbonate Rock Soaked in MF for 24 hours at 200°F and 500 psi / 30% NaCl / Oil	60 ° Rock surface became water wet
Untreated Carbonate Rock / 40% $CaCl_2$ / Oil	70 ° Rock surface is weakly water wet
Carbonate Rock Soaked in MF for 24 hours at 200°F and 500 psi / 50% ($CaCl_2$) / Oil	69° Rock surface became water wet

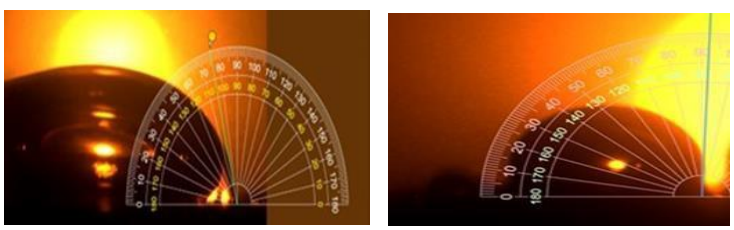


Figure 6. Example of contact angle measurements. Left: Untreated Carbonate Rock / 30% $CaCl_2$ / Oil); Right: Carbonated Rock Soaked in MF for 24 hours at 200°F and 500 psi / 40% $CaCl_2$ / Oil

Table 4. Contact Angle Measurements: Sandstone Rock

System	Contact Angle (degrees) at 200°F / Interpretation
Untreated Clean Sandstone Rock / 30% NaCl / Oil	20 ° Rock surface is water wet
Sandstone Rock Soaked in MF for 24 hours at 200°F and 500 psi / 30% NaCl / Oil	5 ° Rock surface became strongly water wet

Untreated Clean Sandstone Rock/ 40% CaCl2 / Oil	48 ° Rock surface became weakly water wet
Sandstone Rock Soaked in MF for 24 hours at 200°F and 500 psi / 50% (CaCl2) / Oil	30° Rock surface became more water wet

Overall, the contact angle measurements conducted on both glass and reservoir rock substrates confirm the multifunctional formulation's strong and consistent wettability-alteration capability under a wide range of salinity and temperature conditions. Across carbonate and sandstone samples, treatment with the formulation shifted surfaces toward increasingly water-wet behavior, even in highly concentrated NaCl and $CaCl_2$ brines and at elevated temperature and pressure. This wettability improvement was observed regardless of the initial wetting state of the rock, demonstrating the formulation's robustness and adaptability to variable reservoir conditions. By promoting water-wet surfaces, the formulation reduces capillary trapping, enhances fluid mobility, and supports more efficient cleanup and hydrocarbon flow restoration following treatment, reinforcing its suitability for post-frac-hit remediation and complex near-wellbore damage environments.

Interfacial Tension (IFT) Measurements

Interfacial tension measurements were used to quantify the ability of the multifunctional formulation to reduce oil–water interfacial forces relative to water alone. Pendantdrop IFT testing was used to measure the IFT using Wolfcamp crude oil. Results demonstrated a pronounced and rapid reduction in IFT when the crude oil was contacted with the formulation, compared with the baseline oil–water system.

Figures 7 and 8 summarize the averaged initial and stabilized IFT values extracted from the laboratory report. Wolfcamp crude oil in water exhibited initial IFT values of approximately 13–14 mN/m, with only minor reduction over extended measurement times (~8 minutes). In contrast, when Wolfcamp crude oil was introduced into Multifunctional formulation, initial IFT values were reduced by more than an order of magnitude, stabilizing in the range of 0.27–0.34 mN/m within significantly shorter time frames. These results of ultralow IFT ($<10^{-1}$ mN/m) translate into enhances:

- Organic deposit solubilization
- Water cleanup efficiency
- Capillary pressure reduction

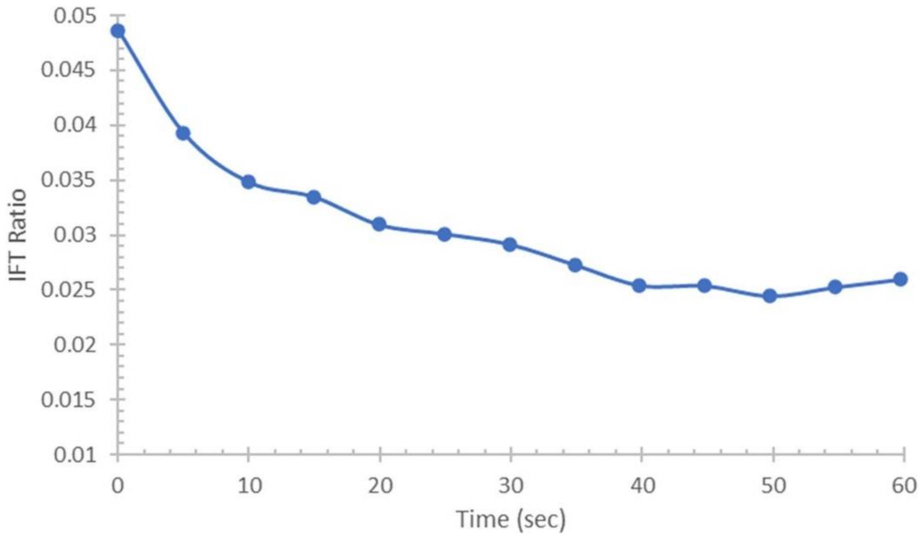


Figure 7. Data curve of IFT Ratio (IFT of $Wolfcamp_{Multifunctional}$/IFT of $Wolfcamp_{H2O}$) as a function of time. Data was plotted for the maximum amount of time the IFT of $Wolcamp_{Multiclean\text{-}2000}$ was measured.

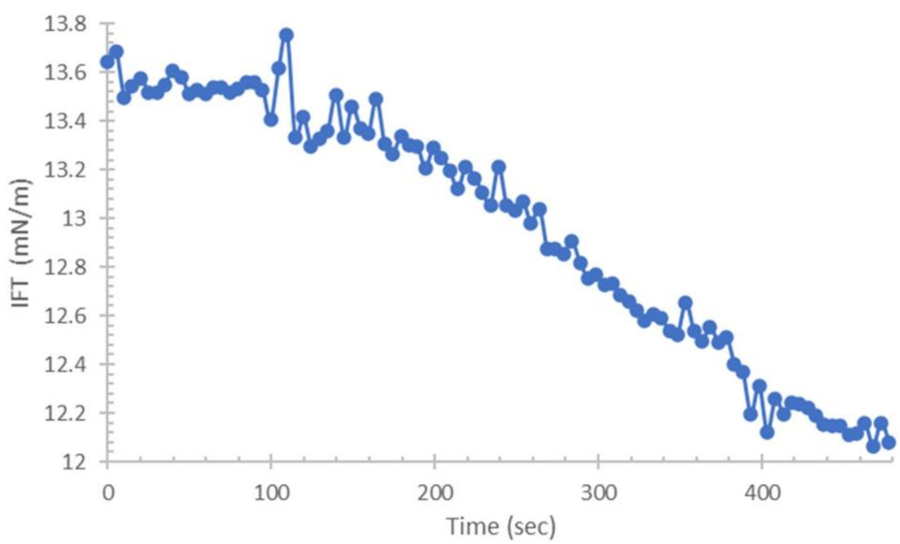


Figure 8. Data curve of IFT of $Wolfcamp_{H2O}$ as a function of time. Data was plotted for maximum amount of time measured (8 minutes).

Acid Compatibility

Traditional treatment approach requires at least a two-stage job design is required due to the differences in densities between the needed fluids in each stage to address the different types of deposits and components present in the drilling mud. In addition, the alteration of rock wettability that results from the adsorption of hydrocarbon components on the rock and surfaces as well as the derivative of the usage of solvents during the clean-ups is detrimental to production (Quintero et al. 2017).

It is well known that to increase the effectiveness of solid deposits clean-ups, a combination of solvents and acid treatments is one of the most common techniques used to stimulate wells around the world. The effect of acid stimulation on oil wells has been studied extensively for years (Morales et al. 2017), as well as the performance limitation of aromatic solvents, as they lose their solubility once they reach saturation. The usage of specialized surfactants can increase the power of solvents, being more effective than aromatic solvent alone for removing hydrocarbon components from formation rock. Aromatic solvents like xylene are not miscible in aqueous solutions like 15% HCl. If the compound does not stay mixed or dispersed as the acid is pumped, it can end up only in the last few gallons of acid.

Acid compatibility testing compared the formulation mixed with 15% HCl against conventional xyleneHCl blends. Xylene separated and floated on the acid phase, resulting in treatment inconsistency and ineffective solids contact. In contrast, the multifunctional formulation was fully miscible in 15% HCl, enabling uniform delivery. When combined with acid, FeS rapidly reacted and dissolved, whereas the xylene-based mixture failed to solubilize FeS, causing solids to migrate into the xylene layer.

Once the problem in a well is frac hit with traditional approaches becomes a problem as the treatment may be less effective since the first volume of pumped acid/xylene mixture will be only acid due to the difference in density of the fluids. Fig 9 shows the bottles filled with 15% HCl (with 5000 ppm of iron in solution). Xylene was added in a 90/10 ratio acid to xylene in bottle (b) and, multifunctional formulation was added as well in a 90/10 acid/formulation ratio. As can be observed in Fig 9, xylene does not mix or disperse in the acid volume (see top layer), while the multifunctional formulation is fully mixed with the volume of the acid. The miscibility in acid of the novel formulation allows to minimize the application to just a one-stage job, improving the efficiency of the treatment.

(a) (b) (c)

Fig 9. From left to right bottle with 15% HCl, 15% HCl with 10% xylene, and 15%HCl with 10% Multifunctional Formulation

Critical Micelle Concentration (CMC)

Critical micelle concentration (CMC) is a parameter that is used to determine the minimum amount of surfactant required to reduce the maximum surface tension of water (Ramesh et al, 2021). To determine the critical micelle concentration, we prepared a 2.00% stock solution of the novel formulation and used it as a dosing solution to incrementally augment the concentration of initially pure distilled water while measuring surface tension after each concentration increase. The critical micelle concentration was determined to be the point in concentration at which the surface tension no longer decreased due to increasing concentration, see Fig 10. Based on this information, the dosage range for the multifunctional formulation is selected. This value varies based on the severity of depositions.

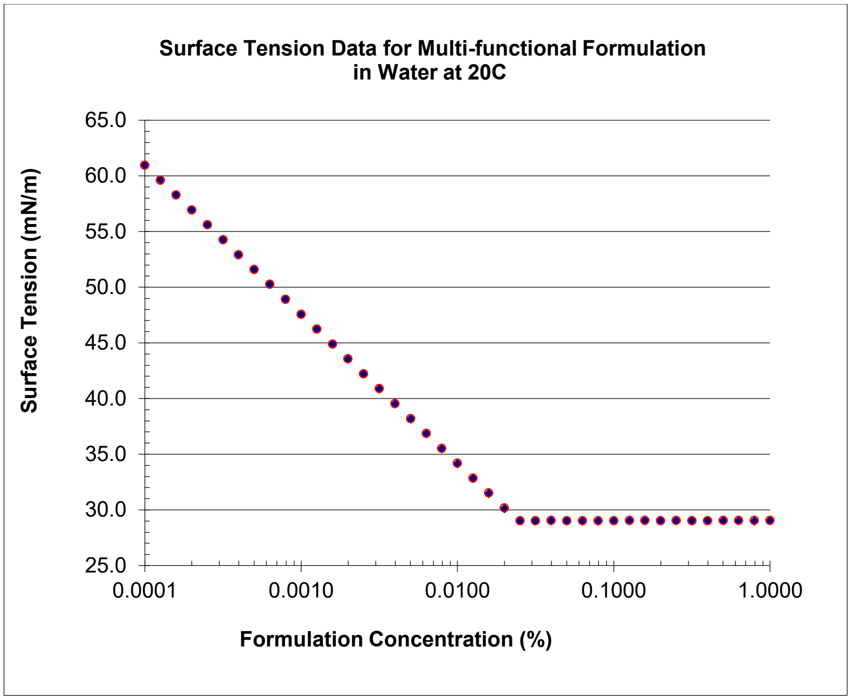


Fig 10. Critical Micelle Concentration of Multi-functional Formulation in Pure Water

FIELD DEPLOYMENT METHOD

Unconventional operators facing production depletion problems in producing wells after frac hit events, tried different approaches to help to unload the wells and build-up pressure unsuccessfully. A full evaluation was conducted in each well to determine the specific damage mechanism encountered in each well to design the treatment strategy.

Field deployment was designed to minimize operational complexity and cost. Treatments were bullheaded into the wellbore, with volumes tailored to wellbore geometry and estimated damage severity. The formulation may be deployed using either fresh water as a carrier fluid or 15% HCl when combined organic–inorganic remediation is required.

3 wells results have been included in this study to show the two applications stated about utilizing fresh water/MF and acid/MF.

The deployment strategy was focused on:

- Bullheading and salt rock diversion for simplicity and reduced cost
- Treatment volumes tailored by wellbore size and damage severity.
- Options: freshwater carrier or 15% HCl for combined organic–inorganic treatments

Selected wells had the following characteristics:

Well 1:

- Location: Eddy County, New Mexico
- Completion: Horizontal well
    - Tubing: 2-7/8” L-80
    - Production Casing: 5-1/2” 23#
    - Intermediate casing: 7-5/8” 29.70#
    - Lateral section: 5-1/2” casing, perforations from 11,671’-22,096’
- Well average production Pre-frac hit: 241 BOPD, 118 BWPD, and 164 MCFD
  Post-frac hit: 0 BOPD, 0 BWPD, and 0 MCFD
- Formation: Wolfcamp
- Oil API Gravity ~45.
- Artificial lift System: ESP
- Frac hit from offset stimulation activities, resulting in significant sand influx into the wellbore Oil and gas production completely declined.
- Planned to do mechanical clean-up to remove sand accumulation as well is completely down.

Well 2:

- Location: Ward, Texas
- Completion: Horizontal well
    - Tubing: 2-7/8” L-80
    - Production Casing: 5-1/2” 23#
    - Lateral section: 4-1/2” production liner, perforations from 11,202’-21,392’
- Well average production: Pre-frac hit: 137 BOPD, 715 BWPD, and 407 MCFD
  Post-frac hit: 50 BOPD, 562 BWPD, and 231 MCFD
- Oil API Gravity ~40.
- Artificial lift System: Gas Lift

Well 3

- Location: Reeves, TX
- Completion: Horizontal well
  - Tubing: 2-7/8” L-80
  - Production Casing: 5-1/2” 23#
  - Intermediate casing: 7-5/8” 29.70#
  - Lateral section: 4-1/2” production liner, perforations from 8,278’-19,719’
- Well average production Pre-frac hit: 200 BOPD, 610 BWPD, and 564 MCFD
  Post-frac hit: 0 BOPD, 0 BWPD, and 0 MCFD
- Formation: Wolfcamp A
- Oil API Gravity ~40.
- Artificial lift System: Gas lift
- Frac Hit Damage

TREATMENT DESIGN

Each well was evaluated utilizing the following data to understand the type of damage mechanism impacting each one of them: well production pre and post frac hit, complete water analysis (CWA), well completion, and current operational condition. This data allowed to design the treatments according to the well needs as presented below:

Well 1 Recommendation

- Decided proactive clean-out with 15%HCl and MultiClean-2000
- Pump high-rate acid job with salt rock diverter with the below volumes:
  - Step 1: 150 bbls of treated fresh water mixed with 150 gallons of MF
  - Step 2: 7,500 gallons of 15% HCl mixed with 750 gallons of MF
  - Step 3: Displace treatment with 150bbls of treated fresh water.
- Soaking time 6-8 hours

Well 2 Recommendation

- Decided proactive clean-out with 15%HCl and MultiClean-2000
- Pump high-rate acid job with salt rock diverter with the below volumes:
  - Step 1: 250 bbls of treated fresh water mixed with 525 gallons of MF
  - Step 2: Displace treatment with 150bbls of treated fresh water.
- Soaking time 12 hours.

Well 3 Recommendation

- Decided clean-out with 15%HCl and MultiClean-2000
- Pump high-rate acid job bull-heading the treatment with the below volumes:
    - Step 1: 150 bbls of fresh water mixed with 250gallons of MF
    - Step 2: 7,500 gallons of 15% HCl mixed with 750 gallons of MF
    - Step 3: Displace treatment with 150bbls of treated fresh water.
- Soaking time 6-8 hours

FIELD APPLICATION RESULTS

Well 1 Results:

Following the chemical acid clean-up on well 1, the well 1 returned to production (Fig 11) with immediate and sustained sand flowback, confirming successful removal of frac-hit-induced near-wellbore restrictions without the need for mechanical intervention. Post-treatment production stabilized at approximately 346 BOPD, 754 BWPD, and 191 MCFD, with oil rates exceeding pre-frac-hit performance by ~40%. The production response shows a clear inflection from zero production after the frac hit to a sustained recovery, demonstrating restored and enhanced well productivity. Controlled sand production to surface eliminated the risk of downhole accumulation and had no adverse impact on ESP performance.

This outcome highlights the simplicity and effectiveness of the chemical solution, which replaced a planned mechanical clean-out with a lower-risk, cost-effective treatment. By mobilizing and producing sand without intervention, the approach enabled a rapid return to service, improved drawdown efficiency, and delivered a measurable uplift in oil production, proving that a straightforward chemical clean-up can both remediate frac-hit damage and materially improve well performance.

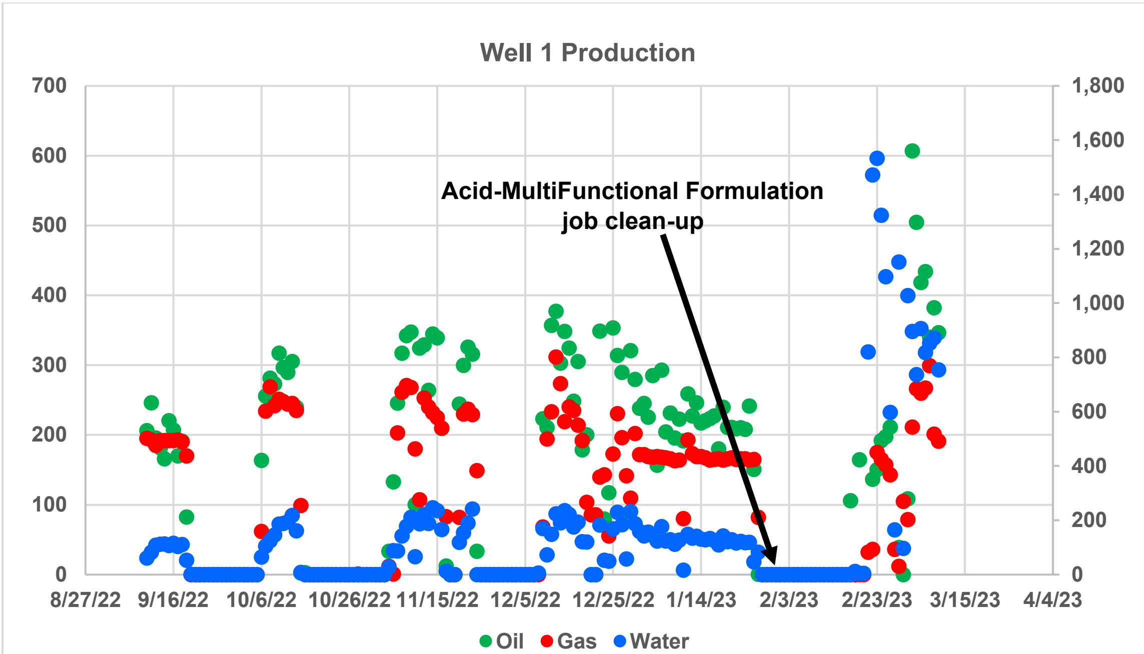


Fig 11 Well 1 Production Plots

Well 2 Results:

Following the frac hit, well 2 experienced a severe production decline, with oil rates dropping from approximately 137 BOPD to 50 BOPD, followed by a slow and incomplete recovery consistent with partial near-wellbore plugging from frac sand and fines. After the non-acid chemical clean-up using a multifunctional formulation and treated fresh water, the production trend showed a clear and sustained inflection. Post-treatment oil production exceeded pre-frac-hit levels by more than 150%, more than doubling relative to pre-treatment rates (Fig 12), indicating effective restoration and enhancement of near-wellbore flow capacity rather than a short-term clean-up response.

In addition to mobilizing and producing frac-related solids to surface, the multifunctional formulation improved near-wellbore wettability and fluid unloading efficiency, reducing capillary hold-up and facilitating more effective removal of trapped water and completion fluids. This contributed to improved drawdown and sustained oil response while eliminating the need for a planned mechanical clean-out, avoiding associated cost, downtime, and operational risk. The treatment was simple, low-risk, and fully compatible with the existing gas lift system, with no adverse operational impacts observed, demonstrating that a straightforward chemical solution can both remediate frac-hit damage and materially improve well performance.

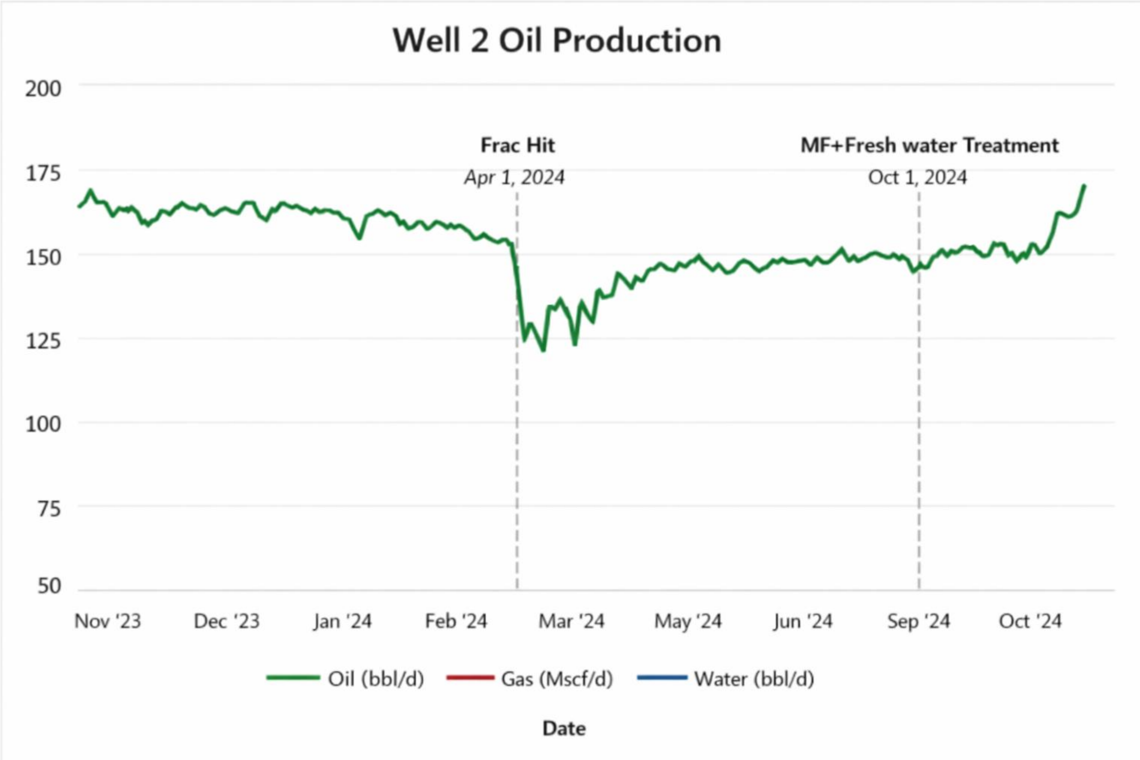


Fig 12. Well 2 Production Plots

Well 3 Results:

After implementation of the chemical clean-out, Well 3 returned to production with immediate and sustained recovery, as solids were effectively mobilized and produced to surface rather than remaining bridged in the wellbore. Post-treatment production stabilized at approximately 395 BOPD, 1,000 BWPD, and 300 MCFD, representing nearly a 100% increase in oil rate relative to pre-frac-hit performance (Fig 13). The production trend shows a sharp inflection from zero production to sustained rates above historical baselines, confirming both restoration and enhancement of near-wellbore flow capacity.

The combination of acid and a multifunctional formulation addressed multiple damage mechanisms simultaneously. The acid component effectively dissolved potential scale precipitation resulting from incompatible fluid migration following the frac hit, while the multifunctional formulation improved wettability, fluid unloading, and solids transport, reducing capillary hold-up and enabling efficient removal of trapped water, fines, and completion debris across the lateral. This integrated approach delivered improved drawdown and a durable production response with no subsequent sanding or re-impairment observed, while fully maintaining stable gas lift performance, demonstrating a simple, low-risk chemical solution capable of resolving complex frac-hit damage mechanisms.

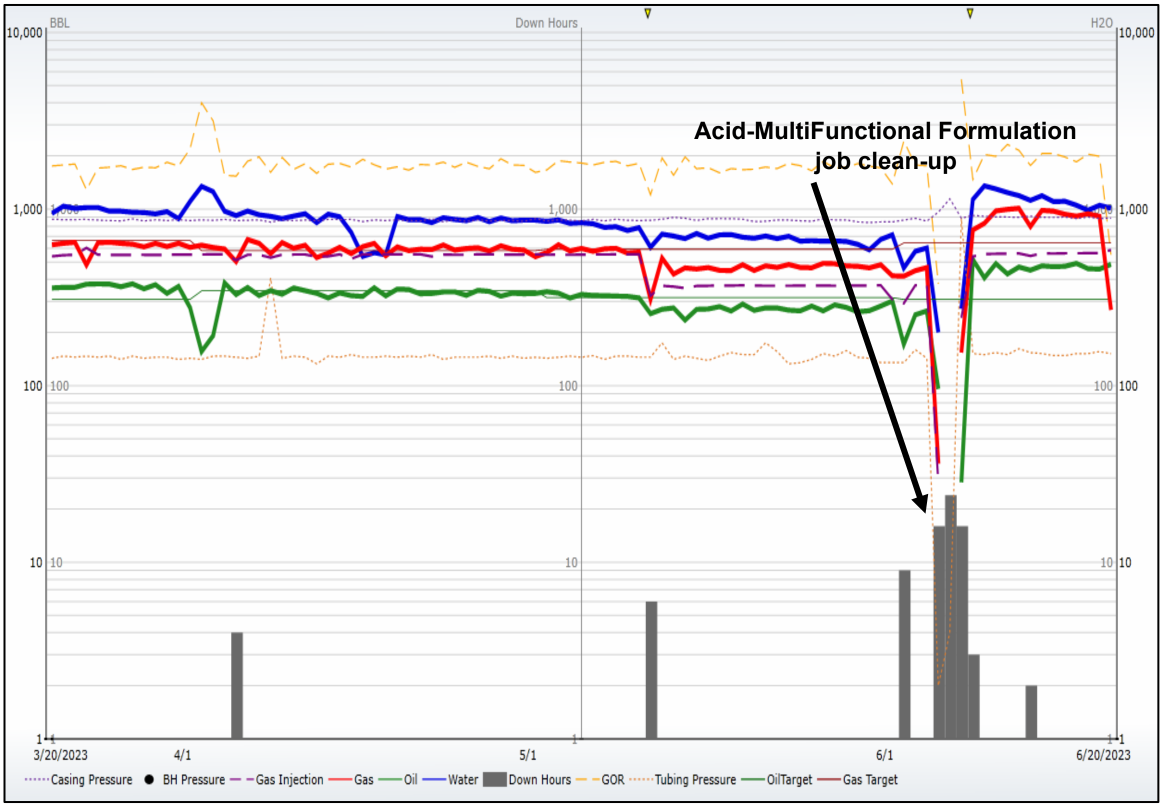


Fig 13. Well 3 Production Plots

CONCLUSIONS

This study demonstrates that frac-hit damage in unconventional wells is fundamentally a multi-mechanism problem involving organic deposition, inorganic scale precipitation, wettability alteration, fines migration, capillary trapping, and fluid incompatibility. Traditional remediation methods, such as standalone acids, solvents, or mechanical cleanouts, are inherently limited because they address only a single damage component at a time. The multifunctional formulation presented in this work was specifically engineered to overcome these limitations by delivering synergistic remediation of multi-skin damage in a single treatment, eliminating the need for solvent preflushes and complex multi-stage designs.

Laboratory testing confirmed the formulation's ability to dissolve and disperse paraffin, maintain miscibility in 15% HCl, reduce interfacial tension to ultralow levels, reverse oil-wet conditions to strongly water-wet, and enhance dissolution of iron sulfide and carbonate scale when combined with acid. These mechanisms directly translate to improved near-wellbore fluid mobility, reduced capillary pressure, and prevention of solids re-agglomeration. Field applications across three frac-hit-impacted horizontal wells validated these findings, with production recoveries ranging from 50% to greater than 100% relative to pre-frac-hit decline trends, including cases where oil production exceeded historical baselines. In all cases, the chemical treatments successfully replaced planned mechanical interventions, reduced operational risk, maintained artificial lift integrity, and enabled rapid return to production.

Overall, the multifunctional formulation provides a cost-effective, operationally simple, and highly adaptable solution for frac-hit remediation and near-wellbore multi-skin damage in unconventional reservoirs. Its ability to simultaneously address organic, inorganic, and wettability-related damage mechanisms makes it particularly well suited for parent wells impacted by fractured-driven interactions, where fluid incompatibility and solids invasion coexist. The results presented herein support broader application of multifunctional chemical systems as a preferred alternative to mechanical cleanouts and single-purpose treatments in modern unconventional field development.

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