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Comparative Study of Cemented Versus Uncemented Multi-Stage Fractured Wells in the Barnett Shale

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Abstract

The industry has made a very quick turn toward both unconventional reservoirs and horizontal, multi-stage fracturing. Some industry experts have begun to question the effectiveness of recoveries in these massive reserve assets. A notable formation in these discussions has been the Barnett Shale, where a variety of methods and technologies have been used to fracture stimulate horizontal wells. In fact, much of the learning curve for completion practices has come from experimental work in this unconventional play.

From 2004 through 2006, a new, open hole, multi-stage system (OHMS) completion technology was run in Denton County, Texas. Using publically available data from the past five years, this study contrasts long-term production results from OHMS completed wells and wells completed with cemented casing.

The data set for OHMS fractured wells compared to the data set for cemented fractured wells indicates that open hole wells, on average, performed better. Significantly, no failures or shut-in periods were observed for the OHMS wells. This establishes the viability, reliability and effectiveness of this technology for the long-term life of wells not only in the Barnett, but for performance enhancement in other shale plays.

Substantial amounts of money are currently being spent to rapidly develop resource plays similar to the Barnett worldwide. Based on short-term results using current completion methods, predictions for ultimate recoveries may be overestimated. This paper evaluates the effectiveness of current completion practices by contrasting two methods in terms of production, economics, operational efficiency, and best fracturing practices to determine whether the completion method can affect overall well performance and long-term recovery.

Introduction

Formation Description. The Barnett Shale is a Mississippian-age shale located in the Forth Worth Basin and covers approximately 5,000 square miles (12,950 km^2) of north-central Texas (Figure 1). The Barnett represents the grandfather of shale reservoirs where “shale as source rock” was first established, and where the necessary set of technologies, namely horizontal drilling and multi-stage fracturing, were developed to make hydrocarbon extraction economically feasible in shale.

The Barnett is conformably overlain by the Pennsylvanian-age Marble Falls Limestone and unconformably overlies the Ordovician-age Viola Limestone/Ellenberger Group, which serves as a frac barrier (Figure 2) (Bowker, 2003; Pollastro et al., 2003). The core area of the Barnett is located in the Denton, Wise and Tarrant Counties where it is approximately 300 to 500 ft. thick with porosity and permeability values in the range of 3 – 5% and 0.00007 – 0.0005 mD, respectively (Fisher et al., 2004; Franz et al., 2005; Ketter et al., 2006). The Barnett is a naturally fractured reservoir where hydraulic stimulation induces development of a complex, interconnected fracture network, resulting in greater access to the formation (Fisher et al., 2004; Warpinski et al., 2005).

Completions History. Vertical wells were first drilled in the Barnett Shale in the early 1980s, but commercial production would not occur until almost two decades later with the advent of horizontal drilling in 2002 (Bowker, 2003; Fisher et al., 2004; Ketter et al., 2006). Because it was the first shale play to be developed, the Barnett has been a testing ground for various completion methods including the following.

Uncemented, open hole, single stage fracturing method. Early completions in the Barnett shale typically used an uncemented casing string through the horizontal well. The fracturing process was commonly referred to as a "Hail Mary" approach. This meant that no method of mechanical diversion was used against the rock face. In most wells the casing was only perforated with a limited number of holes at each of three to four separate intervals along the horizontal lateral. Modified limited entry was "hoped" for by using as high as possible treatment rates, upwards of 160 – 200 BPM. Ball sealers or even rock salt were also used on some jobs in an attempt divert fluid from one set of perforations to another within the casing. However, the fluids were free to move along the annulus between the casing and the open hole, and could initiate fractures anywhere within the horizontal well. Microseismic monitoring during these fracture operations indicated that even when fracture fluid diversion took place inside the casing, the fracture propagation often initiated at random points not opposite casing perforations and was very unpredictable. Monitoring on some of these wells indicated that all fracture activity could take place at a single point along the well bore (Warpinski et al., 2005).

Cemented liner, limited entry fracturing method. The first cemented liner systems installed in the Barnett shale typically attempted to use modified limited entry to provide distribution of fractures throughout the horizontal wellbore. This consisted of very high pumping rates and fluid diversion via ball sealers or rock salt. Monitoring of these wells showed that once again, the fracture propagation often took place randomly and was very unpredictable. The consensus in the play was that mechanical diversion was required to consistently provide enough individual fracture treatments to effectively drain the full length of the horizontal well. Production comparisons from these early experimental methods indicated that open hole wells generally produced at higher rates with higher recoveries than cemented liners, despite the utilization of cement to provide mechanical diversion between the casing and the rock face (Fisher et al., 2004; Warpinski et al., 2005).

Cemented liner, multi-stage fracturing method. This type of completion involves cementing casing in the horizontal wellbore and "plug and perf" stimulation (Blanton and Mackenzie, 2006). Mechanical isolation in the liner is accomplished by the setting of bridge plugs using pump down wireline or coiled tubing (CT), followed by perforating and then fracturing the well to provide access to the reservoir. The cement provides the mechanical diversion in the annulus while the bridge plug provides the mechanical diversion in the liner. This process is then repeated for the number of stimulations desired for the horizontal wellbore. After all the stages have been completed, CT is used to drill out the composite plugs, thus re-establishing access to the toe of the horizontal wellbore. Although an effective method of creating diversion along the horizontal for descrete stage stimulation, the inherent cost of multiple interventions with CT, perforating guns and deployment of fracturing equipment needed for each stage are extremely high, not to mention, very inefficient and time consuming. Production using this method can also be limiting, as cementing the wellbore closes many of the natural fractures and fissures that would otherwise contribute to overall production.

Uncemented, open hole, multi-stage fracturing method. Between 2004 and 2006, a new, open hole, multi-stage system (OHMS) completion technology was run in Denton County, Texas (Lohoefer et al., 2006). OHMS were pioneered in 2001 with the goal of making multi-stage fracturing more efficient, both in terms of time and cost, as well as repeatable and reliable (Seale et al., 2006; Seale, 2007) (Figure 3). OHMS use external packers instead of bridge plugs to isolate sections of the wellbore. These packers typically have elastomer elements that expand to seal against the wellbore and do not need to be removed, or milled out, to produce the well. Instead of perforating the casing to allow fracturing, these systems have sliding sleeve tools to create ports in between the packers. These tools can be opened hydraulically (at a specific pressure) or by dropping size-specific actuation balls into the system to shift the sleeve and expose the port. The major advantage of OHMS is that all the fracture treatments can be performed in a single, continuous pumping operation without the need for a drilling rig, saving time and costs. Once stimulation treatment is complete, the well can be immediately flowed back and production brought on line.

Study Description. This study was undertaken to compare cemented verses uncemented multi-stage fractured wells in the Barnett shale. Previous studies have indicated that uncemented wells perform better than cemented wells in the Barnett (Fisher et al., 2004). However, despite having opened other unconventional plays, the perception persists that open hole completions do not work within certain areas where cemented casing dominates (Britt and Smith, 2009). This study analyzes public production data from OHMS completed wells and offset cemented liner wells completed in the same time period to compare the long-term production recoveries. Differences in economics, operational efficiency, and fracturing practices will also be discussed.

Production Benefits of OHMS

Denton County Newark East Field Study. This study consisted of all non-vertical wells completed in the Newark East field in Denton County (Figure 4). Denton County is one of the core counties of the Barnett shale with the Newark East field being considered the sweet spot of the play (Pollastro et al., 2003). The offset wells were completed during the period the OHMS were being installed, from the beginning of 2004 to the end of 2005. Over 200 wells were evaluated in this study (Figure 5). The field production study evaluated up to 60 months of publically available production (drillinginfo.com) from the subject wells.

Six, 12, 24 and 60 month cumulative gas values were determined for each well in the Newark East Barnett field in 2004 and 2005. These values were then averaged to find the average production for the field at each time point. A total of 105 wells were completed in 2004 and 143 wells were completed in 2005. Cumulative production values were calculated for five OHMS wells and then averaged together to determine a cumulative average for each time point (Figure 6).

- After the first six months of production, the field average was 165 MMCFGE for the 2004 wells, 155 MMCFGE for the 2005 wells and 213 for the OHMS wells. The OHMS wells out-produced the field average by 29% over the 2004 wells and 37% over the 2005 wells.

- At 12 months of production the 2004 wells produced 281 MMCFGE, the 2005 wells 265 MMCFGE and the OHMS produced 350 MMCFGE. The OHMS wells out-produced the field average by 24.5% over the 2004 wells and 32% over the 2005 wells.

- At 24 months of production the 2004 wells produced 451 MMCFGE, the 2005 wells produced 413 MMCFGE and the OHMS produced 528 MMCFGE. The OHMS wells out-produced the field average by 17% over the 2004 wells and 28% over the 2005 wells.

- At 60 months of production the 2004 wells produced 781 MMCFGE, the 2005 wells produced 757 MMCFGE and the OHMS produced 945 MMCFGE. After five full years of production, the OHMS wells were still producing 21% over the 2004 wells and 25% over the 2005 wells.

After five years of production, without any type of intervention or re-fracturing of the wells, the OHMS wells out-produced the cemented liner plug and perf completions in Denton County. Additionally, no failures or shut down periods without production were observed for the OHMS wells.

Subsection of Newark East Field Study. To compare closer offset wells with the OHMS wells, a smaller sample area of wells in the north eastern section of the Newark East Barnett field were sampled and the same analysis performed as with the Denton County study (Figure 8). The offset area encompassed 10 miles east-west and 7 miles north-south of four OHMS wells (Figure 7). There were a total of 14 non-vertical offset wells drilled in 2004 and 15 drilled in 2005.

- After the first six months of production, the offset average was 181 MMCFGE for the 2004 wells, 145 MMCFGE for the 2005 wells and 244 for the OHMS wells. The OHMS wells out-produced the offset average by 35% over the 2004 wells and 68% over the 2005 wells.

- At 12 months of production the 2004 wells produced 303 MMCFGE, the 2005 wells 240 MMCFGE and the OHMS produced 388 MMCFGE. The OHMS wells out-produced the offset average by 28% over the 2004 wells and 61% over the 2005 wells.

- At 24 months of production the 2004 wells produced 475 MMCFGE, the 2005 wells produced 370 MMCFGE and the OHMS produced 585 MMCFGE. The OHMS wells out-produced the field average by 23% over the 2004 wells and 58% over the 2005 wells.

- At 60 months of production the 2004 wells produced 807 MMCFGE, the 2005 wells produced 652 MMCFGE and the OHMS produced 945 MMCFGE. After five full years of production, the OHMS wells were still producing 17% over the 2004 wells and 45% over the 2005 wells.

Therefore, as with the larger Denton County study, the OHMS wells showed consistently higher production compared to closer offset wells in the northeastern part of the Newark East Barnett field.

Operational and Economic Benefits of OHMS

OHMS fracture completion equipment was first introduced in horizontal wells in the Barnett shale to reduce costs, increase safety, simplify the completion process and eliminate long standby time during hydraulic fracturing treatments. The adoption of this uncemented completion option was with the goal of maintaining at least an equivalent well productivity to the traditional cemented completion option, and ideally increasing well productivity over the standard cemented and perforated wells.

Simplified Operations. The OHMS technology eliminated all down hole work after the drilling rig had reached total depth (TD): cementing of the lateral casing, coiled tubing or tubing conveyed toe stage perforating, the setting of 5 or 6 bridge plugs, and perforating runs for a 6 or 7 stage hydraulic fracture treatment design. Then, after fracturing treatment, the long drill out process of bridge plugs set between stages was completely eliminated.

Within three days of the removal of the drilling rig, a well with an OHMS completion could be completed and selling gas. The only exception was if the production casing was a full string of casing cemented using a diversion (DV) tool above the OHMS completion assembly. This would require the DV tool to be drilled out prior to fracture stimulation, which was a simple, three-day operation using a pulling unit with reverse circulating capabilities.

Cost Savings. The OHMS completion method eliminated approximately two weeks of completion operations at a cost savings of $300,000 to $400,000 per well at 2005 pricing. An additional benefit was to greatly increase the availability and flexibility of the service company's hydraulic fracturing treatment equipment schedule. Since a fracture fleet was only needed for a single 24 hour period instead of the normal 4 to 6 day period, fracturing service companies were able to do more frac jobs with the same amount of equipment and personnel in the same amount of time. As a result, the operator benefited from an effectively increased number of frac dates available from the service companies.

Improved Fracture Stimulation. An unexpected benefit of the adoption of OHMS completions was a dramatic reduction of excessive fracture initiation pressure as a treatment problem, as high fracture gradients are a characteristic of shale rock. On earlier cemented liner treatments, it was common that some hydraulic fracture treatments could not be initiated on some stages simply due to excessively high breakdown pressure (Ketter et al., 2006). The operator had no problems performing any fracture treatments after the adoption OHMS except for one stage, where mistakenly lower pressure rated N-80 instead of P110 casing was run and a subsequent 3-D seismic survey showed a major fault line crossing adjacent to that interval.

Conclusions

The data from a side by side comparison of publically available production data (drillinginfo.com) from cemented and uncemented wells shows that OHMS technology is a viable option in the Barnett shale. Cumulative production from OHMS completed wells was between 25 and 37% higher than offsets in Denton County completed in the same years (2004, 2005). This result was mirrored by a comparison of OHMS wells to offsets in a smaller, northeast subsection of the Newark Barnett field with a range of 17 to 68% higher cumulative production values. These studies also validate OHMS as a dependable and reliable completion system free of failures and shut-in periods of no production.

The number of fracture sleeves used in the OHMS completions in this study ranged from just five to seven per well, which currently would be considered low density. New “high density” OHMS technology now allows for up to 22 stages in a single lateral, with the potential for even greater production benefits.

The inherent operational differences between OHMS and cemented liner plug and perf completions presents the basic question of how these methods affect the end goal of optimal reservoir stimulation and production. Development of best fracturing practices over the last few decades would include: not overdisplacing proppant, ensuring near-wellbore conductivity, promoting immediate flowback, optimizing load recovery, keeping breakdown pressures low, minimizing fracture tortuosity and minimizing fluid loading (Themig, 2010). OHMS systems inherently abide by these practices due to the continuous stimulation operation, which doesn’t require large overflush volumes and allows wells to be immediately produced post-stimulation, and the ability for fractures to initiate where breakdown pressures are lowest in each open hole section reducing fracture tortuosity.

In terms of optimizing production of multi-stage stimulated wells, recent modeling simulations of depletion profiles from 6-stage open hole and cemented liner multi-stage completions have shown that open hole completions result in better drainage of the lateral (Themig, 2010). This is because cementing off the lateral prevents the contribution of production from natural fractures and fissures often present in unconventional reservoirs that an open hole lateral would benefit from.

From the results, it is clear that beyond the production benefits, the simplified operations intrinsic to the OHMS method also result in numerous time and cost savings. Additionally, OHMS completions are safer due to the reduced number of trips in and out of well, reduced time on site, as well as no requirement for perforating explosives.

In conclusion, the OHMS completion strategy accomplished all initial efficiency objectives and, after five years of long-term production history, the additional benefit of improved production. In addition to better long-term recoveries, OHMS completions intrinsically use better fracturing practices, as well as being a safer and more efficient use of resources.

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Nomenclature

BPM	=	barrels per minute
km	=	kilometer
mD	=	millidarcy
MMCFGE	=	millions of cubic feet of gas equivalent
Tcf	=	trillion cubic feet of gas

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