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Case History of Sequential and Simultaneous Fracturing of the Barnett Shale in Parker County

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Abstract

Since 2005, Williams Production Gulf Coast Company has drilled over 100 horizontal wells in the Barnett Shale. The Barnett Shale is an unconventional gas reservoir that encompasses a nineteen county area in the Fort Worth Basin. Slick-water fracturing is the primary technique that has been used to hydraulically fracture the wells.

Recently, Williams as well as several operators have tried fracturing two or more adjacent wells simultaneously with the goal of exposing the shale to more pressure and produce a more complex web of fractures, thereby improving the initial rates and reserves. Simultaneous fracturing or simo-frac technique is expensive and requires much more planning, coordination and logistics as well as a larger surface location.

In this paper, the case history of sequential and simultaneous fracturing of four similarly drilled and completed horizontal azimuth wells in Eastern Parker County, is discussed. All the four wells where stimulated with near identical fracture treatments. The sequentially/simultaneously fractured wells resulted in IPs of 3.3 MMscfd to 3.5 MMscfd with 30-day averages ranging from 2.1 MMscfd to 2.9 MMscfd. The 4th well was a single offset horizontal well drilled with effective lateral 2400 ft less than a quarter mile to the north but had significantly lower IP of 2.3 MMscfd and 30-day average production of 1.2 MMscfd. The initial comparative test results are very encouraging and indicate a more complex fracture network being created in the vicinity of the sequentially/simultaneously fractured wells, which results in a significantly improved well performance.

Williams continues to evaluate the benefit of simultaneous fracturing and has done more simo-frac jobs in other counties with good results. As in this case history, due to surface and lease constraints, many of the [cut off] from the same dual pad and have well spacing of the order of 500 ft to 700 ft. The paper also provides an analysis of the simultaneous fracturing jobs done to date in Parker and Johnson County.

Background

The Barnett Shale has evolved into the pre-eminent shale-gas resource plays in the US and is now considered by many as the largest onshore natural gas field in the United States. The productive part of the formation is estimated to stretch an area covering 5000 square miles, encompassing 19 counties (Figure 1). According to the latest figures from the Texas Railroad Commision published in June 2008, there are more than 7700 producing wells and 185 active operators in the Barnett Shale with permits for more than 4,500 additional wells. Production from Barnett Shale currently exceeds 3.7 Bcf/d, accounting for more than 15% of Texas gas production, and more than 3.8 Tcf of gas has been produced from the Barnett Shale since 2000[1].

Simultaneous fracturing (simo-fracs) of paired offset wells is one of the recent trends in Barnett fracturing and is being increasingly used by many operators. In this technique, two or more adjacent wells that are roughly parallel to each other, are fractured simultaneously. The goal is to expose the shale to more pressure and produce a more complex, "three-dimensional web" of fractures by increasing the density of the hydraulic fracture network and increasing the surface area created by the frac job. The drainage area of each of the wells is enhanced as the frac fluid is pushed into the space between the two wells that would not have been fractured if the operator had drilled only well [2-3].

Simo-fracs are expensive and require much more co-time, they are cost-effective as the frac equipment is being utilized more efficiently and two wells are being completed in one week instead of two weeks.

Initially, when it first started, simultaneous fracturing in Barnett primarily involved dual fracs, involving two horizontal wells in close proximity to each other. Today, operators are now experimenting with triple fracs (‘trifectas’) or even quad-fracs in some cases.

Case History

Since 2005, Williams Production Gulf Coast Company has drilled over 100 horizontal wells in the Barnett Shale. In this paper, the case history of sequential and simultaneous fracturing of three horizontal wells in eastern Parker County, is discussed. Figure 2 shows the well layout of the wells. Well A, a 2200 ft long lateral, was drilled from a separate pad, and two wells, well B, and, well C, of lateral lengths 1900 ft to 2000 ft, were drilled from a single pad. Wells A and C are spaced 900 ft apart at the heel and the minimum well spacing is approximately 500 ft at the toe of the wells. A 4th stand-alone horizontal well, well D, with an effective lateral 2400 ft, was drilled less than half mile to the north. Due to lease constraints, only one well could be drilled on the well D pad.

The hydraulic fracturing of wells A, B, and C involved both sequential and simultaneous fracturing. Hydraulic fracturing of well A was completed over 5 stages in the first week. This was followed by simultaneous fracturing of wells B and C in the following week.

Figure 3 shows the production performance of the 4 wells over the first 6 months of their production life. The three simo/sequentially fraced wells had IPs of 3.3 MMscfd to 3.5 MMscfd and the first month averages ranged from 2.1 MMscfd to 2.9 MMscfd. The stand-alone well D well to the north had significantly lower IP of 2.3 MMscfd and the first month average production was also lower at 1.2 MMscfd. The initial results for the simo/sequentially fraced wells are very encouraging and indicate a more complex fracture network being created in the vicinity of the simultaneously fractured wells, contributing to a significantly improved well performance.

The graph shows that the average 5 month production of the 3 sequentially-fraced/simo-fraced wells was almost double the stand-alone D well, which was completed and had first sales about a month later than the 3 sequentially-fraced/simo-fraced wells. Well B well has the best production among the three wells, and is possibly draining a larger area to the east. The well A fracture network was likely enhanced due the the subsequent simo-fracing of wells B and C, resulting in enhanced production. Well C well has the lowest production among the three wells which may be attributed to interference

Successive stimulations of a multi-stage treatment often show a significant influence of the prior stage, including potential charging of the reservoir. The fluid from the prior stage remains at a somewhat elevated pressure, pushing subsequent stages away due to increased stress generated by the volume of pressurized fluid [4]. In general, reactivation of existing fracture networks is thought to be less beneficial than creating new fracture networks [5]. The production data from the 3 wells appears to indicate that simo-fracing results in more enhanced fracture network and production gains compared to sequential fracturing. This aspect needs to be further understood and more data is needed to validate this inference.

Table 1 shows a comparison of the IPs of the simo/sequentially fraced wells versus the stand-alone well D. A comparison of average IP based on first 30-day production of the wells shows a four fold improvement due to sequential and simo-fracing (Table 1). Based on IP/linear ft of lateral drilled, the simo-fraced wells showed a five fold improvement.

Well	Actual Lateral ft	30 Day Avg Act. Mcfd	IP/Lateral Length Mcfd/ft	Current Rate Mcfd
Well A (Sequential Frac)	2,195	2,576	1.17	885
Well B (Simo Frac)	1,955	2,864	1.46	890
Well C (Simo Frac-infill well)	1,889	2,097	1.11	655
Average	2,013	2,512	1.25	810
Well D (Stand-alone well)	2,413	615	0.25	467

Table 1 : Summary of IP Comparison

Table 2 shows a summary of the EUR and recovery factor calculations. The EUR estimates were based on decline curve analysis and the gas-in-place was estimated assuming a drainage radius of 500 ft from the horizontal wells and from the toe and the heel of the horizontal wells. The combined drainage area for the 3 wells (A, B, and, C) was calculated to be 130 acres and the calculated drainage area was 85 acres for well D. Based on a gross reservoir thickness of 335 ft, a reservoir porosity of 3%, the calculated corresponding GIP was 21.1 Bcf and 13.8 Bcf, respectively. The adsorbed gas GIP was based on a gas content of 96 scf/ton.

Well	Actual Lateral ft	EUR Bcf	EUR/ Lateral Length MMcf/ft	Recovery Factor
Well A (Sequential Frac)	2,195	2.06	0.94	
Well B (Simo Frac)	1,955	2.22	1.14	
Well C (Simo Frac-infill well)	1,889	1.18	0.62	
Average	2,013	5.46	0.90	25.9%
Well D	2,413	0.89	0.37	6.4%

The analysis indicates a four-fold increase in recovery factor from 6.4% for the stand-alone well D to a recovery factor of approximately 26% for the simo-fraced wells. The average EUR per lateral length also showed a 2.5 fold benefit and was 0.9 MMcf per ft of lateral for the simo-fraced wells versus 0.37 MMcf per ft of lateral for the stand alone well.

The case history discussed shows a significant enhancement in IPs, EURs, and recovery factors as a result of simo-fracing the wells compared to a stand-alone well.

Production Data Analysis

Conventional graphical-interpretation techniques in hydraulically fractured tight gas wells are typically based on analysis of flow-regimes, such as linear, bilinear, or pseudo-radial flow. For low-permeability wells such as in the Barnett, the time to radial flow can be impractically long and most of the production data in Barnett wells can be characterized as either bi-linear or linear flow. In bi-linear flow, the flow occurs both inside the fracture and outside the fracture perpendicular to the fracture (Figure 4). If the fracture has low permeability, bi-linear flow will occur over a longer period of time. On the other hand, in linear flow, the flow occurs only perpendicular to the fracture. If the fracture has sufficient permeability, bi-linear flow will last for a short period of time before starting the linear flow.

Figure 5 shows the production data of the 4 wells on a log-log diagnostic plot of production versus time. The plot indicates that well D production data is a lot closer to bi-linear flow (1/4 slope) compared to the other three wells, which can be represented by linear flow (1/2 slope). This implies that the quality of fracture is not as good in well D compared to other three wells, which may be attributed to the type of fracture created. Since the three southern were simo-fraced, it is likely that better fractures were created for these three wells as compared to well D.

Frac Data Analysis

The frac data from the fracturing jobs was reviewed to evaluate possible reasons behind benefits from simultaneous /sequential fracturing. It has been suggested that interaction of the fluid from the different fractures might provide additional energy to enhance the intensity of fracturing, either through higher net pressures or forced diversion of the fluids at they contact other fluid-filled fractures[4].

Table 3 provides a summary of the frac fluid recoveries and the net pressures for the 4 wells. The results do indicate better production performance from wells A and B, which had higher net pressures in the range of 1000 to

The % fluid recovery also appears to correlate with the well production performance. It has been suggested that rapid fluid cleanup with a high percentage of load recovery (> 50%) may actually be an indication that significant fracture network was not generated and only a simple fracture was created that acts like a “balloon” and quickly deflates back into the wellbore [6]. The data below are not consistent with the above observation and further analysis is needed in this regard. In the first 100 hours of flowback, wells A and B had higher fluid recoveries ranging from 20.8% to 10.5%, respectively, whereas the other two wells had fluid recoveries ranging from 3 to 4%. However, well C despite being a better well compared to the stand-alone well D, had relatively poorer fluid recovery. It is likely that due to the simo-frac and the higher fracture network created in the vicinity of the well, part of the flowback fluid was recovered in the offset wells, A and B, both of which had high recoveries.

Well	Lateral Length	Net Pressure	Fluid Recovery			
			100 hrs		300 hrs	
	ft	psi	bbls	%	bbl	%
Well A (Sequential Frac)	2,195	1000 to 1400 psi	10,738	20.8%	22,292	43.3%
Well B (Simo Frac)	1,955	1500 to 1600 psi	4,749	10.5%	11,197	24.7%
Well C (Simo Frac-infill well)	1,889	400 to 900 psi	1,421	3.0%	1,457	Max bbls
Well D (Stand-alone well)	2,413	200 to 300 psi	3,073	4.0%	6,359	Max bbls

Table 3 : Summary of Net Pressures and Frac Job Fluid Recoveries

Parker County Simo Frac Study

To further quantify the benefit from simultaneous fracturing, a comprehensive study was undertaken to evaluate the data of simo-fraced wells in Parker County based on public information.

A total of 29 groups of simo-fraced wells were identified based on first date of production being in the same month or within one month of each other. The production performance of these wells was then compared with that of stand-alone wells drilled within a distance of approximately 1 to 1.5 miles from the simo-fraced wells. Thus, each group of wells consisted of a total 3 wells, the two simo-fraced wells and the stand-alone well. For approximately 75% of the cases, the simo-fraced wells and the stand alone wells were drilled by the same operator. The analysis is based on production performance alone and provides general guidelines and does not consider the influence of other parameters, such as, local geology, frac design, frac injection rates, number of stages, etc. which can all impact the production performance.

Figure 6 provides a distribution of the simo-fraced wells by well spacing and quadrant. Of the 29 groups, approximately 55 % (16 groups) had wells drilled on spacing. Most of the drilling activity in Parker county has been in the eastern half where the reservoir thickness is relatively higher. Thus, in terms of the location of the wells, almost 72% (21 groups) were in SE quadrant, and, 90% (26 groups) of the well groups were in eastern half of Parker County.

For the analysis of the Parker County production data for simo-fraced wells the time-lag between 1st sales of simo-fraced and stand-alone wells was evaluated as a possible factor in the success of the simo-frac over stand-alone wells. Figure 7 provides a distribution of simo-fraced well groups with less than 3 month lag between 1st sales of simo-fraced and stand-alone wells sorted by Well spacing and quadrant in Parker County. Approximately 50% of the well groups fell in this category, with many of the wells drilled on 1000 ft spacing.

Figure 8 provides a summary of the production enhancement seen in each of the quadrants of Parker county. The comparisons were based on comparing peak monthly production, which for most of the cases, is in the first or 2nd month of well life. The analysis for wells in SE quadrant, which accounted for more than 70% of well groups, suggests that wells that had less than 3 months of time-lag between the simo-fraced wells and the stand-alone wells had the best success rate to see incremental production and reserves due to simo-fracing. In NE quadrant, irrespective of when the wells were completed, the simo-fraced wells outperformed the stand-alone wells. Again, this might be attributed to factors such as variations in frac design, injection rates, etc. as well as regional geology.

Johnson County Simo Frac Study

In terms of drilling activity, Johnson county has seen a significant increase in recent years and some the best producing wells in Barnett Shale have been drilled in the county. For Johnson county, the number of simo-fraced wells to date is significantly higher compared to Parker county. A total of 104 groups of simo-fraced wells were identified in Johnson county based on first date of production being in the same month or within one month of each other.

Figure 9 provides a distribution of the simo-fraced wells by well spacing and quadrant. Of the 104 groups, approximately 33 % (34 groups) of them, had wells drilled on 500 ft spacing. Due to thick shale resource and the presence of the Voila in the eastern part of Johnson county, some of the operators have began experimenting with 250 ft spacing and another 33% (34 groups) had wells drilled on 250 ft spacing. In terms of the well groups location by quadrant, approximately 40% (40 groups) were in NE quadrant of Johnson county and another 33% (34 groups) were in the NW quadrant.

simo-fraced wells indicated the time-lag between 1st sales of simo-fraced and stand-alone wells was a key factor in the success of the simo-frac over stand-alone wells. The data suggests that wells that had less than 3 months of time-lag between the simo-fraced wells and the stand-alone wells had the best success rate to see incremental production and reserves due to simo-fracing.

Figure 10 provides a distribution of the simo-fraced wells with less than 3 months of time-lag between 1st production from simo-fraced wells and stand-alone wells, sorted by well spacing and quadrant. A comparison of Figure 9 and 10 shows that only 20 to 30% of the well groups fell in this category, and, the majority of the simo-fraced wells (70 to 80%) were drilled anywhere from 4 months to 3+ years after the stand alone well was drilled. A few instances were also identified where the stand-alone well was drilled later after the simo-fraced wells by a different operator on an offset lease. In such instances, the simo-fraced wells did better than the stand-alone well.

Figure 11 provides a summary of the production enhancement of simo-fraced wells over stand alone wells sorted by well spacing. The comparisons were based on comparing peak monthly production, which for most of the cases, is in the first or 2nd month of well life. The results indicate an average enhancement of 56% in production of simo-fraced wells over offset non-simofraced wells. As expected, the greater the well spacing, lower are the interference and depletion effects. Thus, wells with 1000 ft spacing had greater incremental gain compared to wells with 500 ft spacing, which did better than the 250 ft spacing wells.

If the simo-frac well was drilled beyond 3 months, the production performance fell significantly and the average IP of simo-fraced wells was less than the stand-alone well (85% of the stand alone well). This is attributed to possible interference and depletion effects, which might change the stress profile in the vicinity of the wellbore. Again, the 250 ft spacing wells were most affected by interference and depletion effects and had the lowest IPs compared to stand alone wells at 80%.

Figure 12 provides a summary of the production enhancement seen sorted by quadrant for Johnson county. The results indicate an average enhancement of 53% in production of simo-fraced wells over offset non-simofraced wells. If the simo-frac well was drilled beyond 3 months, the average IP of simo-fraced wells was 87% of the stand-alone well. Surprisingly, the lowest IPs of simo-fraced wells compared to stand-alone wells (70% factor) were in the NE quadrant in Johnson county, which generally has seen prolific producing wells. This may be due to the fact that the presence of Voila barrier in most of the NE quadrant has resulted in operators fracturing and high injection rates and there have been excellent simo-fraced wells (which were identified from maps) may not have been completed by the same operator. Again, the contrast in results could be due to differences in frac design, injection rates, number of stages, completion design, etc.

Conclusions

Simultaneous fracturing is being increasingly used by operators in the Barnett to produce a more complex web of fractures, increase the surface area created by the frac job, thereby enhancing initial production rates and ultimate recovery.

A case history and results of simultaneous and sequential fracturing in south-east Parker county is presented in the paper, which showed an average 100% enhancement in rates compared to a stand-alone well producing from the same leasing unit. The data also appears to indicate that simo-fracing results in more enhanced fracture network and production gains compared to sequential fracturing.

The analysis of the data from simo-fraced wells in Parker and Johnson county showed an enhancement in average peak IP rates of 21% to 55% over stand-alone wells, for wells which had less than a 3 month lag between 1^{st} sales from simo-fraced wells and stand alone wells.

On the other hand, if the time lag between 1^{st} sales from simo-fraced wells and stand alone wells was greater than 3 months, the simo-fraced wells showed lower average IP rates compared to stand-alone wells. Any material production from the same reservoir sink from interference and depletion effects, causes changes in stress profile in the vicinity of the wellbore, which impacts the production performance of the simo-fraced wells.

Overall, the analysis suggests simultaneous fracturing is a viable technique for application in the Barnett shale reservoir. For the best chance of success, simultaneous fracturing should be planned in the initial wells that are drilled to develop a new lease.

Nomenclature

IP : Initial Potential
EUR : Estimated Ultimate Recovery
Simo-frac : Simultaneous fracturing

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References

1. Carillo, V. G. :"Barnett Shale Update", Platts Shale Developer Conference,Houston TX, June 2008.
2. LaFollete, R. and Schein, G: "Understanding the Barnett Shale", Supplement to Oil and Gas Investor , January 2007.
3. Durham, L.S.: "Barnett Shale Play Can Be Complex : Their Success Doesn't Ensure Yours", AAPG Explorer Bulletin, September 2007.
4. Leonard, R. et al: "Barnett Shale Completions : A Method for Assessing New Completion Strategies", SPE 110809, presented at the 2007 SPE Annual Technical Conference and Exhibition, Anaheim, California, November 2007.
5. Daniels J., Waters G., LeCalvez J., Lassek J., and Bentley D.: "Contacting More of the Barnett Shale Through an Integration of Real-Time-Microseismic Monitoring, Petrophysics, and Hydraulic-Fracture Design," SPE 110562, presented at the 2007 SPE Annual Technical Conference and Exhibition, Anaheim, California, November 2007.
6. Warpinski, N.R. et al: "Stimulating Unconventional Reservoirs: Maximizing Network Growth while Optimizing Fracture Conductivity", SPE 114173, presented at 2008 SPE Unconventional Reservoirs Conference, Keystone, CO, February 2008.

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