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Advancement in Friction Reducer Development with an ESG Focus

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Abstract

Innovations in hydraulic fracturing techniques have driven increased production rates in unconventional shale rocks. This process creates flow paths in the rock by pumping large volumes of fluid at a high rate with sufficient pressure to create and propagate cracks or fractures in the rock. These flow paths are simultaneously filled with sand or proppant to keep the fractures open for long term production. The use of chemical friction reducers are essential to field operations by reducing frictional forces that develop along the pipe wall while pumping at high flow rates. The control of the frictional pressure in the pipe, in turn minimizes the load on the surface pumping equipment and also keeps the maximum pressure below the safe operating pressure of the pipe being used. Standard friction reducers were originally designed for use in freshwater and utilize turbulence for transport which limits their proppant carrying capacity when compared to polymer viscosified fluids. There has been a developmental need for a non-damaging viscosified fluid that can be utilized in recycled / produced water.

A new series of high viscosity friction reducers (HVFR's) have been developed & field tested, allowing the operators to utilize produced water for fracking while also transporting higher loadings of proppant. It has been determined that there is a direct correlation between the amount of proppant placed per stage and the resultant production from the wells, so the industry as a whole have been striving to find economical and efficient ways to carry more proppant downhole. Besides the advantages on performance, the application of these new HVFR's can lower the environmental impact of field operations by conserving freshwater resources and thereby achieving improvement on the ESG profile of the job. In addition, the high proppant carrying capacity of these HVFR's can also improve ESG by facilitating the simultaneous fracturing of multiple wells, thereby lowering the overall carbon footprint of the operations on a per well basis. This paper will discuss the laboratory work done to evaluate the performance and applicability for use of these new HVFR's and highlight success seen in the field.

Introduction

The technology of hydraulic fracturing for hydrocarbon well stimulation is not new, but only recently has become a very common and widespread technique, especially in North America, due to technological advances that have allowed extracting oil and gas from so-called unconventional reservoirs (tight sands, coal beds and shale formations). The conjunction of techniques such as directional drilling, high volume fracturing, micro-seismic monitoring, etc. with the development of multi-well pads has been especially successful in the last years in their application to shales, making oil and gas production from shales technically and economically feasible. In Europe, the potential application of this technology has led to both great worries and high expectations: worries regarding the alleged magnitude of the environmental impact, and expectations about production of indigenous hydrocarbons (Gandossi et al. 2015).

The process of hydraulic fracturing involves pumping large amounts of fluid at a high rate and pressure to create and propagate cracks or fractures in the rock, while simultaneously filling these cracks with sand or proppant to keep the fractures open for long term production (see Figure 1). Utilizing water as a based liquid for hydraulic fracturing is a recent development. Before 1952, numerous fracking operations were at first performed with gelled crude and later with gelled kerosene. In 1953, however, water began to be used as a fracking liquid and various gelled fluids were created. Historically, our industry used aqueous fluids viscosified using natural polymers (linear or crosslinked) to transport the proppant into the created fractures. This practice continue until recently when it was determined that these natural polymers gelled fluids were highly damaging to the ultimate production from the wells, then a change was made to a cleaner system.

More recently the industry has opted to omit the use of these conductivity damaging natural polymers in favor of using extremely high pumping rates for the fluid to transport proppant in a turbulent flow regime. Traditional friction reducers have been used in stimulation treatments to reduce the friction pressure that develops along the pipe walls while pumping at highly turbulent flow rates. These fluid systems are known as Slickwater and mainly rely on the turbulent flow regimes formed by pumping the fluids at an extremely high rate, in most cases greater than 80 bbls/min. Of course, pumping at high flow rates also result in the need for extremely large volumes of fluid so as to maximize the area of reservoir exploited and to transport the volume of proppant required to keep the created fractures open after the pumping stops.

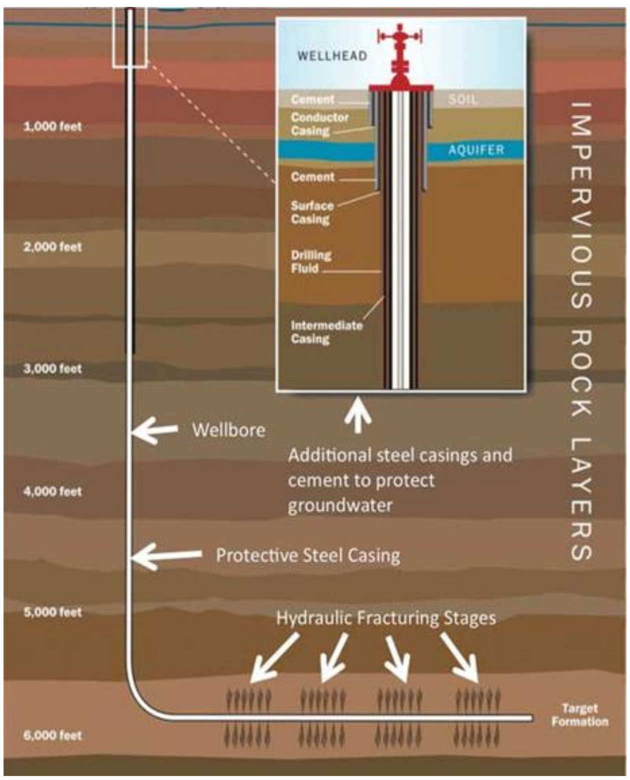

Figure 1 Unconventional Hydraulic Fracturing Well Completion Diagram

Traditional Slickwater designs were used successfully to create significant Stimulated Reservoir Volume (SRV) however, because of lower proppant carrying capacity, they were limited in the amount of Propped Reservoir Volume (PRV) they could achieve. Other disadvantages of these systems were the need for potable water and their limited transport capacity due to their low viscosity or elasticity to suspend the larger particle sized sand or proppant over significant distances in the reservoir. Reservoir engineers have come to realize that there is direct correlation between the amount of proppant that can be placed into a fracturing stage and the resultant amount of production achievable from said stage. This conclusion has prompted the change in modern fracturing designs to contain as much as 40 to 50 million pounds of sand per well. To be able to transport this amount of sand using standard Slickwater designs, it will require up to 20 million gallons of water per well. In fact, estimates of direct water use indicated an upward trend in the amount of water used in the Permian Basin from 2010 to 2019, ranging from 3,003 million gallons per year (Mgal/yr) in 2010 to 72,220 Mgal/yr in 2019 in Texas and from 353 Mgal/yr in 2010 to 11,403 Mgal/yr in 2019 in New Mexico. In the Permian Basin alone, estimates of water use per well for hydraulic fracturing were 29 times higher in 2019 than in 2010 (Valder et al. 2010). During that time however, little has changed with the ability of friction reducing polymers to be able to function effectively in produced or recycled brines as opposed to freshwater and the latter has continued to dominate the fracturing market because of the lack of innovation to the chemistry of these polymers.

The ideal fracturing fluid thus becomes one that can exhibit all of the advantageous properties of a Slickwater system while having proppant carrying capacity that is close to that of polymer gelled fluids. Recently, high viscosity friction reducers (HVFR's) have been successfully introduced into the market to address the need for a product that combines lower frictional pressures during high-rate pumping operations while also having the ability to build viscosity and elasticity for better proppant transport. HVFR's do also have the ability to reduce water consumption and minimize chemical usage compared to traditional FR's for placement of the same amount of proppant per stage. Also, dependent upon the job design, HVFR's can require less operating equipment on location and can significantly shorten pumping times because of their better sand/proppant carrying capacity.

Since HVFR's have the ability to carry more proppant due to their ability to build viscosity or because of their inherent elasticity, fracturing designs using HVFR's can load more proppant per gallon of water, resulting the well stages being completed with the maximum amount of sand but utilizing less water than conventional designs. In addition, the more advanced HVFR's that are brine tolerant can also accommodate the same design criteria utilizing produced or recycled brines instead of freshwater. Many jurisdictions in West Texas and in the Mid-Con are now restricting the re-injection / disposal of large quantities produced water from fracturing activities prompting operators to find other uses for this "waste" material. The regulations pertaining to the disposal of large quantities of produced water in these areas is hinged to an increase in seismic activity near the location of large clusters of these wells that are used for disposal. The ability to reuse this produced water from hydraulic fracturing and the savings derived from not having to truck the water over long distanced has multiple environmental benefits for the oil and gas operator.

In addition to the lower water consumption when using modern HVFR's for hydraulic fracturing, the average fracturing stage can also be completed in less time according to design. Since the HVFR's can carry more proppant per gallon of brine, for a given fluid pumping rate, e.g. 100 bbls / min, the same amount of proppant can be pumped in less time. This means that stages can be completed in a shorter period of time and overall, well completion time is by extension also reduced. This shortened well completion time for the wells mean less time for the pumping equipment to be running onsite. The resultant reduction in carbon footprint as a result of a shorter well completion time is of course greater for diesel fleets as compared to dual-fuel or electric fleets but just as beneficial for all.

Laboratory Testing

Performance of the newly developed High Viscosity Friction Reducer (HVFR) product was verified in the laboratory, to extrapolate field performance, by running a series of tests for the determination of friction reduction, viscosity and elasticity characteristics. The first step was to test and compare, the new engineering design for the HVFR to standard HVFRs in different brines at room temperature for friction reduction. A Chandler Friction Flow Loop with a 1/2 inch (outer diameter) pipe was used with a flow rate of 8 gallons/minute. The Reynold's number for this set up was around 70K. Figure 2 shows the friction reduction performance of a standard HVFR in two different brines. This type of HVFR was originally developed to be used in fresh water rather than brines. As it can be seen below, the standard HVFR had a friction reduction of > 70% when tested in fresh water but when brine was used its performance decreased to ~ 30%. It is this latter observation that has resulted in the slow change of the industry, from freshwater to being able to utilize more produced / recycled water in fracturing operations.

The New HVFR is a anionic polyacrylamide polymer that was developed to have good performance in salty brines from low to high TDS. It has a molecular weight of > 15 Million Dalton. Figure 3 shows the friction reduction of the New HVFR in

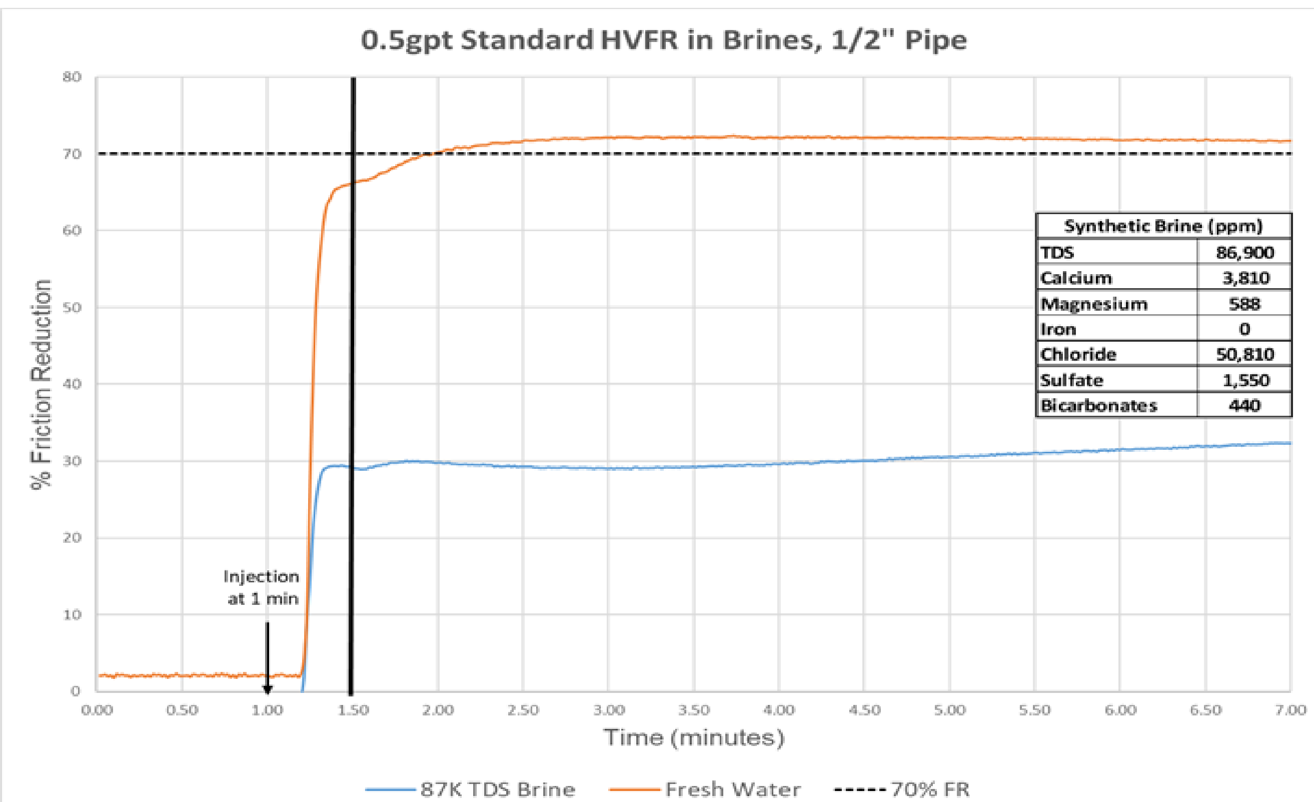

Figure 2: Friction reduction of Standard HVFR in brines

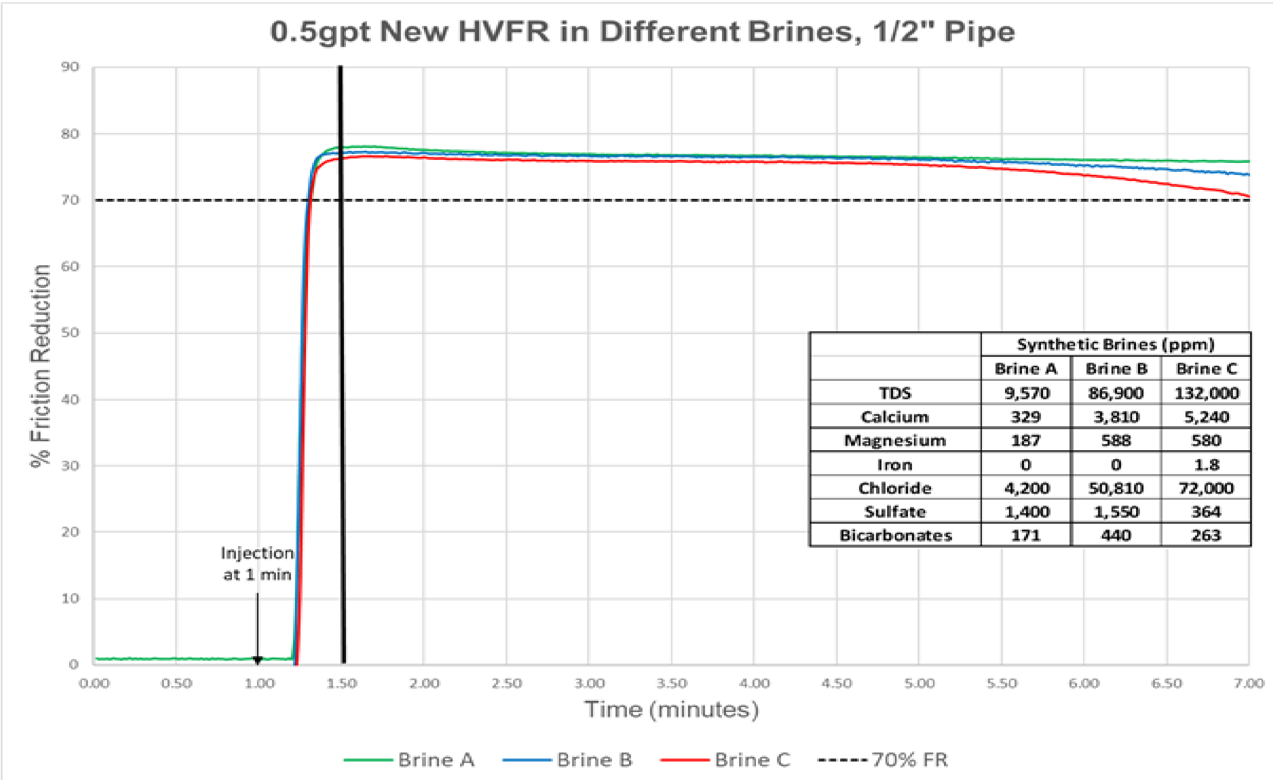

Figure 3: Friction reduction of New HVFR in brines

brines from 10K to 131K TDS @ 0.5 gpt loading and different combinations of divalent ions that could potentially affect the performance of the product. In addition to the overall TDS of the brines, it is the brine hardness (governed largely by the Calcium ion concentration) and the presence of soluble Iron that significantly impeeds the Standard Friction Reducing polymers from functioning effectively in produced or recycled brines. However, the testing results for our newly engineered HVFR, revealed that the friction reductions in all brines were > 70% with hydration in ≤ 15 seconds and inversion of ≤ 30 seconds. A significant improvement on friction reduction from 30 % to > 70% can be seen when comparing the performance of the standard HVFR to the New HVFR in the 87K TDS brine. The New HVFR also had a good performance at the same loading of 0.5gpt even when more salty brine of > 100K TDS was used.

The second phase of testing was to determine the rheological properties of the New HVFR as compared to the Standard HVFR in fresh water and different brines. Viscosity tests were performed using a Grace M3600 viscometer. Figure 4 shows an example of viscosities using a loading of 3gpt in fresh water and 9K TDS brine for standard HVFR. This HVFR exhibited viscosity of 11 cP in fresh water but when tested with brine,it was reduced to 2 cP. These results indicates that the standard HVFR viscosity building is drastically affected by the presence of salts and only able to carry proppant to the hydraulic fracture network when fresh water is used.To

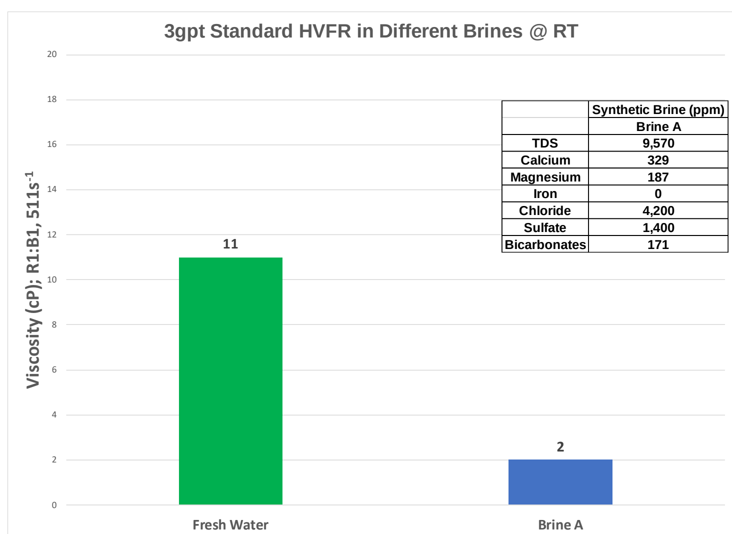

Figure 4: Viscosities of Standard HVFR in brines

characterized the rheological properties of the New HVFR, viscosity testing was also performed in fresh water and brines typical of produced / recycled water in West Texas. Figure 5 shows the viscosities of the New HVFR in fresh water to 250K TDS brines at a loading of 3gpt. The viscosity of the New HVFR showed a gradual decreased as the TDS, brine hardness and soluble iron content were increased. However, the New HVFR still outperformed the ability of the Standard HVFR to build viscosity in these brines. The high concentrations of Calcium (>15,000ppm) and other divalent ions affected the performance of the product but still show good viscosity at these extreme concentrations when compared to historical products in the market.

The friction reduction and viscosity results for New HVFR show the tolerance of this product to brines that can be > 6 times saltier than typical seawater. This means that the amount of fresh water needed to complete the work in unconventional shale reservoirs can be reduced and also the product can be an option in places where the availability of fresh water is limited or an expensive commodity.

The last phase of the laboratory work was to conduct oscillation testing, which measures the elastic properties of the polymer solution, and this was used to compared a Standard HVFR vs. New HVFR. An Antone Paar Rheometer Model MCR 102 with Double Gap configuration (DG-42) was used. This type of test calculates the Storage Modulus (G') and Loss Modulus (G"). G' represents the elastic behavior while G" represents the viscous behavior of a sample. Fluids that have G' measurements that are equal to G" measurements are considered to be visco-elastic. If however, the fluid has G" greater than G', this signifies a gel like structure is present and the fluid has greater viscous properties. If G' is greater than G" this represents a liquid with good elastic properties. A product with more elastic behvior will be able to carry more proppant into the open fractures than if it exhibited

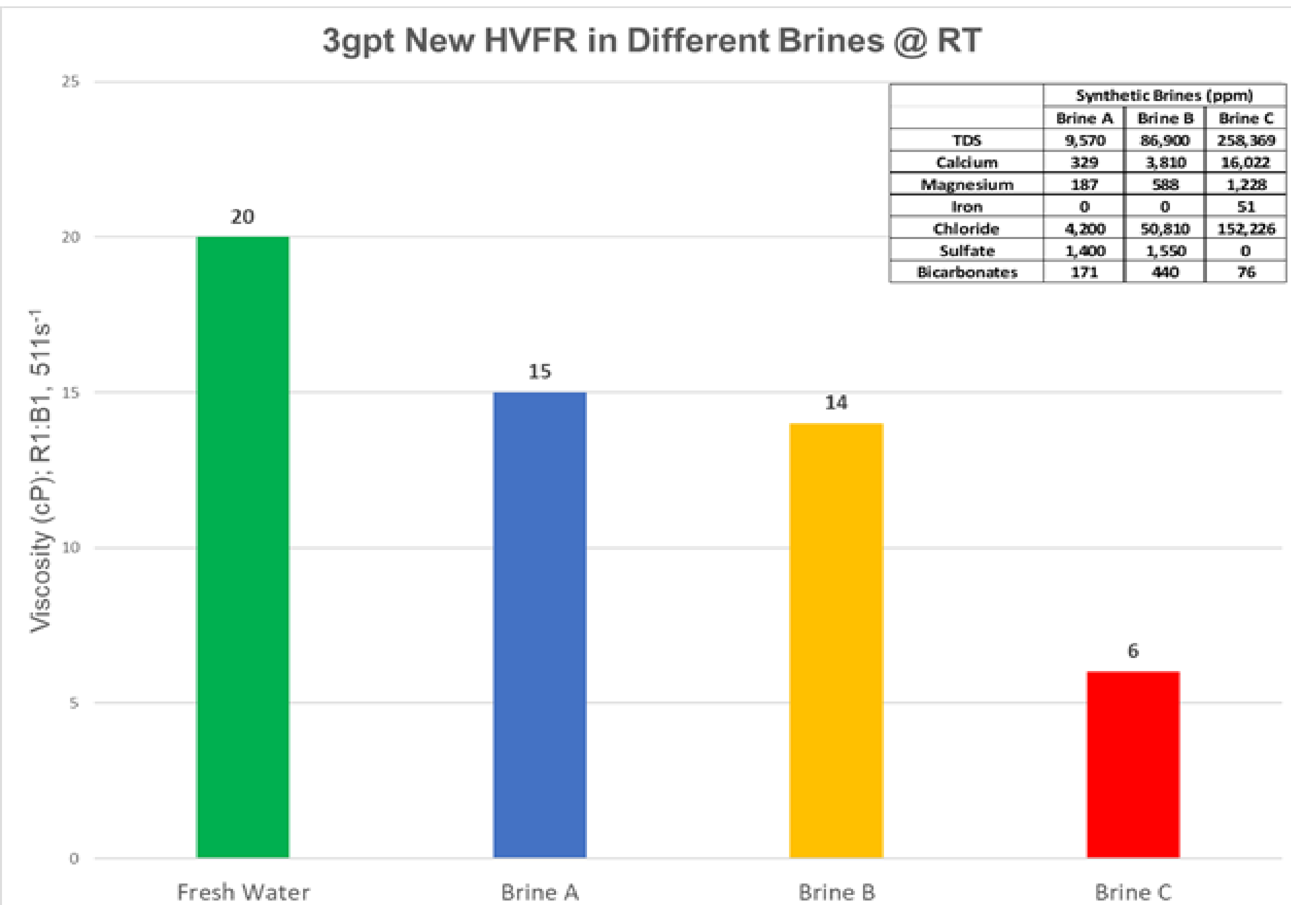

Figure 5: Viscosities of New HVFR in different brines

predominantely viscous behavior. Figure 6 shows the oscillation results for a Standard HVFR in fresh water @ 3 gpt. It can be seen that the product displays G" > G' and is therefore a liquid with more viscous behavior rather than elastic. The amount of proppant carried by this product in a high shear envioronment can be limited, because these systems tend to be shear-thinning. Since these types of fluids have less proppant carrying capacity than fluids with greater elastic properties, longer pumping times would be needed to place the same amount of proppant per stage, resulting in a larger carbon footprint for the overal job. From viscosity and friction reduction testing it was established that the salinity of the brines affected the performance of the standard HVFR; therefore it was only tested in fresh water.

The New HVFR has shown a viscosity tolerance to salty brines and therefore was tested for oscillating properties at 3 gpt & in two different brines. Brine A had a TDS of 150K and Brine B a 250K TDS but with double/or triple the amount of divalent ions. Figure 7 shows the Storage and Loss Moduli results fo the testing at room temperature. The product had mostly G' > G" in both brines which correlates to good elastic behavior along with the excellent viscous properties. This indicates a fluid with great proppant carrying capacity because when the fluid shear or temperature thins as it is pumped into the reservoir, the elastic properties remain intact so as to place greater concentration and size of proppant into fractures. It

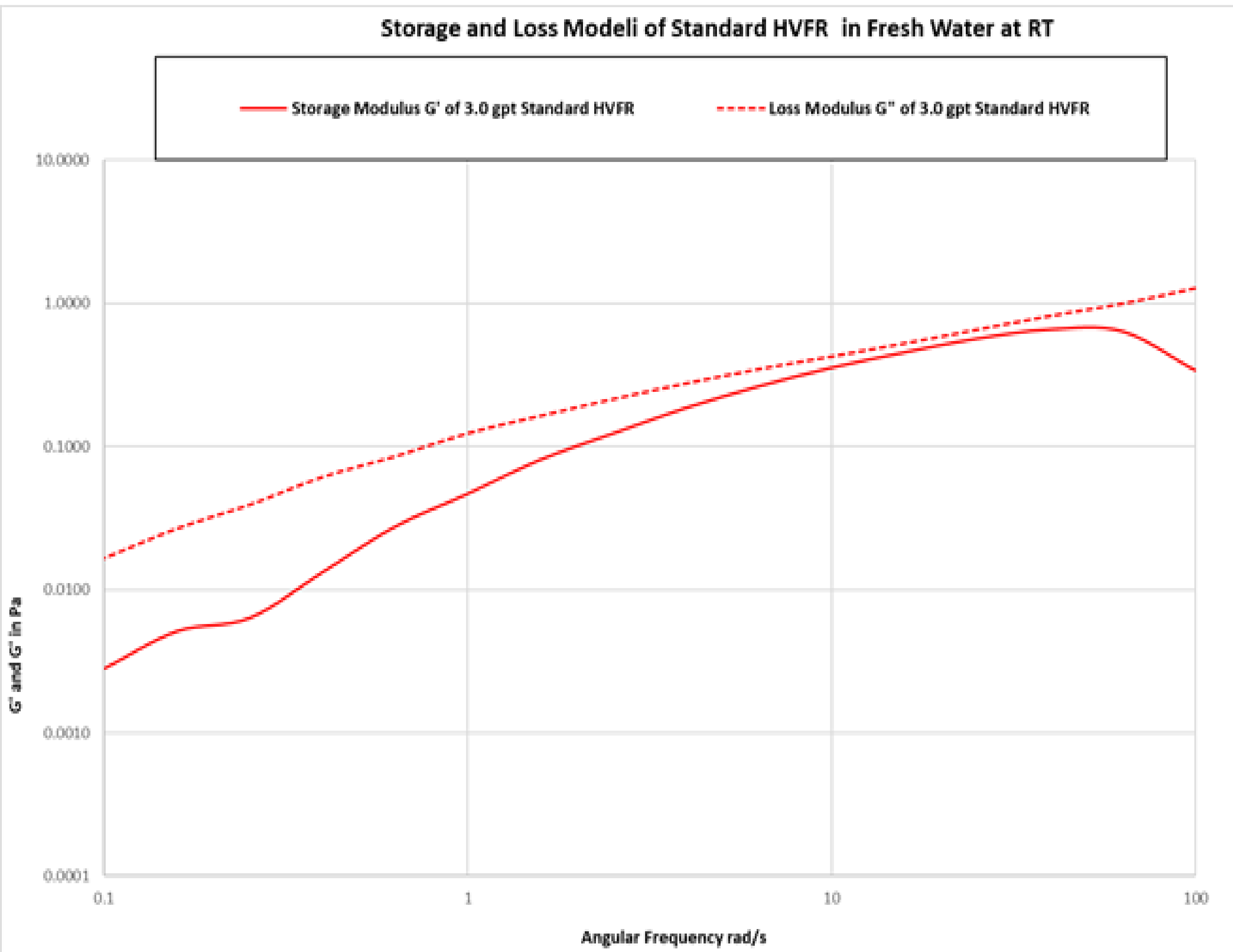

Figure 6: G' & G" for Standard HVFR in Fresh water

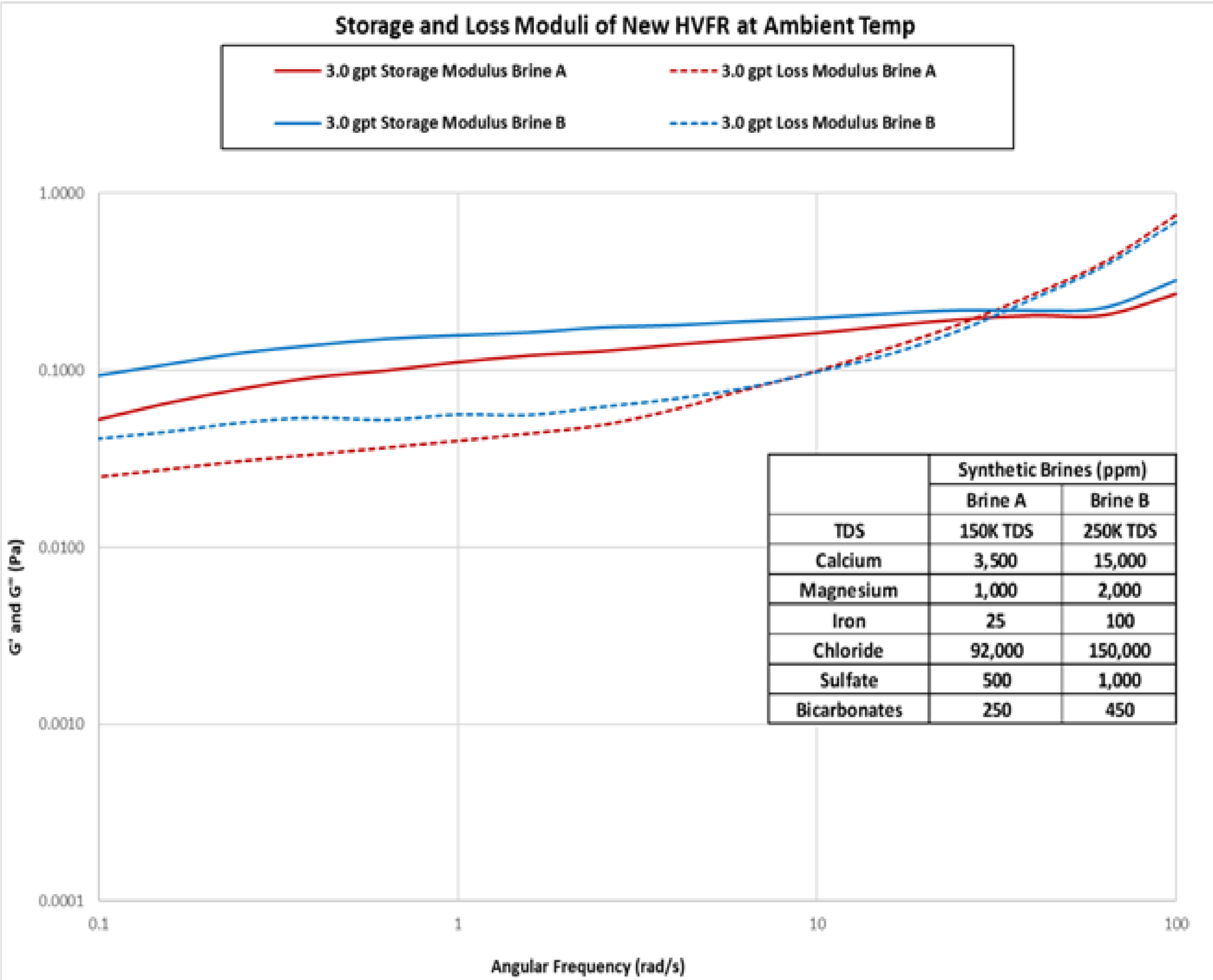

Figure 7: G' & G" for New HVFR in brines

was also established that the salinity of the brine didn't affect the performance of the product very much. Results from the laboratory testing had shown that the New HVFR is tolerant to salty brines with good friction reduction and viscosity building properties. It also has an elastic behavior which results in excellent capacity of carrying proppant into the fractures.

Field Application

An operator in West Texas was in search of a new HVFR that was not only cost effective but would be tolerant of any changes in water chemistry they saw while hydraulic fracturing. In most practical cases in the field, water quality used during the job changes depending on which water is available in sufficient quantities. Many jobs in West Texas frequently start with almost freshwater and then move to a mixture of fresh and produced brine and finally to pure brine if it is available. To avoid operational issues, the ideal friction reducer needs to be robust enough to function efficiently in the changing water chemistry since it is impractical to change the friction reducing polymer on the jobsite as the water quality changes.

A high-level description of the operator's objectives involved reducing surface treating pressure while carrying and placing high proppant concentrations in varying amounts of production water. The Operator was looking for a Polyacrylamide based polymer engineered to build viscosity and elasticity even in the presence of production waters with high iron and calcium. The goal was to be able to control frictional pumping pressures, build viscosity and with this, place larger mesh size proppants at high concentration deep into formation while saving time and water.

Saving pumping time is always a tangible goal as most operators can quickly link that time to cost. However, the intangible part from the ESG side is the overall change in carbon footprint that results from being able to complete the fracturing of each stage with the desired design, simply with the selection of a better engineered friction reducing polymer. For the average fracturing fleet, this change amounts to less noise generation, less work exposure to high pressure, less diesel consumption, less carbon emitted to the atmosphere and of course less time the pumping equipment is on that pad.

Figures 8 and 9 show the pumping charts for both early and late stages on the pad for this West Texas customer during the job. The conditions of the job as explained previously was that the chosen HVFR needed to be tolerant of varying brine chemistry while still allowing for the increasing addition of proppant as each stage was completed. In addition to the concentration of proppant being used, the fracturing design also called for a change from lighter 100 mesh proppant to heavier 40/70 mesh proppant. Being able to carry higher loading of proppant per gallon of water means that the overall job would require a lower water consumption, which is a benefit in and of itself in the arid conditions that exist in West Texas. Just being able to do the former would have been considered a successful trial, however, if the use of a highly engineered HVFR could also allow for the more efficient placement of the proppant, with size and loading as designed, and do so in a shorter pumping time then that would be considered a bonus.

Shorter pumping times mean less operational costs for manpower and equipment onsite but also result in a better ESG profile for the job. The type of pumping equipment the fleet is using dictates the degree of improvement of the ESG profile, with Diesel fleets having the most impactful change followed by dual-fuel fleets and lastly electric fleets. Nevertheless, regardless of the pumping equipment, any reduction in the time to complete a stage, the full well or the entire pad has significant cost and environmental impacts.

During this trial, the New HVFR was able to effectively place higher concentrations (3.5+ ppa) of larger 40/70 proppant into

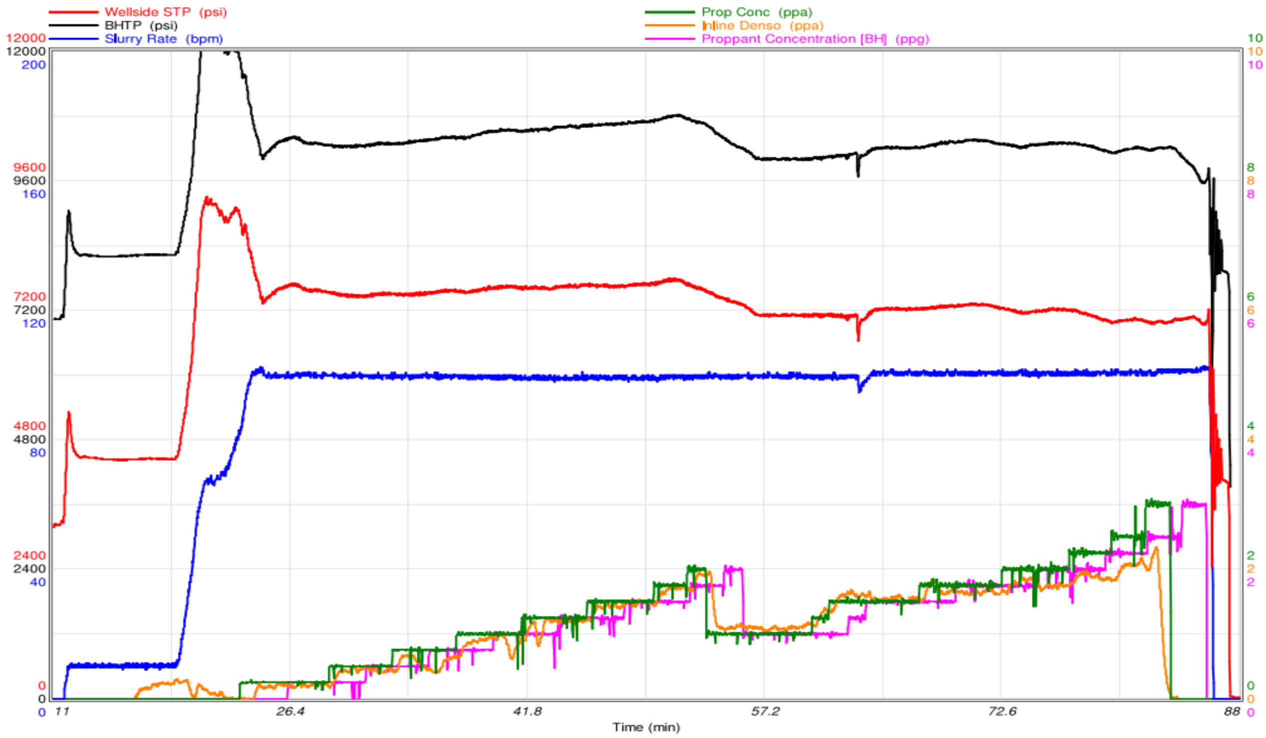

Figure 8: Early Stages

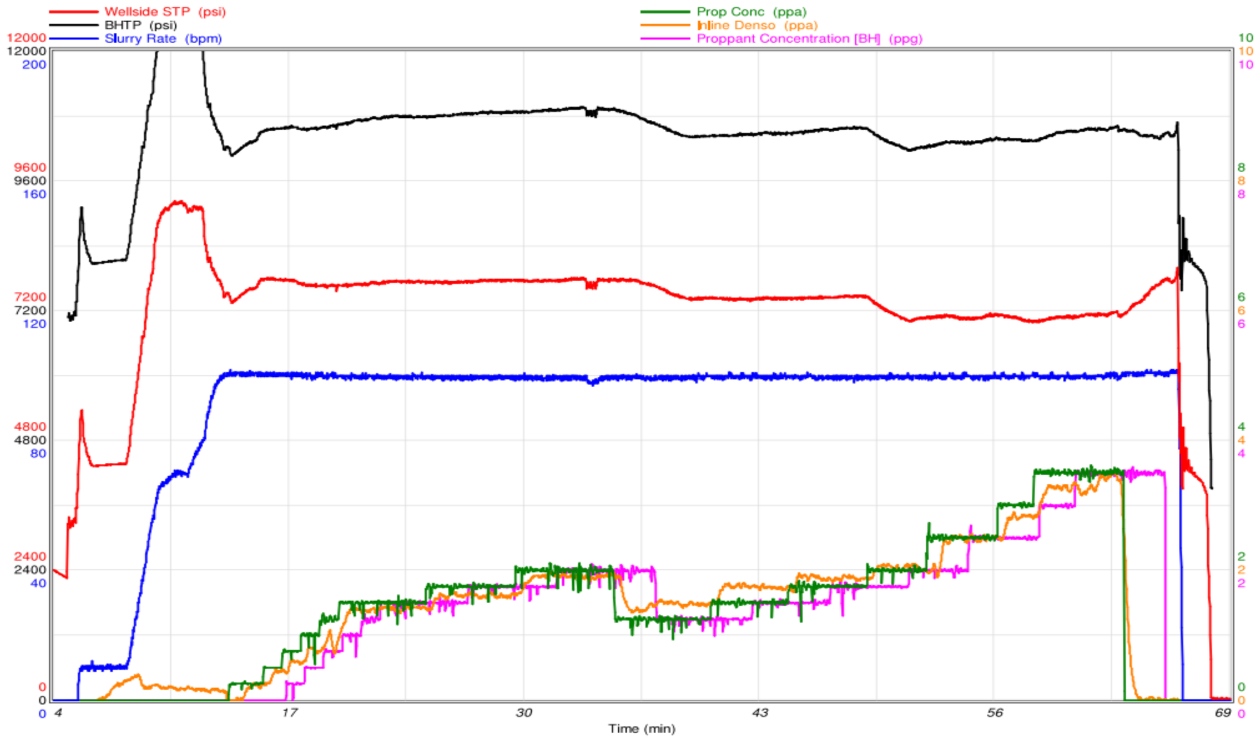

Figure 9: Late Stages

formation saving 13.25 min and 1,200 bbl of fresh water per stage. Not only did this improve ESG metrics by utilizing various amounts of production water (20-55%) but it also cut down the amount of CO_2 produced from the Fracturing operation by utilizing less diesel / natural gas substitution.

The tables below show a field case with CO_2 abatement in two different scenarios. Table 1 shows a 100% diesel fleet while Table 2 shows a Tier IV fleet with 70% substation. The CO_2 abatement could be increased by doing a more inclusive life cycle analysis to include manpower and trucking of the diesel fuel and water that would have to be used.

Table 1: 100% Diesel Fleet

100% Diesel Fleet	
90	Gallon of Diesel per Hour [1]
22.38	lbs. CO2 / gallon [2]
16	Pumps on location
13.25	Minutes of time saved per stage
66	Stages per well
3	Wells per pad
1440	Gallon of Diesel burned per Hour
0.2208	Time savings in Hours
318	Gallons of Diesel Saved
7,117	lbs. CO2 abated per stage
469,711	lbs. CO2 abated per well
1,409,134	lbs. CO2 abated per pad

Table 2: Tier IV Fleet, 70% Substation DGB

Tier IV Feleet 70% Substation DGB	
139.3	Diesel gallon equivalent (SCF) [3]
121.31	CO2 / Thousand cubic feet [4]
90	Gallon of Diesel per Hour [1]
22.38	lbs. CO2 / gallon [2]
70%	Diesel Substitution for Tier IV Duel Fuel [1]
16	Pumps on location
13.25	Minutes of time saved per stage
66	Stages per well
3	Wells per pad
432	Gallon of Diesel burned per Hour
140,414	SCF Burned per Hour
0.2208	Time savings in Hours
95.4	Gallons of Diesel Saved
31,008	SCF of Natural Gas Saved
5,897	lbs. CO2 abated per stage
389,179	lbs. CO2 abated per well
1,167,538	lbs. CO2 abated per pad

Conclusion

Laboratory design and testing proved that the newly developed HVFR had excellent performance when used in high salinity produced water with the ability to carry higher proppant loading into the hydraulic fracturing network. From the laboratory results, the New HVFR had good friction reduction & viscosity building capacity in brines with TDS >100K and in presence of divalent ions. Its elastic behavior in oscillatory testing confirmed that the product also has excellent proppant carrying capacity that is not affected by salinity of brines. The field application confirmed the laboratory results and showed that the New HVFR was more robust to changes in brine chemistry and this lowered the amount of fresh water used during the job. This correlates to a decrease of fresh water needed to complete the work in a typical unconventional shale reservoirs and the possibility to be used in places where the availability of fresh water is limited or an expensive commodity. In addition, there was also an improvement in the ESG metrics for the job. The shorter pumping time to complete an average stage, resulted in a decrease in the amount of CO_2 produced from the operation by utilizing less diesel/natural gas for jobs of this type regardless of fleet type.

Acknowledgements

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Nomenclature

HVFR = High Viscosity Friction reducer
ESG = Environmental, Social and Governance
bbls/min = Barrels per Minute
SRV = Stimulated Reservoir Volume
PRV = Propped Reservoir Volume
Mgal/yr = Million Gallons per Year
ppa = Pounds Proppant Added

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