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Early Applications of Viscosifying Friction Reducers for Hydraulic Fracturing Operations in the Vaca Muerta Formation, Argentina

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Abstract

Early hydraulic fracturing completions in the Vaca Muerta Formation in central Argentina have incorporated the use of conventional fluid systems, such as linear and crosslinked guar-based polymers. Within the past few years, however, the benefits of viscosifying friction reducers (VFR) have been demonstrated in the industry, predominantly within the United States. The objective of this project was to trial the VFR fluid technology in fracturing operations in this area for potential use for full field development.

After studying the potential advantages of the VFR technology including cost savings, simplified operations and enhanced well production, a project was initiated to determine if those same benefits could be obtained. To accomplish this, studies were performed to ensure economic and technical justification through a stepwise process of laboratory testing, logistical and operational considerations, a single well field trial, and a five well development phase evaluation project. The pilot project was performed on a horizontal, 27 stage lateral in the Aguada Pichana Oeste field in the Neuquen Basin of Argentina. The five well development phase evaluation project was performed in the Lindero Atravesado field.

Positive laboratory test results led to a field trial using this technology, during which several benefits of the VFR fluid system began to emerge. Operational efficiency was an early success, including a reduction in the quantity of chemicals on location, more simplified pumping schedules, and low pumping pressures. Secondly, significant cost savings were realized compared to previous fluid system packages. Finally, positive production results were observed, leading to the decision to incorporate this technology into full field development operations. This paper will review the results of the stepwise evaluation process along with a focus on the economic benefits and well production from the development phase evaluation project.

This paper describes the transition by Pan American Energy (PAE) from conventional fracturing fluids to viscosifying friction reducer (VFR) technology in the Vaca Muerta Formation. The paper highlights the performance of a relatively new treatment fluid which delivered positive results in a strategic international asset. The project has led to full field development using this technology. The same efficiencies provided by this system can potentially be realized through applications in other basins.

The Vaca Muerta

The targeted formation for the work described in this paper is the Vaca Muerta located in the Neuquén Basin in northern Patagonia, Argentina (Figure 1). The Vaca Muerta is one of the world's largest shale plays and the source rock for major deposits of shale oil and shale gas in this area (Jacobs, T., 2017; Donnelly, J., 2018; Rassefoss, S., 2018). Recent development activity in the Vaca Muerta has helped to increase the oil production from the Neuquén Basin by 25% in 2019, with approximately two thirds of the production coming from the Vaca Muerta (Newberry, C., 2019).

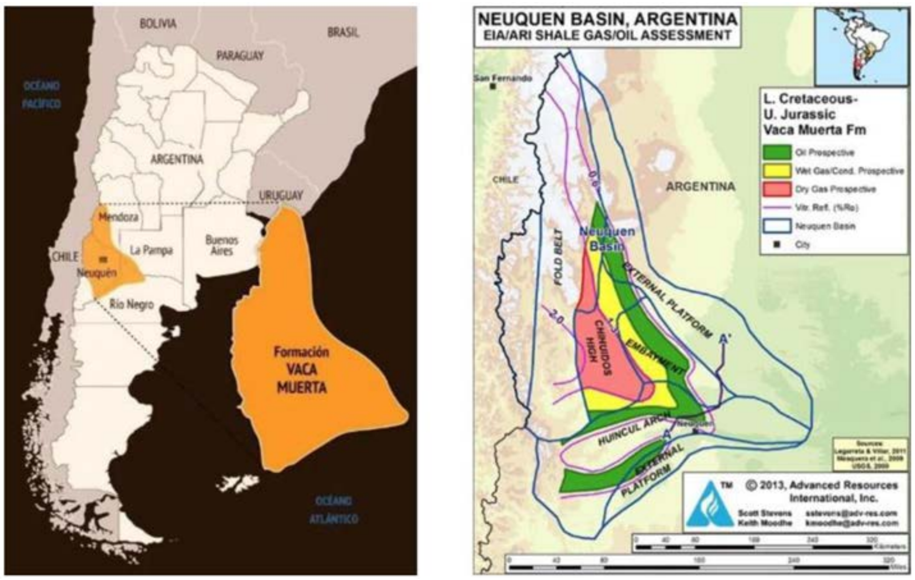

Figure 1—Map of Neuquén Basin in Argentina

Within the sector of these operations, the Vaca Muerta is of Tithonian age and develops in a deep basin to an external ramp environment. A dominant lithology of sludgeolites rich in organic matter exists towards the top of the sequence with an increasing content of carbonates and silicates, which are described as dolomitic clay and/or carbonic fangs. The suprayacent deposits are assigned to the Quintuco Formation of Barresian-Valanginian age and correspond to limestones with textures of packestones and wackestones associated with carbonatic ramp. Figure 2 shows a stratagraphic chart of the Vaca Muerta and surrounding lithology.

The total organic content (TOC) of the Vaca Muerta shows a clear declining trend from the base to the top of the stratigraphic unit. The lower section, informally known as "The Kitchen" and corresponding to the basal transgressive deposits, shows TOC contents of up to 6%, while towards the ceiling the sequence presents characteristics that are progradant with TOC of up to 3%.

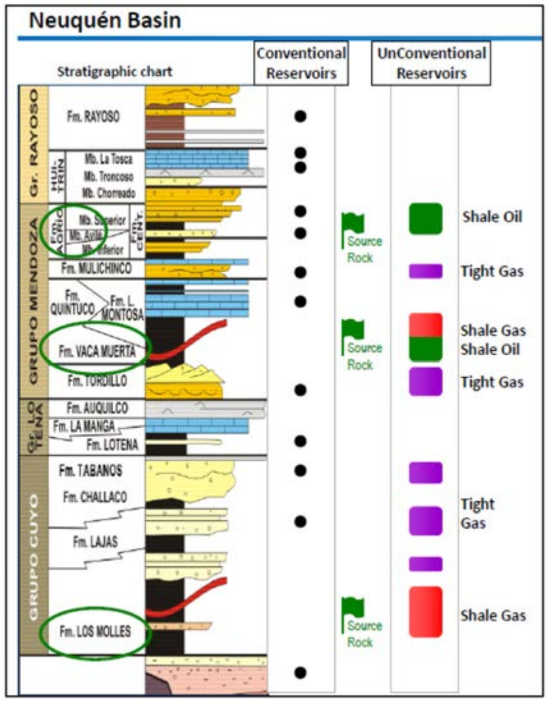

Figure 2—Stratagraphic Chart of the Vaca Muerta and Surrounding Lithology

Area of Operations

The area of operations for this project is shown in Figure 3. Within the Neuquén Basin, Pan American Energy operates in four areas which are active for tight gas as well as shale oil and gas. The field trial described in this paper took place in the Aguada Pichana Oeste block in the western part of the area, while the development project took place in the Lindero Atravesado block in the east, near to the Mari Menuco reservoir. Within the Lindero Atravesado block, the El Chanar deposit corresponds to the first development of unconventional shale oil from the Vaca Muerta in this block.

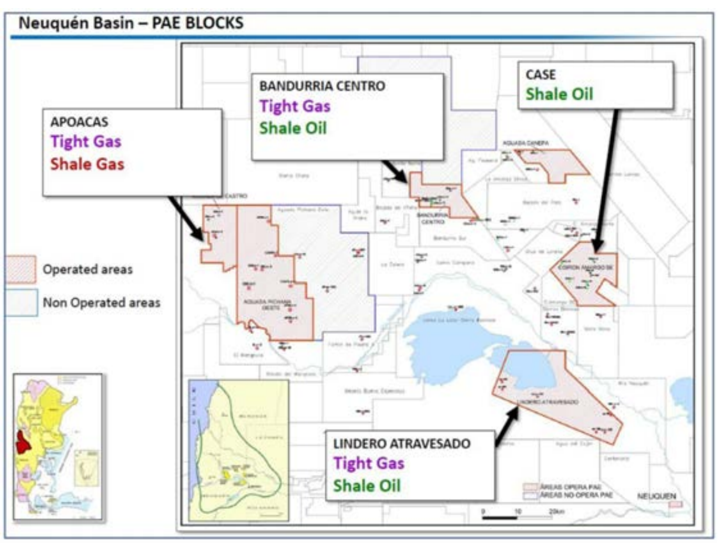

Figure 3—Area of Operations in the Neuquen Basin

Viscosifying Friction Reducers

Over the past four to five years, polyacrylamide-based viscosifying friction reducers (VFR) have become a standard fracturing fluid system for many operators in the oil and gas industry. Industry publications (Van Domelen, et. al, 2017; Dahlgren, et. al., 2018; Ba Geri, et. al, 2019) and case histories have highlighted the benefits of this type of fluid system over conventional guar-based fracturing fluids. Those benefits include:

- Cost Reduction and Simplified Logistics
- Viscosity Development at Low Concentrations
- Efficient Proppant Transport
- High Fracture Conductivities and Enhanced Well Production

Cost reduction opportunities with VFRs can materialize through several different mechanisms. The first is through the reduction of chemical additives required on location. A VFR fluid system can be run with as little as a single component, the VFR polymer itself, mixed in water. Many operators however choose to use a few other additives such as biocide, clay control, and/or surfactant, depending upon several factors including water source type and formation mineralogy. For this project, only three additives were used on a regular basis; biocide, the VFR, and a surfactant. The fluid system used in this area prior to this project included the use of three different fluid chemical types; slickwater, linear guar, and crosslinked guar. Compared to this "hybrid" type fluid system, the number of additives required on location for the VFR was reduced, simplifying logistics and tankage requirements for the operation.

Another area of cost reduction with VFR systems commonly occurs through the actual cost of the materials themselves. Fracturing fluid material costs vary across the industry, however many operators report a significant cost savings when comparing a hybrid fluid system to a VFR system. For this project, an average of 34% cost savings were observed.

A final area of cost savings arises with the potential for less fracturing equipment required on location. Gel hydration units which are required for guar-based fluid systems are not required for VFR fluids due to rapid hydration rate of the VFR polymer. Also, with the friction reducing properties of the VFR fluid, pumping pressures and therefore hydraulic horsepower requirements are commonly much lower than those using crosslinked gel at similar rates. Significant friction pressure and horsepower reductions were observed during the pilot project described later in this paper.

Fluid viscosity was an important consideration on this project when evaluating the possible switch to the VFR system. With proppant concentrations planned to reach or exceed five pounds per gallon (ppg) with the frac designs, the VFR was required to provide adequate viscosity. Using a relatively clean frac water source, excellent viscosities were observed with the VFR system and are described in more detail in the laboratory testing section of this paper.

Along with fluid viscosity, efficient transport of proppant into the reservoir is also an important requirement for a fracturing fluid. The VFR system used on this project has been tested extensively at two independent laboratories in which pipe and slot flow transport properties are measured. The VFR was also used in a recent industry consortium project, the results of which are detailed in SPE 196073, recently presented at the 2019 Annual Technical Conference and Exhibition (Anschutz, et. al., 2019). A photo of the slot flow testing apparatus used for this consortium project is shown in Figure 4.

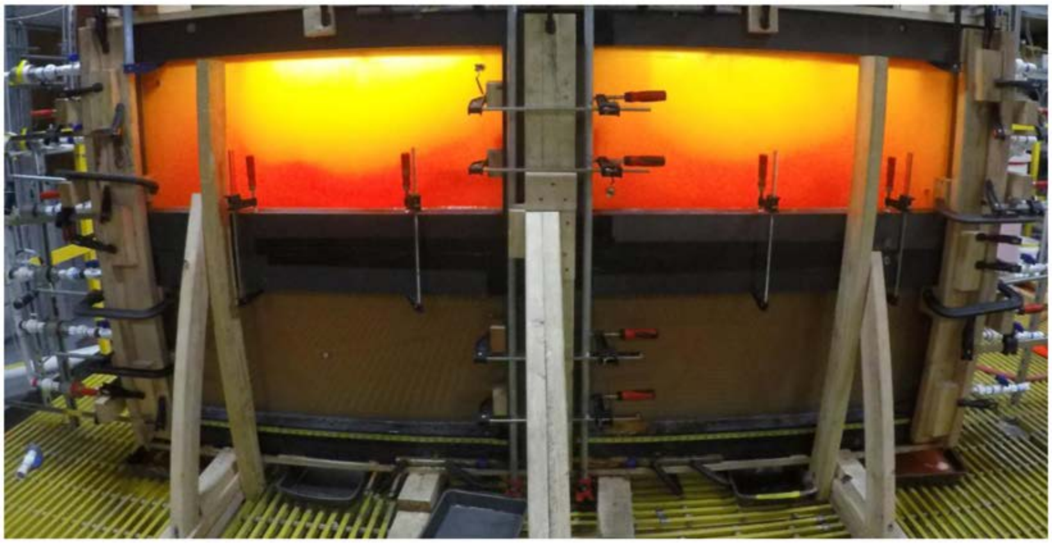

Figure 4—Slot Flow Testing Apparatus (photo courtesy of PropTester Inc)

The final desired benefit of the VFR system expected for this project was for the fluid to exhibit non-damaging properties. Regain fracture conductivity test results (shown in Figure 5) for this fluid system are high when compared to a guar based linear or crosslinked fluid systems. The cleaner proppant packs provide for maximum hydrocarbon flow rates from the reservoir to the well and have shown to provide enhanced well production. Production results for this project are shown in more detail in the case history section of the paper.

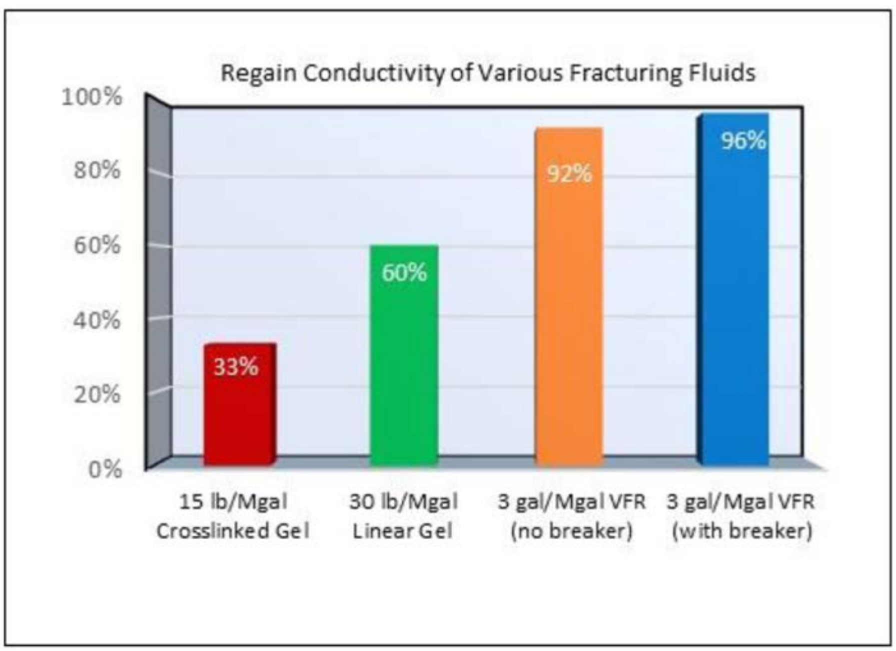

Figure 5—Regain Fracture Conductivity Comparison of Guar-based Fluids and VFR System

Laboratory Testing

The VFR fluid system was tested extensively in the laboratory prior to the start of this project in order to help ensure that the fracturing operations were successful. Table 1 shows the compositional analysis of the water used for laboratory testing, based on the complete water analyses provided for the actual source water. Recent work (Hazra, et. al, 2019) has provided more insight on how individual ions impact the performance of friction reducers. As observed from Table 1, the water was relatively clean with low levels of hardness (calcium and magnesium), total iron and overall total dissolved solids (TDS).

Table 1—Compositional Analysis of Fracturing Source Water

Brine chemistry summary:	
Water Analysis	
Properties:	
pH (72 °F)	8.89
Specific Gravity (70 °F)	1.01
Total Dissolved Solids (ppm)	1590 (mg/L)
Hardness Cations	
Calcium (Ca_{+2})	6.1 (mg/L)
Magnesium (Mg_{+2})	0.6 (mg/L)
Anions (mg/L):	
Chlorides (Cl_{-})	350 (mg/L)
Sulfates (SO_{42-})	702 (mg/L)
Alkalinity (mg/L):	
Bicarbonates (HCO_{3-})	215 (mg/L)
Select Ions (mg/L):	
Total Iron	<0.01 (mg/L)

Given the excellent water composition, the VFR system performed as expected with good results in the laboratory. The first set of testing performed was to evaluate friction loss in a flow loop apparatus. The flow loop consists of a 3/8" diameter pipe and is used to evaluate the level of friction reduction provided by the fluid system. Figure 6 shows the results of the flow loop test in which the level of friction reduction is plotted as a function of time. For this test, increasing concentrations of VFR were used knowing that the higher concentrations would likely be used during the field trial. The VFR showed excellent friction reduction of 70% at the lower concentrations and dropped to 55% at 3 gpt due to increasing viscosity.

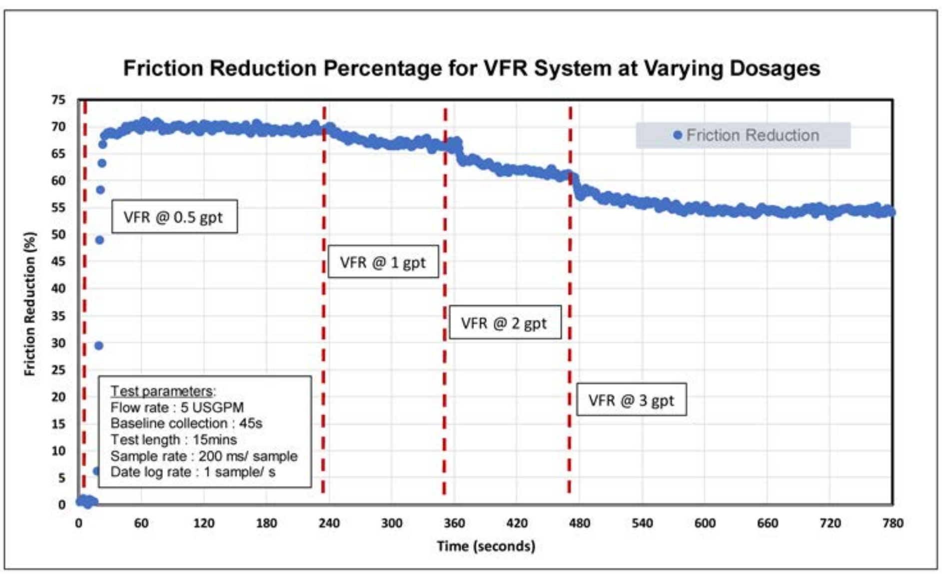

Figure 6—Friction Reduction Flow Loop Test

The next set of testing performed was to evaluate the viscosity performance of the VFR system. Figure 7 shows the viscosity profiles exhibited from the VFR system at various concentrations. These tests were run at 210 deg F. One can observe from the chart that high viscosities were achieved with the VFR, reaching 20 cp at 2 gpt concentration and over 50 cp at 5 gpt. Based on previous experience with the VFR, these rheological properties would be sufficient to transport proppant effectively during the field trial.

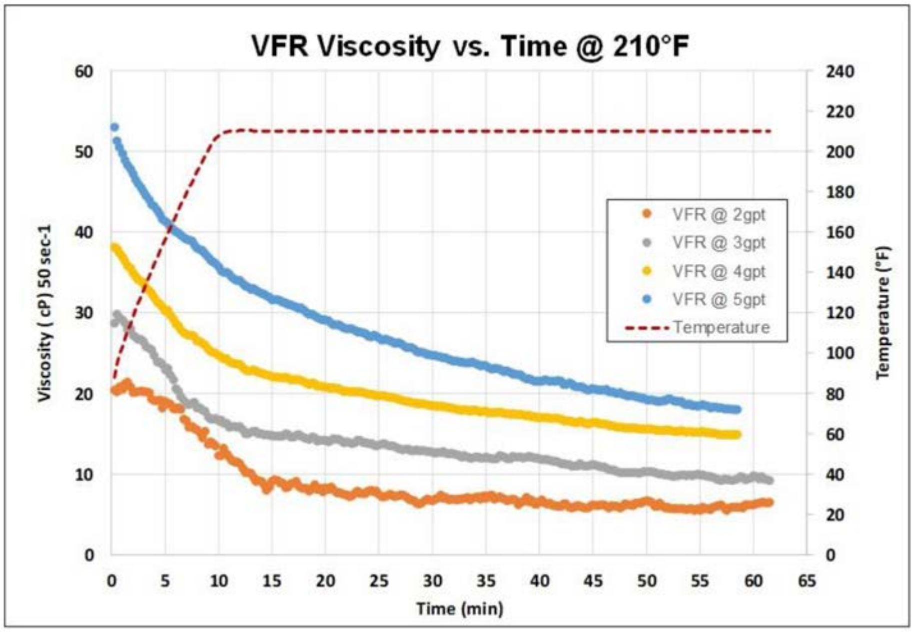

Figure 7—Viscosity Profiles of VFR at Different Concentrations

The above viscosity profiles were generated at a shear rate of 50 sec-1 in the lab which is representative of the shear rates commonly assumed within hydraulic fractures. As a quality control check, however, the viscosities were also measured on a Fann 35 viscometer at 511 sec-1 and shown in Table 2 below. Fann 35 viscometers are commonly present on fracturing locations, so the data in Table 2 could be used as a quality control check to ensure that the products on location were performing as expected.

Table 2—Fann 35 Table of VFR Viscosities

VFR Concentration	VFR Viscosity @ 511 sec-1
2 gpt	6 cP
3 gpt	11 cP
4 gpt	16 cP
5 gpt	21 cP
Fann 35 Viscometer	
R1B1 Geometry at 300 rpm or 511 sec-1	

The Field Trial

After successful testing in the laboratory, the next step in this project was to perform a field trial using the VFR system. The field trial was started in February 2019 on a horizontal well in the Neuquen Basin. An offset horizontal well was fracture stimulated from the same location using a conventional guar-based hybrid/crosslink fluid design, so it would be possible to compare treating pressures between the two wells, and the two different fluid systems, at similar treatment conditions. The field trial well was designed for 27 frac stages, placing approximately 540,000 lbs of 100 mesh, 40/70 mesh and 30/70 mesh sand. Planned pump rate was 90 bpm. Prior to the start of the field trial well operations, quality control checks were performed with the VFR chemicals on location to ensure that the viscosities obtained matched with those measured in the laboratory testing.

Table 3 shows the planned pumping schedule employed for the frac stages on the field trial well. As can be observed from the pumping schedule, the VFR concentration would start at 0.5 gallon per thousand (gpt) and then be risen as the sand concentration reached 1.5 pounds per gallon added (ppa). From that point to the end of the treatment, the VFR concentration was run at approximately the same concentration as the sand (ie; 3 ppa sand => 3 gpt VFR). While this 1:1 approach for sand to VFR concentration was useful as a conservative starting point, the VFR concentration was lowered in later stages as more experience was obtained with the system.

Table 3—Pumping Schedule for Field Trial

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

During the field trial, several of the benefits of the VFR system began to emerge. Firstly, all of the 27 frac stages were placed as designed with minimal problems, achieving 5 ppa sand concentration downhole on most stages. Figure 8 shows a treating plot from one of the field trial frac stages. From a proppant transport perspective, it was encouraging to observe the relatively high sand concentrations being placed with a fluid system with only 15-20 cp viscosity and showed that a crosslinked gel system with significantly higher viscosity and operational complexity was not required for job placement.

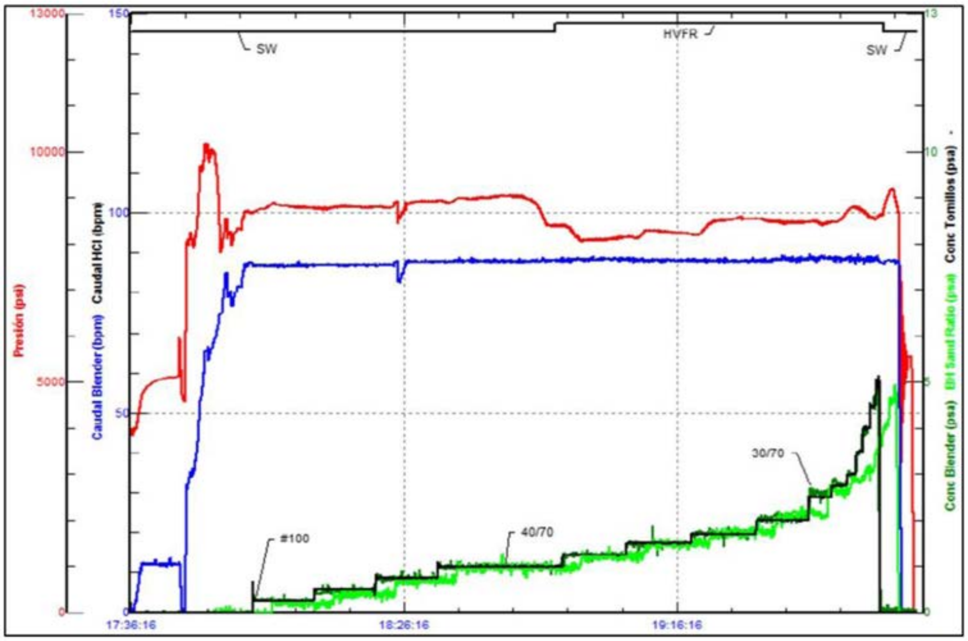

Figure 8—Treating Chart from the Field Trial

Secondly, surface treating pressures ranged from 8,000 - 9,000 psi for most of the frac stages on the field trial well, with total friction measured at 2,700 – 3,000 psi. This equates to a hydraulic horsepower of about 19,500 HHP. These pressures were much lower than the treating pressures and pipe friction observed on an earlier offset well in which a slickwater/linear/crosslinked gel hybrid frac fluid system was used at similar pump rates. Figure 9 shows a treating chart from one of the offset well frac stages. Average treating pressures for the offset well were around 12,000 psi with friction pressure estimated at around 6,000 psi. Although the field trial well was 13% shallower than the offset, the more than 50% reduction in pipe friction and 7,000 HHP lower horsepower required highlighted one of the key benefits of the VFR system.

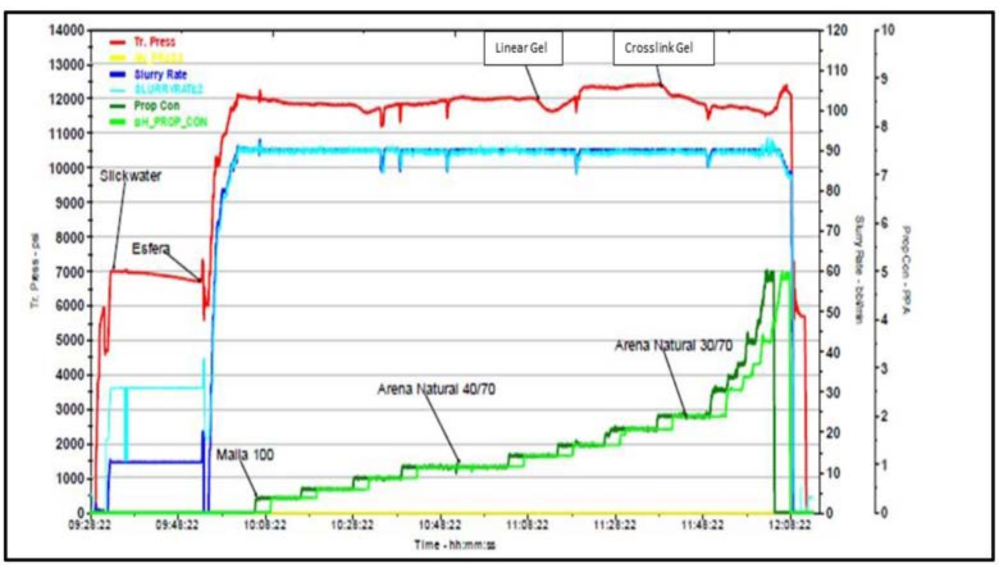

Figure 9—Treating Chart using Previous Fluid System

The final benefit realized during the field trial was the cost savings that were realized switching from the hybrid type fluid system to the VFR system. Considering just the chemical costs alone, a 32% reduction in cost was realized with the VFR system.

Field Development Case History

After the successful pilot project, the decision was taken to continue use of the fluid system in the Lindero Atravesado block. The next phase of the project would be to try and compare the production performance of the VFR system with the fracturing fluid system that had been previously used which was a hybrid type fluid design.

Figure 10 shows a map of the specific area for this next phase of operations in which six wells were completed. Wells 1 and 2 were completed using the hybrid fluid system design, and wells 3 through 6 using the VFR system. Wells 1 and 2 were completed approximately 6-12 months prior to the completions on wells 3 through 6. (Well 6 was completed in a zone which is different than the zone in which Wells 1-5 were completed in, so will not be included in the comparison discussions below).

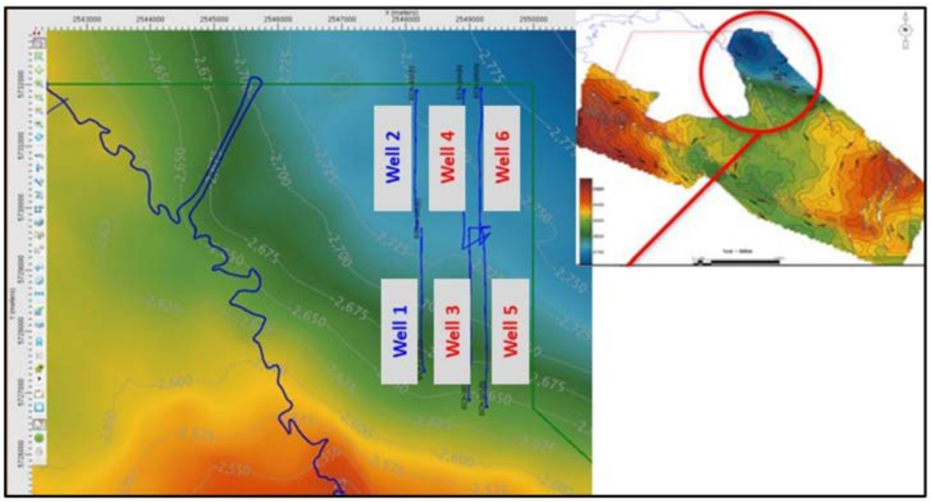

Figure 10—Well Positions for Development Phase Trial

In general, the fracture treating conditions on wells 1-5 were quite similar except for higher pump rates being used on wells 3-5 (about 88 bpm) compare to wells 1 and 2 (72 bpm). Proppant volumes placed ranged from 550,000 to 700,000 lbs per stage. All frac stages were placed according to plan, with no screenouts occurring.

Figure 11 shows the normalized production for wells 1-5, expressed in cubic meters per day per psi of pressure drop (m3d/psi), versus time function. The magnitudes of the inflow performance (IP) data are correctly expressed in relation to each well, however a constant was used as a multiplier for the IP data in order to protect specificity of the actual values.

The production performance data shown above was a very encouraging sign that the VFR fluid system capable of delivering enhanced production compared to the fluid systems used historically in this area. As mentioned previously, another objective of this project was to determine if an overall cost reduction could be realized using the new fluid system. Cost analyses performed by PAE showed that by switching fluid systems, an average of 34% reduction in product costs were obtained.

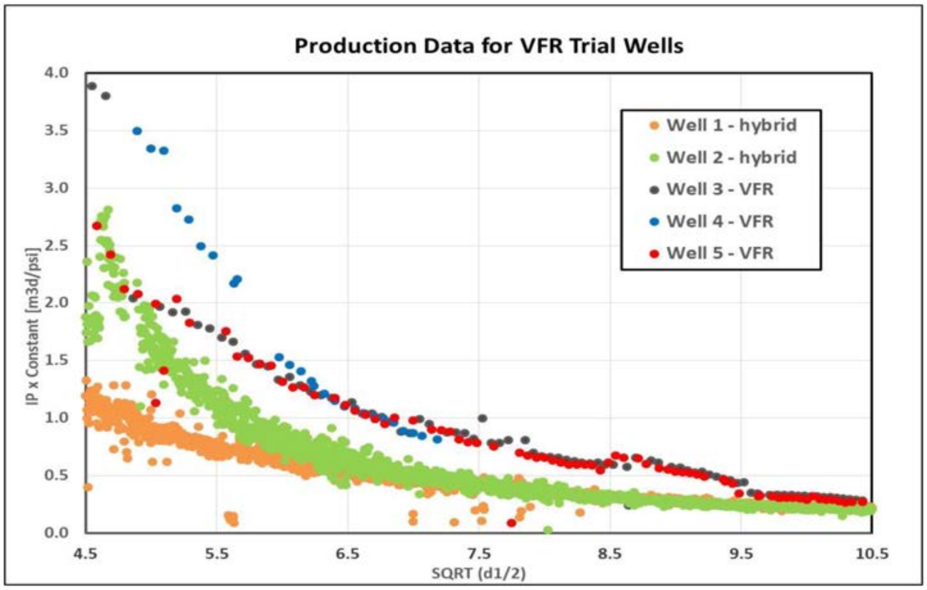

Figure 11—Normalized Production Chart for Development Phase VFR Trial

Conclusions

To date, a total of 19 wells have now been completed using the VFR fluid system, and the project was successful in terms of achieving the overall objectives. During the field trial and development phase evaluation, many of the published benefits of the VFR system were observed and are summarized below.

- The VFR system provided an effective combination of friction pressure reduction at low concentrations, along with good viscosity development and proppant transport at higher concentrations.
- Fracture operations were simplified by having a single fluid system on location, including less materials on location and requiring fewer chemical additive pumps on the frac blender.
- The VFR polymer hydrates quickly, which eliminated the need for a hydration unit on location.
- Concentrations of the VFR could be easily adjusted during a frac stage to reduce chemical volume usage or increased if needed to assist with frac placement.
- Significant product cost reduction was obtained.
- Positive early-time production results have been observed, indicating that the VFR system provided enhanced production results over the previous fluid system.

Areas of future improvement opportunities exist as well. One example is potential elimination of the use of totes for product storage. Each storage tote holds only a fraction of the total volume required, so it was necessary to have many totes transported to (and from) location. Use of larger storage vessels (such as ISO tanks) would reduce the amount of unused product (tank bottoms), eliminate container disposal costs, and reduce the overall footprint required for the operation. A final area of improvement is to evaluate the feasibility of using dry FR powder, rather than the liquid emulsion, in order to reduce chemical product and shipping costs.

Acknowledgements

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