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Interwell Communication Study of UWC and MWC Wells in the HFTS

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Abstract

The focus of this paper is to examine the water, oil and proppant communication between wells at the Hydraulic Fracturing Test Site (HFTS) in the Permian Basin. Unique tracers were employed during the stimulation of the HFTS pad in conjunction with many additional diagnostic technologies to evaluate interwell communication, fracture behavior, proppant transport and reservoir drainage.

Water and oil chemical tracers were utilized on four Upper Wolfcamp (UWC) and four Middle Wolfcamp (MWC) horizontal wells on the HFTS pad. Each traced well was divided into three or four uniquely traced segments. The segments consisted of consecutive stage groupings that were stimulated with the same water and oil tracers. During the production phase of the project, oil and water samples from a combined total of 33 horizontal and vertical wells were analyzed for the presence of the tracers from the eight wells. Additionally, proppant tracers were employed in the stimulation of two UWC and one MWC horizontal well. After all the wells were completed, a spectral gamma ray log was run on each well to identify the proppant coverage, cluster efficiency, near-wellbore (NWB) fracture behavior and/or any proppant communication that occurred.

The results of this project provide a better understanding of the fluid and hydrocarbon communication that is taking place between and within the UWC and MWC wells over an initial short-term period as well as the long term. Additionally, the target zone, stimulation design, production methodology and stimulation sequencing are discussed so that comparisons could be made with other diagnostic data from this project.

The insights from this two-year study highlight the continued need to optimize completion designs, even while targeting different benches of the same formation. Additionally, future fracture modeling and design criteria can be enhanced with the hydraulic fracture and propped fracture heights and half-lengths determined from fluid and proppant communication to the offset wells.

Introduction

The hydraulic fracturing test site (HFTS) is located in Reagan County, Texas. The site is comprised of multiple wells, both vertical and horizontal, in the Wolfcamp formation and is operated by Laredo Petroleum. The Wolfcamp formation is a hydrocarbon-producing zone in the Permian Basin (**Figure 1**). Located in West Texas and extending into the southeast portion of New Mexico, it is primarily a basinal structure. Covering the Midland, Delaware and Central Platform sub-basins (Scotia Howard Weil, 2014; Schwartz et al., 2015), it varies in thickness depending on location, with some areas exceeding 2,000 ft.

Figure 1 – Permian Basin (source: Encyclopedia Britannica).

The HFTS focused on understanding the hydraulic fracturing process, in particular fracture propagation and well spacing and how these processes vary with changes in lithology (Upper vs Middle Wolfcamp) and completion design. This paper highlights the inter-well communication observed between the 11 newly completed horizontal wells and 22 existing vertical and horizontal wells in the UWC and MWC through the evaluation of proppant, frac fluid and hydrocarbon tracers. In addition, the conclusions of this paper will highlight the completion effectiveness across three of the newly completed horizontals, as well as an evaluation of frac fluid and hydrocarbon recovery trends across the section. **Figure 2** below highlights the wellbore positioning of the 11 newly completed horizontal wells and the drilled but not completed traverse well (6TW). The traverse well was intended to be drilled as near as possible to both the 6U and 6M wells, with the goal of intersecting the created fracture networks in both formations.

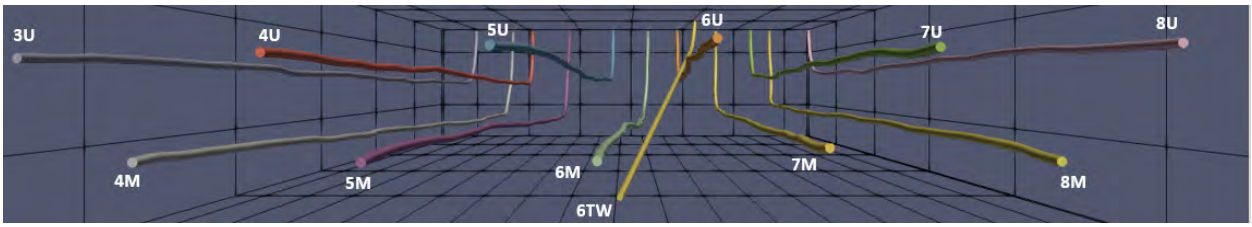

Figure 2 – Wellbore positioning and spacing of the 12 newly drilled wells in the HFTS.

Methods

To evaluate near-wellbore completion effectiveness and any potential interwell proppant communication, proppant tracers were utilized in only three of the 11 newly drilled horizontal wells. Proppant tracing utilizes three distinct low-level gamma-emitting sources: Iridium-192 (red), Scandium-46 (yellow), Antimony-124 (blue). They are pumped primarily throughout the proppant-laden portion of the stimulation treatment (Fisher et al., 1995; Reis et al, 1996). A spectral gamma-ray log was run to identify near-wellbore proppant placement of each individual tracer. This diagnostic technology was utilized to evaluate unstimulated perf clusters, proppant coverage across the lateral, as well as cluster and stage spacing. In addition, spectral gamma-ray logging of untraced offset wells was used to identify proppant communication and transport between wells (Warren et al., 2016).

The 4U, 6U and 6M wells were selected to be proppant traced. All stages were traced in each of the aforementioned wells with a single isotope unique to that well: 4U – Antimony (blue), 6U – Iridium (red), 6M – Scandium (yellow) (**Figure 3**). Selecting these wells was primarily based on their proximity to the traverse well and

allowed for a comparison of the same frac design in a UWC and MWC. Additionally, it provided a comparison of a 3-cluster 90' spacing design to that of a higher density 50' cluster spacing design within the same UWC bench. Immediately following the completion/drill-out of the 11 horizontal wells, each of the wells was logged with a spectral gamma-ray tool to determine near-wellbore proppant placement.

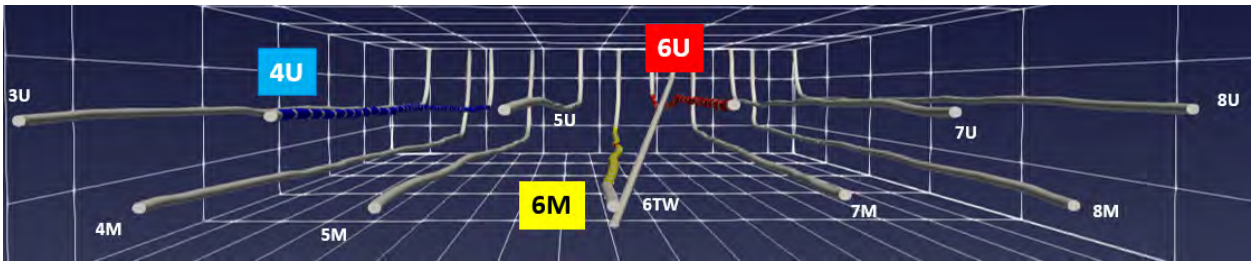

Figure 3 – Proppant traced wells highlighted with corresponding tracer color utilized.

In addition to proppant tracing and spectral gamma ray logging, 8 of the 11 new horizontal wells utilized both frac fluid and hydrocarbon chemical tracers (**Figure 4**). Frac fluid tracers are injected during the pad and proppant-laden fluid at a set concentration. The frac fluid tracers are chemical compounds designed to remain in the frac fluid as it is produced to surface. Water samples are then collected at surface and analyzed with gas chromatography/mass spectrometry techniques to determine the concentrations of frac fluid tracer in the water. Untraced offset wells are sampled for the presence of the frac fluid tracers injected in a traced offset well for interwell frac fluid communication analysis (Asadi et al., 2008; King et al., 2011; Leonard et al. 2007).

Liquid oil tracers are injected as a slug in the early portion of the proppant-ladden fluid during the hydraulic fracture treatment. Similar to the frac fluid tracers, unique oil tracers are utilized across multiple segments of the lateral. As oil is produced at surface, samples are collected and analyzed in a similar fashion to the frac fluid tracers. These diagnostics are used to evaluate oil production along the lateral as well as interwell oil communication (Warren).

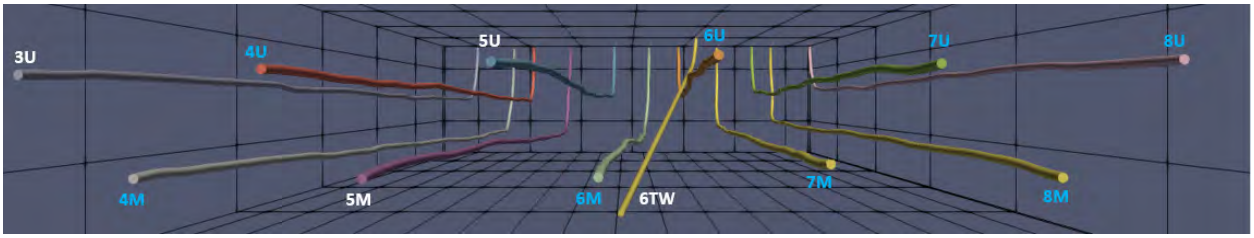

Figure 4 – 3U, 5M, 5U and 6TW wells labeled in white were not traced.

The 3M, 5M and 5U were selected as the only wells to not be traced. The rest of the wells were either divided into thirds or fourths with each segment of the lateral receiving its own unique frac fluid and oil tracer as displayed in **Figure 5** below**.** Fluid sampling data in this paper cover a two-year timespan, December 2015 thru December 2017.

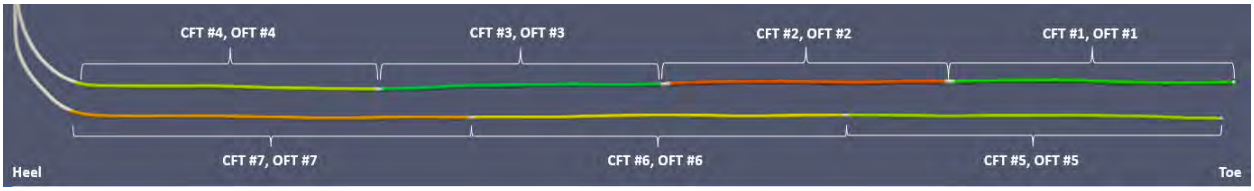

Figure 5 – Break down of oil (OFT) and frac fluid (CFT) tracer injection intervals for 3 and 4 segment wells.

Results

Analysis of the spectral gamma-ray logging on the three proppant-traced wells showed an overall high degree (>80%) of cluster efficiency across all three wells and relatively low near-wellbore coverage. Near-wellbore coverage is calculated by creating a ratio of the total lateral length where proppant tracer counts were detected to the total lateral length. The 6U well, completed with 270' stages utilizing three clusters per stage and a proppant concentration of 1,100 lb per lateral ft, exhibited a cluster efficiency of 91% and a near-wellbore coverage of 63%. An example stage is shown in **Figure 6.** This stage exhibits a relatively even distribution of tracer counts amongst the three perf clusters with minimal inter-cluster growth and gaps with no near-wellbore tracer counts. The 6M well, located in the MWC bench, was completed with the same design and showed similar results to that of the 6U. Overall cluster efficiency was 90% and total near-wellbore coverage was 73%, highlighting a slight improvement in inter-cluster growth and overall near-wellbore proppant placement. **Figure 7** shows an example stage from the 6M well. The 4U well utilized a slightly larger design than the 6U/6M wells of 1,800 lb per lateral foot. In addition to the larger proppant volume, two different perforating schemes were tested in this well. The toe and heel portions of the lateral utilized 5 clusters at 50' spacing and the middle portion of the well utilized 3 clusters at 50' spacing. The resulting spectral gamma-ray log showed no loss in cluster efficiency (92%) compared to the 6U and 6M wells and an improvement in near-wellbore coverage to 86%. **Figures 8 & 9** below highlight both a five cluster and three cluster stage in the 4U well. Full log results are shown in **Appendix Figures A1-A3.**

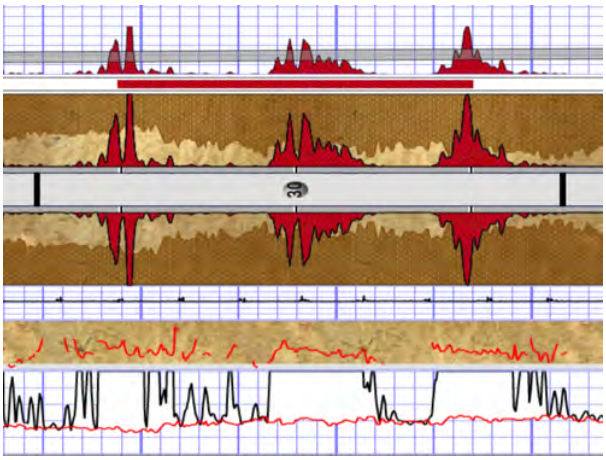

Figure 6 – 6U well, stage 30.

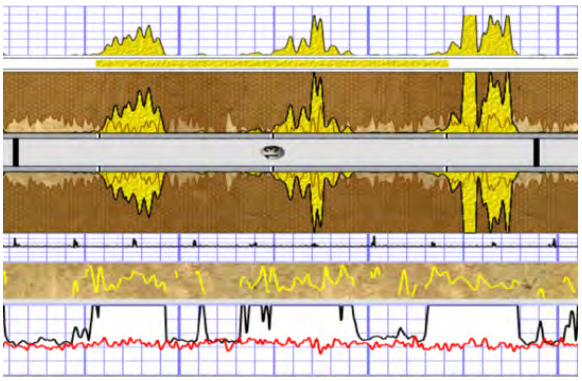

Figure 7 – 6M well, stage 13.

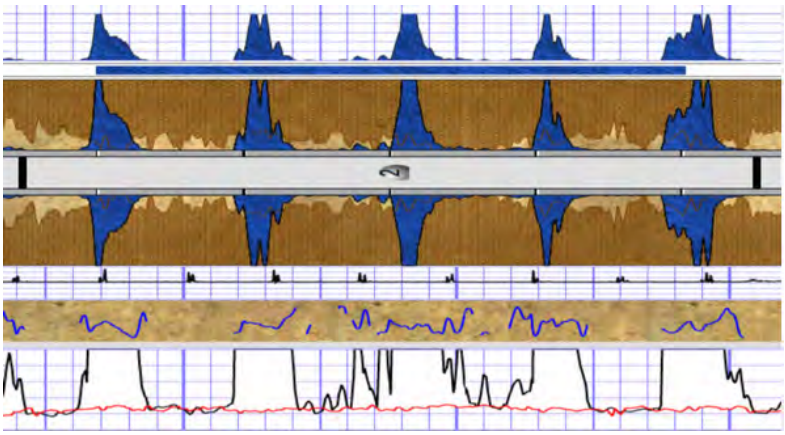

Figure 8 – 4U well, stage 2 – 5 cluster design.

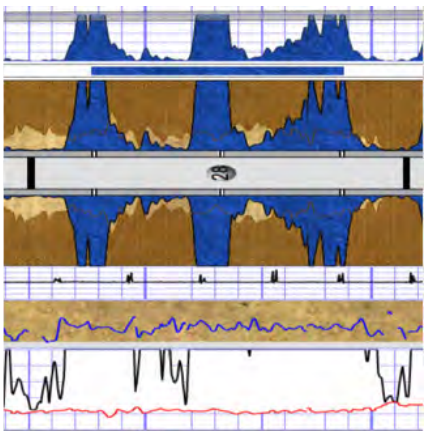

Figure 9 – 4U well stage 28 – 3 cluster design.

Analysis of the offset horizontal well logs showed that four of the nine offset wells detected proppant communication from at least one of the traced wells. The 7U, 7M, 8U and 6TW wells did not reveal any proppant tracer communication. **Appendix Figure A4** displays the horizontal wells which received proppant communication from each of the traced wells. In addition, it depicts the total tracer counts detected and the interval in which those counts were observed. A comparison of the total tracer counts in all of the offset wells reveals that the 5U had the highest tracer counts. All three proppant traced wells communicated with four offset wells. In addition, proppant tracer from the 6M well showed the highest counts in the offset wells. No proppant tracers were detected during the drilling or logging of the 6TW well.

Results from two years of flowback sampling indicate a high degree of both oil and water tracer communication amongst all the newly completed horizontal wells in the HFTS and 17 of the 21 earlier completed horizontal and vertical wells. Initial results from flowback sampling show that all traced wells sustained hydraulic communication with at least one offset horizontal well. A comparison of treatment well frac fluid recoveries to offset well recoveries revealed that the MWC wells had a significantly higher degree of lateral and vertical hydraulic communication than the UWC wells. Analysis of the frac fluid communication shows a noticeable contrast in the magnitude, duration and total number of communicating segments between the UWC and MWC wells. The MWC wells have a higher degree of communication amongst wells in the same horizon. The UWC wells exhibit a lesser degree of communication amongst wells in the same horizon. The MWC wells indicate more vertical communication up to UWC wells than the reverse. These trends have continued through two years of sampling with all traced wells indicating hydraulic communication with at least one offset well.

Figure 10 summarizes the normalized time-weighted average tracer recoveries for both treatment and offset wells through the entire two years of sampling. The traced wells are listed vertically down the left column and the sampled wells are listed horizontally across the top. The time-weighted average of the treatment well recoveries are highlighted in gray cells within the matrix. Offset communication from these wells is shown in the cells on each side of the treatment well recovery. The offset well recoveries are shaded based on the extent of communication from the treatment well to the offset wells. The categories of communication within the matrix include significant, moderate and minimal communication. Significant communication for this project occurs when offset well recoveries exceed 50% of the treatment well recovery. Moderate communication is from 10%-49% , and minimal communication is when the offset recoveries show less than 10% of the treatment wells' recoveries over the same time period. The two columns on the right side of the chart indicate the percentage of tracer returns detected in the traced and offset wells. A distinct contrast is noticed between the UWC and MWC wells based on this metric. As mentioned earlier, all frac fluid traced segments of the MWC wells exhibit greater total frac fluid tracer recoveries in offset wells. Whereas only one traced segment on an UWC well shows a similar trend. The 6TW well was never completed or produced, thus no fluid samples were collected from the well. Analysis of rehydrated mud from the coring of the 6TW well indicates the presence of frac fluid tracers from the 6U well.

Looking closer at the newly completed horizontal wells, the 4M well demonstrates the highest magnitude of communication both in terms of concentration of frac fluid tracers detected in offsets as well as the frequency of communication with offset wells. This well utilized the larger proppant loading and narrower cluster spacing **(Appendix Figure A5)**. Conversely the 7U well shows the least amount of frac fluid communication to offsets wells. The 4M well received the least amount of frac fluid tracer communication of all the horizontal wells and the 8M well the most. In a similar trend to the other MWC wells, most of the offset communication to the 4M was from the nearest offsetting MWC wells. The 4U and 4M wells are the only two wells to utilize the larger 1,800 lb per lateral ft design, and showed slight increases in hydraulic communication when compared to other horizontal wells utilizing the smaller proppant volume.

Traced Well		Segment	Tracer	Sampled Wells: #1U	#2M	#3U	#4M	#4U	#5M	#5U	#6M	#6U	#6TW	#7M	#7U	#8M	#8U	#1RM	#1RU	Tracer Total Communication (Norm. ppb)	% Frac Fluid Recovered in Offsets	% Frac Fluid Recovered from Treatment Well
		Units		Norm. ppb																Norm. ppb	%	
	#4M	1	CFT A	3.9	4.1	4.9	11.2	3.2	2.1	0.9	1.5	0.4	0.0	0.7	0.1	0.2	0.0	0.0	0.0	22.0	66%	34%
		2	CFT B	7.4	19.9	3.8	8.8	2.2	2.6	0.9	2.3	0.4	0.0	1.4	0.2	0.5	0.0	0.1	0.0	41.9	83%	17%
		3	CFT C	6.6	4.5	4.8	9.9	3.5	2.8	1.5	2.0	0.6	0.0	1.2	0.1	0.4	0.0	0.1	0.0	28.3	74%	26%
	#4U	1	CFT D	0.1	0.0	0.4	0.0	2.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	24%	76%
		2	CFT E	0.8	0.1	1.1	0.1	4.6	0.0	0.7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	38%	62%
		3	CFT F	0.2	0.9	0.9	0.2	4.0	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	43%	57%
	#6M	1	CFT G	0.4	3.1	0.2	2.4	0.4	2.4	2.7	4.1	3.2	0.0	3.8	1.0	3.2	1.0	0.1	0.0	23.8	85%	15%
		2	CFT H	0.0	1.0	0.0	0.8	0.0	1.2	1.1	3.5	1.9	0.0	1.8	0.2	1.2	0.0	1.4	0.0	10.7	75%	25%
		3	CFT I	0.1	2.8	0.0	0.7	0.0	1.1	0.8	2.0	1.0	0.0	1.2	0.1	0.8	0.0	1.1	0.1	10.0	83%	17%
		4	CFT J	0.0	0.0	0.0	0.0	0.0	0.1	0.6	1.5	0.3	0.0	0.4	0.0	0.1	0.0	0.0	0.0	1.5	49%	51%
	#6U	1	CFT K	0.0	0.3	0.0	0.0	0.0	0.0	0.5	0.2	3.5	0.0	0.2	1.8	0.0	0.0	0.0	0.0	3.0	47%	53%
		2	CFT L	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	11%	89%
		3	CFT M	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	2.1	0.0	0.1	0.2	0.0	0.0	0.0	0.0	1.0	33%	67%
		4	CFT N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1%	99%
	#7M	1	CFT O	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.1	2.1	0.0	4.4	2.4	3.4	0.8	0.0	0.0	10.9	71%	29%
		2	CFT P	0.0	0.0	0.0	0.1	0.0	0.4	0.6	2.7	4.5	0.0	4.7	3.4	4.5	1.7	1.4	0.4	19.8	81%	19%
		3	CFT Q	0.0	0.0	0.0	0.0	0.0	0.3	0.5	4.8	3.4	0.0	7.5	2.7	8.1	0.4	1.2	0.1	21.6	74%	26%
		4	CFT R	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.8	0.0	2.3	0.7	1.6	0.0	0.0	0.0	3.8	63%	37%
	#7U	1	CFT S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.1	0.0	0.0	0.1	5%	95%
		2	CFT T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	1.6	0.1	0.7	0.0	0.0	1.1	40%	60%
		3	CFT U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.3	0.0	0.0	0.3	18%	82%
		4	CFT V	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.6	0.0	0.0	0.6	31%	69%
	#8M	1	CFT W	0.6	1.7	0.1	0.1	0.2	0.0	0.0	0.9	0.9	0.0	2.0	2.6	6.3	3.6	0.7	0.1	13.5	68%	32%
		2	CFT X	0.6	3.3	0.0	0.4	0.0	0.7	0.2	1.6	0.8	0.0	1.9	1.7	3.9	2.3	4.5	1.0	18.9	83%	17%
		3	CFT Y	0.3	2.1	0.0	0.0	0.0	0.2	0.4	2.3	1.4	0.0	3.4	4.5	6.5	3.4	4.3	3.6	25.8	80%	20%
	#8U	1	CFT Z	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.1	4.3	0.0	0.1	0.7	14%	86%
		2	CFT AA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.1	0.7	0.9	29%	71%
		3	CFT BB	2.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.2	2.9	0.4	3.4	7.6	72%	28%
	# Samples Taken From Well			44	44	45	47	48	51	41	54	51	0	58	49	50	54	46	49			
	Sample Dates		12/24/15 - 10/12/17																			
																				Communication Tiers	Significant	Moderate	Minimal

Figure 10 – Frac fluid communication matrix for the HFTS horizontal wells.

Oil tracer communication highlights similar trends to that of the frac fluid tracers. However, the overall oil tracer recovery in offset wells was significantly less both in terms of magnitude and duration. Initial oil sampling indicates that all newly completed horizontal wells had oil communication with at least one offset well. Through 11 months, only eight of the 16 horizontal wells are exhibiting communication, with no significant communication as defined above. **Figure 11** shows the normalized time-weighted average of hydrocarbon tracer recoveries in both treatment and offset horizontal wells over the two years of sampling. In a fashion similar to the frac fluid tracers, there is a strong trend between the magnitude and extent of communication based on the bench of the well. The MWC wells showed more communication both laterally as well as vertically when compared to UWC wells.

On an individual well basis, results indicate that the 4M well has the most oil communication with offset wells. Conversely the 6U well shows the least amount of oil tracer recovery in offset wells. These results are consistent with the frac size variations, with the 4M utilizing the largest design and the 6U the smallest. The 6M received the most oil tracer communication and the 4M received the least. Most of the oil tracer communication observed going to the 6M well can be attributed to one segment of the 4M well.

Traced Well	Segment	Tracer	Sampled Wells: #1U	#2M	#3U	#4M	#4U	#5M	#5U	#6M	#6U	#6TW	#7M	#7U	#8M	#8U	#1RM	#1RU	Tracer Total Communication (Norm. ppb)	% OFT Recovered in Offsets	% OFT Recovered from Treatment Well
		Units	Norm. ppb																Norm. ppb	%	
#4M	1	OFT A	0.6	1.2	0.7	33.6	0.9	3.4	7.7	0.0	0.1	0.0	0.0	0.5	0.5	0.0	0.0	0.0	15.7	32%	68%
	2	OFT B	0.0	1.2	0.0	43.0	0.4	4.5	0.0	214.1	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	220.7	84%	16%
	3	OFT C	0.0	0.0	0.0	35.3	0.5	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	8.7	20%	80%
#4U	1	OFT D	0.0	0.0	0.4	1.4	34.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	5%	95%
	2	OFT E	0.0	0.0	0.6	1.0	24.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	6%	94%
	3	OFT F	0.0	0.0	0.0	1.3	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	4%	96%
#6M	1	OFT G	0.0	0.0	0.1	0.0	0.0	0.3	0.3	43.4	0.8	0.0	2.5	0.0	0.3	0.0	0.0	0.0	4.3	9%	91%
	2	OFT H	0.0	0.0	0.1	0.0	0.0	0.3	0.0	56.0	0.4	0.0	3.4	0.0	0.5	0.0	0.0	0.0	4.7	8%	92%
	3	OFT I	0.0	0.0	0.1	0.0	0.0	0.1	0.0	37.2	0.0	0.0	2.8	0.0	0.3	0.0	0.0	0.0	3.2	8%	92%
	4	OFT J	0.0	0.0	0.0	0.0	0.0	0.1	0.0	19.5	0.0	0.0	1.3	0.0	0.3	0.0	0.0	0.0	1.8	8%	92%
#6U	1	OFT K	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	1%	99%
	2	OFT L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	100%
	3	OFT M	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.5	24.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	5%	95%
	4	OFT N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	19.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.8	4%	96%
#7M	1	OFT O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.2	0.0	42.6	0.1	1.2	0.1	0.0	0.0	4.5	9%	91%
	2	OFT P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	52.7	0.1	1.1	0.7	0.0	0.0	2.4	4%	96%
	3	OFT Q	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	46.6	0.1	1.6	0.0	0.0	0.0	1.8	4%	96%
	4	OFT R	0.6	0.0	0.2	0.0	0.0	0.3	0.0	0.1	0.4	0.0	72.8	0.5	2.8	1.2	1.6	0.0	7.7	10%	90%
#7U	1	OFT S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.5	0.0	0.9	0.1	0.0	1.0	4%	96%
	2	OFT T	3.9	8.2	3.1	0.0	4.3	2.5	0.0	0.0	4.0	0.0	0.0	20.2	2.2	3.1	0.0	0.0	31.4	61%	39%
	3	OFT U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	18.9	0.0	0.0	0.0	0.0	0.2	1%	99%
	4	OFT V	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	0.0	0.2	0.0	0.0	0.2	3%	97%
#8M	1	OFT W	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0	38.2	0.3	0.0	0.0	5.3	12%	88%
	2	OFT X	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.1	48.6	0.1	0.4	0.0	5.9	11%	89%
	3	OFT Y	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.8	0.0	20.9	0.0	3.2	1.5	6.6	24%	76%
#8U	1	OFT Z	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	32.8	0.9	0.9	2.6	7%	93%
	2	OFT AA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	14.9	1.0	0.9	2.0	12%	88%
	3	OFT BB	0.7	0.0	0.9	0.0	0.0	0.0	7.2	0.0	0.0	0.0	0.3	4.1	0.6	37.0	1.8	6.1	21.7	37%	63%
	# Samples Taken From Well		28	33	42	46	47	51	9	51	50	0	52	50	50	52	49	52			
	Sample Dates	12/26/15 - 10/12/17																			

Communication Tiers: Significant | Moderate | Minimal

Figure 11 – Oil communication matrix for the HFTS horizontal wells.

Discussion

A comparison of interwell communication between the three tracer types shows that frac fluid communication across the section is far more prevalent than for both the proppant and oil tracers. Oil tracer communication is more prevalent than proppant communication, however, all three diagnostics exhibit the same general trend in interwell communication. The MWC is responsible for the most communication overall. In addition, attributing differences in interwell communication to any one factor is difficult due to the total number of variables involved in the completion process (frac design variations, well location within the section, completion order, etc.).

Also, included in this study but not highlighted in this paper are two previously completed horizontal wells in the UWC and MWC benches. More information on these wells can be found in Courtier et al. 2016. These wells were refractured for fracture hit protection refracs prior to the completion of the HFTS horizontal wells. Both refractured wells did receive oil and frac fluid tracer communication, but the majority of the communication was limited to the immediate offset wells, the 8U and 8M. Analysis of the direction and magnitude of the communication from the 8U and 8M wells indicates that their frac fluid shows a higher degree of communication to the refractured wells than to the newly fractured 7U/M wells that were offset in the opposite direction. This trend was similar to the oil tracer results for the 8U well, however, the 8M well showed a higher degree of oil communication back to the newly fractured 7M well.

Conclusions and Recommendations

- Proppant tracer results indicated a high degree of cluster efficiency can be obtained through the three-cluster 90’ spacing design, however, it left behind a larger percentage of unstimulated rock.
- Stimulated rock coverage increased through a higher density, five-cluster, 50’ spacing perf scheme without sacrificing perf cluster efficiency.
- Proppant tracers showed similar near-wellbore proppant placement when applying the same completion strategy to both the Upper and Middle Wolfcamp benches.
- Proppant, frac fluid and oil tracers all exhibited interwell communication.
- Interwell communication within MWC wells was significantly higher than communication within UWC wells.
- Vertical communication was greater from MWC wells to the UWC wells.
- Communication results were consistent for all three tracer types.
- The frac fluid communication observed, while stronger in magnitude early, continued through two years of flowback sampling.

- The majority of oil communication observed through hydrocarbon tracers disappeared by the end of the first year of sampling.
- Communication was significantly different for the Upper and Middle benches even though the completion designs were the same.
- A need exists to further optimize completion designs and/or well spacing by not only formation, but also by each bench within the formation.

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Appendix

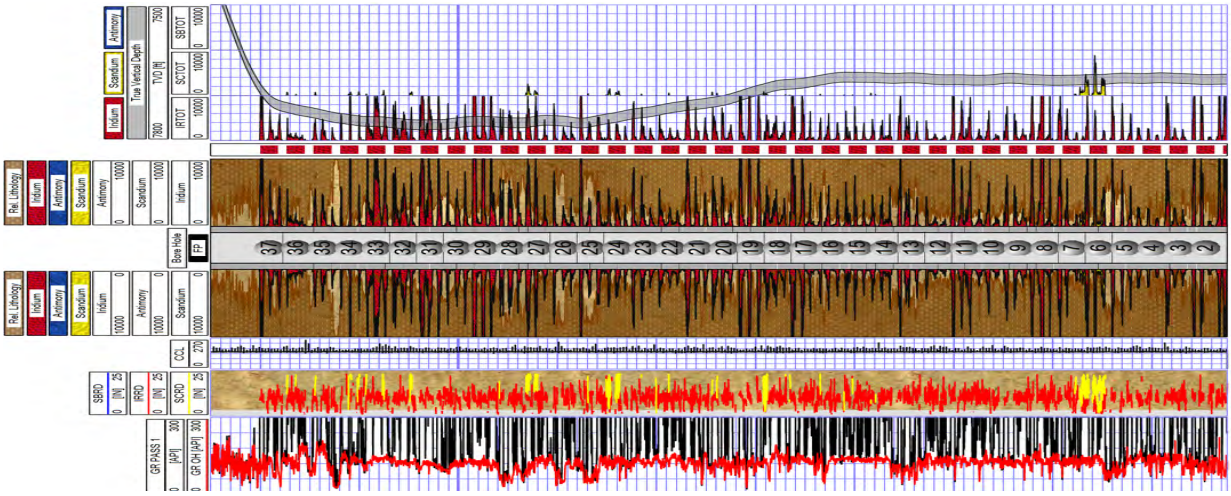

Figure A1: Spectral gamma ray log for 6U well.

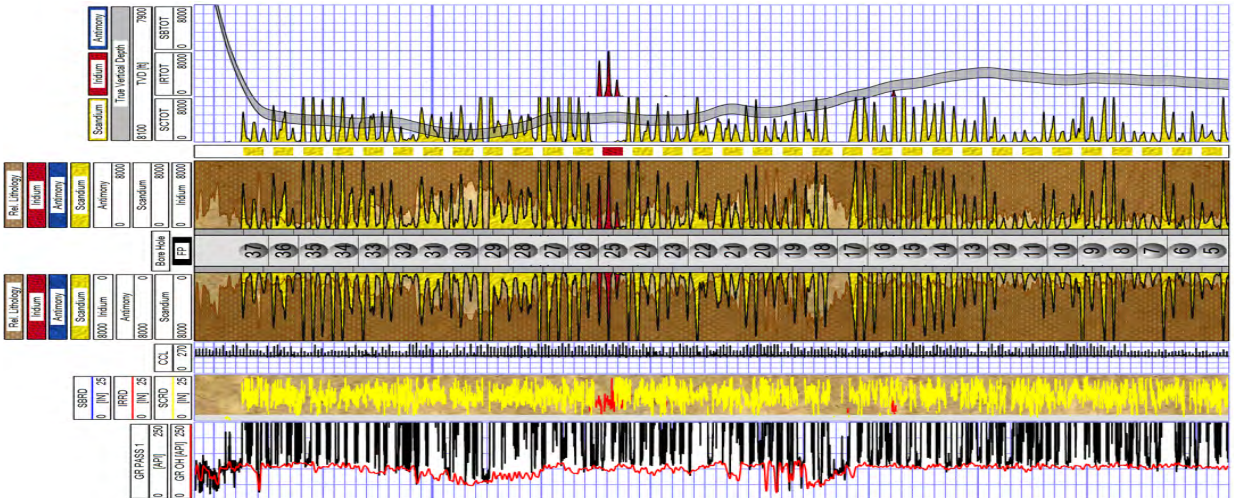

Figure A2: Spectral gamma ray log for 6M well.

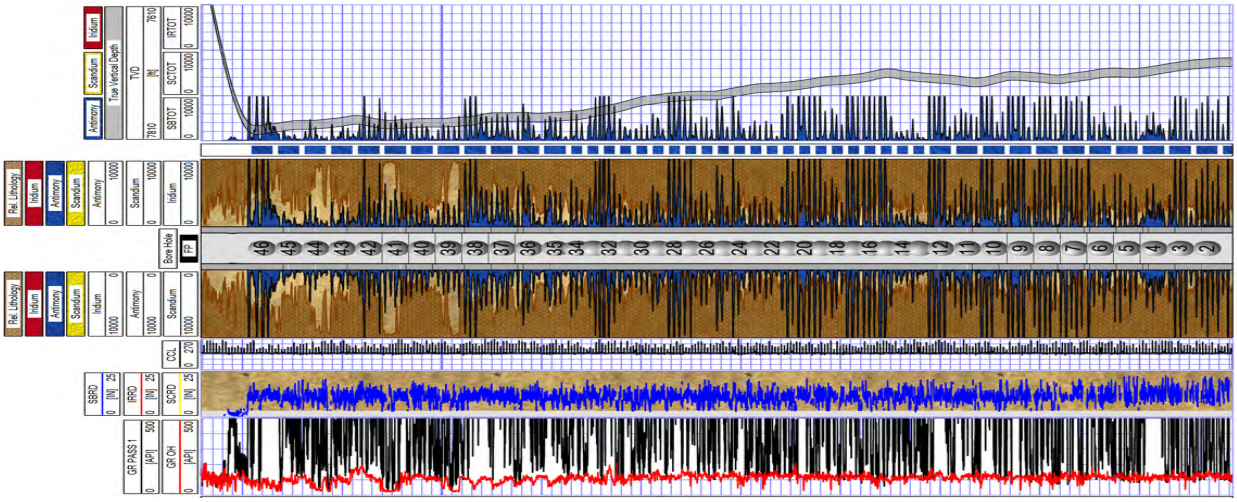

Figure A3: Spectral gamma ray log for 4U well.

		Treatment Well Parameters				#3U			#4M			#4U			#5M			#5U			#6M			#6U			All Wells	All Wells	Avg. Comm. Tracer Counts	Avg. Comm. Ft.
WellName	Target	Target Interval TMD	Tracer Pumped	Cluster Treatment %	Traced Well Tracer Coverage %	Tracer Counts	Tracer Interval TMD	Comm %	Tracer Counts	Tracer Interval TMD	Comm %	Tracer Counts	Tracer Interval TMD	Comm %	Tracer Counts	Tracer Interval TMD	Comm %	Tracer Counts	Tracer Interval TMD	Comm %	Tracer Counts	Tracer Interval TMD	Comm %	Tracer Counts	Tracer Interval TMD	Comm %	Tracer Counts	Tracer Interval	Tracer Counts	Tracer Interval
#4U	Upper Wolfcamp	9,876	Antimony	92.0%	86.0%	226,596	221	0.25%	117,612	86	0.13%	91,495,398	8,459	99.5%	98,553	296	0.11%	1,086	4	0.00%							91,939,245	9,066	110,962	152
#6M	Middle Wolfcamp	8,784	Scandium	90.0%	73.1%	10,317	7	0.01%							24,454	177	0.03%	482,720	355	0.66%	70,361,313	6,417	95.7%	2,659,079	572	3.62%	73,537,883	7,528	794,143	278
#6U	Upper Wolfcamp	9,803	Iridium	91.0%	63.4%	1,637	3	0.00%							2,123	25	0.00%	890,471	877	1.23%	97,881	48	0.14%	71,205,056	6,218	98.6%	72,197,168	7,171	248,028	238

Figure A4: Summarizes total tracer counts logged in each well and over what total lateral length those counts were located. The total counts of each isotope are summed up and a ratio created for each well based on what percentage of total counts of each isotope were located in the well.

3M	4M	4U	5M	5U	6M	6U	7M	7U	8M	8U
5 Clusters	5 Clusters	5 Clusters	3 Clusters	3 Clusters	3 Clusters	3 Clusters	3 Clusters	3 Clusters	5 Clusters	3 Clusters
53' Spacing	53' Spacing	53' Spacing	90' Spacing	90' Spacing	90' Spacing	90' Spacing	53' Spacing	53' Spacing	53' Spacing	90' Spacing
1,400 lbs/ft	1,800 lbs/ft	1,800 lbs/ft	1,100 lbs/ft	1,100 lbs/ft	1,100 lbs/ft	1,100 lbs/ft	1,100 lbs/ft	1,100 lbs/ft	1,400 lbs/ft	1,100 lbs/ft
		3 Clusters					5 Clusters	5 Clusters		
		53' Spacing					53' Spacing	53' Spacing		
		1,800 lbs/ft					1,100 lbs/ft	1,100 lbs/ft		
		5 Clusters					3 Clusters	3 Clusters		
		53' Spacing					53' Spacing	90' Spacing		
		1,800 lbs/ft					1,100 lbs/ft	1,100 lbs/ft		
							5 Clusters			
							53' Spacing			
							1,100 lbs/ft			

Figure A5: Fracture design parameters for newly completed HFTS horizontal wells. Where multiple designs are listed, they represent different designs utilized for different segments of the lateral. The toe-most segment is at the bottom and the heel-most at the top of the column.