SHALE COMPLETION CEMENTING IN THE ARKOMA BASIN

Curtis Huff and Scott Nelson
BJ Services Company

ABSTRACT

Successful primary cementing of shale completions requires slurry design considerations that conventional cementing operations typically do not consider. The unique petrophysical and geological properties of shale must be factored into the design along with future stimulation plans to provide zonal isolation and casing support. This paper focuses on Woodford Shale wells cemented in the Arkoma Basin.

Cement slurry design is a critical part of any successful cementing operation. This is particularly true for shale wells where the unique nature of shale and its completion methodologies put additional demands on the cement. Slurry design considerations and successful slurry formulations for the area will be discussed along with an overview of primary cementing practices. Operational considerations as they apply to cementing horizontal shale wells in the study area will be discussed. Conclusions and recommended practices for optimum results will also be presented.

INTRODUCTION

The Arkoma Basin has seen increasing activity in recent years in the drilling of Woodford Shale gas in southeast Oklahoma[1]. The opening of the Woodford Shale play owes its existence, and is a direct technological extension of the lessons learned in the application of horizontal drilling technologies from the Barnett Shale of north Texas. The drilling and completion of horizontal wells within the Woodford Shale formation is the key that has made the economics of these wells feasible. With the increasing activity in the area a study of the cementing operations was needed. This study looks at cemented horizontal long strings and liners in Atoka, Coal, Hughes and Pittsburg counties in southeastern Oklahoma. The study wells are displayed in Figure 1. The wells in this study have the Woodford Shale as the primary target although other up hole formations may be a completion target as well. Well information, as well as, cement and stimulation job data were collected from a proprietary Geographical Information System[2] in addition to publicly available data. The data selected for this study is from one service company only.

Today most wells drilled to the Woodford Shale are horizontal, and most of the wellbores are cemented in place for isolation of fracture treatments. Hydraulic fractures are typically propagated from the lateral in regular intervals that are spaced roughly 50 feet to 150 feet apart per fracturing stage. The total amount of fracturing stages that are applied to each wellbore is then related directly to its length. It is the use of cement and perforations that simplify the completion process over other methods, such as those that employ mechanical solutions to perform staging.

Woodford wells typically have two to three casing strings cemented in them. A surface casing, usually 9 5/8”, is set over fresh water zones and cemented to surface. Typical well plans below the surface fall into one of two categories, those with and those without an intermediate casing string. Depending on the drilling conditions of an area or up hole completion plans an intermediate casing string, usually 7”, is set at the top of the Woodford. Drilling to the intermediate point is usually done with air and/or water based mud. The intermediate is conventionally cemented. After the intermediate is set the mud system is switched over to oil based drilling mud. The Woodford is then drilled with a 6 1/8” to 7 7/8” hole for 4 ½” long strings and liners or 7 7/8” to 8 ¾” hole for 5 ½” long strings and liners. Those wells where drilling conditions allow and operator preference dictates no intermediate casing the wells are drilled to total depth with oil base mud. Just prior to or during the cementing operation the oil-based mud is circulated out of the well to be recycled and is replaced with either water-based mud or 2% KCl water.

DESIGN CONSIDERATIONS

The primary objectives of a completion cement job are the hydraulic isolation of the zone and casing support[3]. Hydraulic isolation is especially important along the lateral as four to ten or more fracture treatment stages may be performed. Each fracture treatment must be isolated from the adjacent stages to maximize the effectiveness of the fracture treatment and the resulting production. One important aspect beyond hydraulic isolation is that no impairment on the pumping of the stimulation treatment is made as a result of the cement system being used.

Woodford Shale fracture treatments are known to create a complex fracture geometry[4]. The type of cement used in the lateral section can have an impact on fracture initiation and the cement design must take this into consideration. The main challenges in obtaining a good horizontal cement job are hole cleaning, mud displacement, centralization and slurry design[5]. Proper slurry design is a critical part of a successful cement job but it is not the only factor that needs to be considered. A perfect slurry pumped without regard to the other challenges will probably not result in a successful cement job. Hole cleaning starts with conditioning the hole prior to starting cementing operations. Once the casing or liner is on bottom and sufficient circulation has been made the next step in hole cleaning and transition to mud displacement is the running of spacers. Oil based mud being used in drilling a typical Woodford well requires a spacer that is compatible with oil based mud and the cement. Many wells have the oil based mud recycled by replacing it with water based systems during the cementing operations. In this case a spacer that is compatible with both the oil based mud and the water based mud will be ran between the two mud systems. A second spacer is then used between the water based system and the cement. Spacer volumes vary depending upon cement coverage, casing and hole size and mud properties. Spacer volumes typically recommended for conventional wells is to pump a volume sufficient to provide 300 to 500 feet of annular fill[6]. For the common casing and hole configurations this would equate to 20 - 25 barrels. A general rule of thumb for the Woodford wells that is often recommended is 10 barrels of spacer for every 1000 feet of cement coverage. A minimum volume of 20 to 25 barrels is recommended for cases when cement coverage is less than 2000 feet. A critical aspect of hole cleaning, mud displacement and cement placement in horizontal wellbores is centralization of the casing within the hole[7]. However due to concerns over pipe drag and sticking on long laterals minimal or no centralization is commonly used.

Cementing operations to date have been performed with as many as four distinct slurry types. Each of the cement systems utilized however has been designed for a single common purpose beyond casing support and zonal isolation. That is to allow for the treatment of each and every intended hydraulic fracturing stage throughout the lateral. If a portion of the lateral pay can not be pumped into in order to propagate fractures, then that area of the wellbore will not contribute its proportional share of the well's production potential. Early horizontal laterals would often contain sections where the formation would not sufficiently break down. Abnormally high pressures during some fracturing treatments would not allow for sufficient pumping rate to initiate and grow well-developed fractures. It was believed that the issues were related to fracture complexity[4], and that reducing the integrity and strength of the cement sheath around the casing might help to mitigate the abnormally high treating pressures encountered. Cement systems were modified to insure that they did not impede the ability of the intended fractures to propagate into a single main initiated fracture. To accomplish this, cement slurries consisting of foamed cement, acid-soluble cement, foamed acid-soluble cement, as well as lighter density slurries containing pozzolan were developed. While each of these slurry types had varying properties one common property they each had was a 0% free water. Horizontal cement slurries require 0% free water to prevent a water channel from forming along the top of the hole allowing a path for fluid migration and loss of zonal isolation[5,8].

Foamed slurries are created out of a base slurry consisting of Portland Class H cement. The Class H base is mixed at 15.6 to16.4 pounds per gallon (ppg) and foamed with nitrogen to a weight of 13.4 to 14.4 ppg. Operationally the foaming of cement that is placed in a horizontal wellbore is the simplest condition of foamed cementing. The absence of a changing hydrostatic pressure or bottom hole static temperature along the cemented horizontal lateral section of the wellbore allows the nitrogen to be added at a constant ratio because the nitrogen properties are constant. Adding nitrogen to create a foamed cement, the strength is reduced from that of the base cement due to the reduction of Portland cement per given area. An additional benefit is that foamed cement slurries expanded to fit the size of the annulus when placed. Foamed cements can also have increased mud displacement capabilities over conventional cements[9].

Another cement system was borrowed directly from the cementing practices being utilized throughout the Barnett Shale play in north Texas, namely the use of acid-soluble cement. The term acid-soluble cement is given to slurries that contain sufficient amounts of calcium carbonate to react in the presence of hydrochloric acid. These slurries when cured and exposed to HCl acid are weakened due to the removal of the calcium carbonate from the cement matrix. Historically acid-soluble cements have been used in temporarily sealing off lost circulation in productive zone[10]. The intent being that if a HCl acid spearhead were to be placed in front of the fracturing fluid, then the cement sheath around the casing directly across from the perforated interval would be weakened and easily removed. The cement remaining between each perforated interval would still provide isolation between sets of perforations.

A cement system that has also been pumped combines the benefits of both foamed cement and acid soluble cement by creating a foamed acid-soluble cement. This obviously produces the characteristics of a foamed cement, as well as, a partially soluble cement. A typical foamed acid-soluble cement starts with a base slurry of Class H, with calcium carbonate added for increased acid solubility, mixed at 15.9 ppg. This base slurry is then foamed with nitrogen to a density of 13.4 ppg. On some wells in conjunction with the foamed slurry a non foamed cap on top of the foamed slurry is ran or a non foamed tail slurry around the shoe joint is sometimes used.

Lastly, medium density and strength cements have utilized the common slurry chemistry associated with a 50:50 Pozzolan and Class H system. These systems are typically mixed in the range of 13.8 to 14.5 ppg. The reduction in set cement strength, as compared to moderate density slurries, and its high resistance to formation leak-off, is intended to make it easier for the hydraulic fractures to breakdown the formation and propagate the intended fractures. The use of these systems has shown to reduce cement loss and breakdown pressures in coal seam completions where natural fractures, cleat systems, are present[11]. The use of fluid loss additives and tailored loss circulation materials will also reduce cement loss into shales.

These cement types were all developed and employed in response to the higher than anticipated pressures encountered during hydraulic fracturing treatments along Woodford Shale horizontal laterals. The question of why this occurred must be answered in order to determine which of the various cementing solutions actually provide a remedy for the observed abnormally high pumping pressures. The Woodford Shale throughout the Arkoma Basin is naturally fractured, and these fractures intersect the drilled wellbore in various frequencies along its length. Areas where an above average number of well-developed natural fractures are apparent have been termed as areas containing "fracture swarms". It has been observed that when operators have perforated across from these areas that often much greater hydraulic pumping pressures into the formation are encountered. This phenomenon is counterintuitive to the condition that would be expected. Examples exist where these fracture swarms have been perforated, and re-perforated, in an effort to reduce high pumping pressures. The addition of more perforations however can be ineffective. Clues to the condition being observed can be found in recent work that has been performed during the drilling of these Arkoma Basin Woodford wells. Operators have experimented successfully with the idea that it is possible to strengthen low permeability shales by creating a "stress cage" effect along the drilled wellbore[12]. By pumping and bridging particles into fractured areas, drilling operations have been able to impart a hoop stress at the wellbore. The increased pressure created by bridging near-wellbore fractures open causes a measurable increase in the formations' ability to resist fracturing. It therefore becomes apparent that the increased fracturing pressures observed are likely a result of whole cement, or lost circulation materials, or both being placed into areas of high permeability such as the before mentioned fracture swarms. As long as the cement remains in the fractures along the near-wellbore the hoop stress condition will remain in effect. If the condition were reversed then normal pumping pressures could be achieved during the hydraulic fracturing process.

Economics must also be considered in slurry design. Typically, the more complex the slurry the greater the cost is. Acid-soluble or foamed acid-soluble is usually more expensive than a medium density slurry or a foamed conventional slurry. Increased cementing costs however can be more than justified if fracture treatment success can be achieved throughout the lateral.

CASE HISTORIES

Example 1.

This Woodford well has 5 ½" casing set at a measured depth (MD) just over 10,500' in 8 ¾" hole. True vertical depth (TVD) averaged 6,620' with an average bottom hole static temperature (BHST) of 167°F. A 30 barrel oil based mud compatible spacer, mixed at 10 ppg, was pumped ahead of the cement. The spacer was followed by 180 sacks of medium density 50:50 Poz:H cement, mixed at 14.3 ppg, to be placed in the vertical section of the hole. After the non foamed lead a second lead of 735 sacks foamed acid-soluble cement was pumped to be placed across the lateral. This acid-soluble slurry was mixed at 15.9 ppg and foamed to 13.4 ppg. A non foamed acid-soluble tail of 20 sacks was placed at the shoe and was mixed at 15.9 ppg. Table 1 details the slurry properties for each slurry. A subsequent fracture treatment was performed on seven separate intervals along the lateral. All seven fracture treatments were pumped at the designed rate of 90 barrels per minute (bpm) without excess injection pressures or rate limitations.

Example 2.

This Woodford well has 4 ½” casing set near 12,900’ MD in 6 1/4” hole. TVD averaged just over 9300’ with an average BHST of 203°F. A 40 barrel oil based mud compatible spacer, mixed at 10.5 ppg, was pumped ahead of 8.8 ppg water based mud to displace the oil based mud out of the hole. The water based mud was followed by 12 barrels of water based mud wash spacer mixed at 8.45 ppg. A single cement slurry consisting of 400 sacks of medium density 50:50 Poz:H cement, mixed at 13.8 ppg, was pumped. Table 2 details the slurry properties for this slurry. A subsequent fracture treatment was performed on four separate intervals along the lateral. All four fracture treatments were pumped to completion near the expected treating pressures.

SUMMARY AND CONCLUSIONS

Solutions applied during the cementing of these horizontal wells then have taken two forms to reduce injection problems during subsequent fracture treatments. First, allowing for the removal of cement that may be placed into natural fracture swarms by reducing the cement matrix integrity. Second, by pumping specialty cement systems that have been specifically designed to prevent cement loss into permeable formations. This second category of cement consists of 50:50 Pozzolan and Class H, originally designed to overcome the difficulties associated with cementing across coal bed methane formations. The unique components of the 50:50 poz slurry have been formulated from decades of experience in the Arkoma Basin to allow for its lift above the highly permeable coals. Likewise it has been used with success in cementing Woodford Shale horizontal laterals since the ability to keep the cement in the annulus eliminates the introduction of hoop stresses within the near-wellbore region. Slurry compositions can be varied depending upon the area and degree of natural or drilling induced fracture. Slurry compositions can be varied depending upon the area and degree of natural or drilling induced fractures.

REFERENCES

1. Brian J. Cardott: “Overview of the Woodford Gas Shale Play in Oklahoma”, presented at the Woodford Gas Shale Conference, Oklahoma City, Oklahoma, May 2007.
2. Bilden, D.: “Database Package Facilitates Stimulation Treatments,” *Hart’s E&P*, (April 2000), 126.
3. Smith, D.K.: *Cementing*, SPE, Richardson, Texas (1996) 1, 57.
4. Vulgamore, T., Clawson, T., Pope, C., Wolhart, S., Mayerhofer, M., Machovoe, S. and Waltman, C.: “Applying Hydraulic Fracture Diagnostics To Optimize Stimulations in the Woodford Shale” SPE 110029, SPE Annual Technical Conference, Anaheim, CA, November 11-14, 2007.
5. Sabins, F. L.: “Problems Cementing Horizontal Wells”, *Journal of Petroleum Technology*, (April 1990), 400.
6. Smith, D.K.: *Cementing*, SPE, Richardson, Texas (1996) 62, 63.
7. Sabins, F. L.: “Problems Cementing Horizontal Wells”, *Journal of Petroleum Technology*, (April 1990), 399.
8. Zurdo, C. and Martin, M.:”Mud and Cement for Horizontal Wells” SPE 15464, SPE Annual Technical Conference, New Orleans, LA, CA, October 5 – 8, 1986.
9. Harlan, T., Foreman, J., Reed, S. and Griffith, J.: “Foamed Cement Selection for Horizontal Liners Proves Effective for Zonal Isolation-Case History” SPE 71055, SPE Rocky Mountain Petroleum Conference, Keystone, CO, May 21-23, 2001.
10. Vinson, E., Totten, P. and Middaugh, R.: “Acid Removable Cement System Helps Lost Circulation in Productive Zones” IADC/SPE 23929, IADC/SPE Drilling Conference, New Orleans, LA, February 18-21, 1992.
11. Huff, C. and Merritt, J.: Coal Seal-Well Cementing in Northestern Oklahoma” SPE 80938, SPE Production and Operations Symposium, Oklahoma City, OK, March 22-25, 2003.
12. Aston, M.S., Alberty, M.W., Duncum, S., Bruton, J.R., Friedheim, J.E. and Sanders, M.W. “A New Treatment for Wellbore Strengthening in Shale.” SPE 110713, SPE Annual Technical Conference, Anaheim, CA, November 11-14, 2007.

Table 1 Example 1 Slurry Properties						
Slurry Description	**Slurry Composition**	**Mixing Density**	**Mixed Yield**	**Foamed Density**	**Average Foamed Yield**
Non Foamed Lead	50:50 Poz:H + 3% bwow Salt + 0.5% bwoc Fluid Loss + 0.5% bwoc Extender + 0.125 lbs/sack LCM Flake + 4 lbs/sack Granular LCM + 52.9% Fresh Water	14.3	1.26		
Foamed Acid Soluble Lead	Class H Cement + 213 scf/bbl N2 + 0.75% bwoc Retarder + 2% bwow Potassium Chloride + 0.1% bwoc Anti Settling Agent + 1.1% bwoc Extender + 0.2 gps Foaming Agent + 0.75% bwoc Fluid Loss + 25 lbs/sack Calcium Carbonate + 50.1% Fresh Water	15.9	1.44	13.4	1.75
Non Foamed Acid Soluble Tail	Class H Cement + 0.75% bwoc Retarder + 2% bwow Potassium Chloride + 0.1% bwoc Anti Settling Agent + 1.1% bwoc Extender + 0.2 gps Foaming Agent + 0.75% bwoc Fluid Loss + 25 lbs/sack Calcium Carbonate + 53.2% Fresh Water	15.9	1.46		

Table 2 Example 2 Slurry Properties			
Slurry Description	**Slurry Composition**	**Mixing Density**	**Mixed Yield**
Non Foamed Lead	50:50 Poz:H + 0.75% bwoc Fluid Loss + 0.025% bwoc Retarder + 0.25 lbs/sack LCM Flake + 0.25% bwoc Dispersant + 0.5% bwoc Extender + 62.1% Fresh Water	13.8	1.33

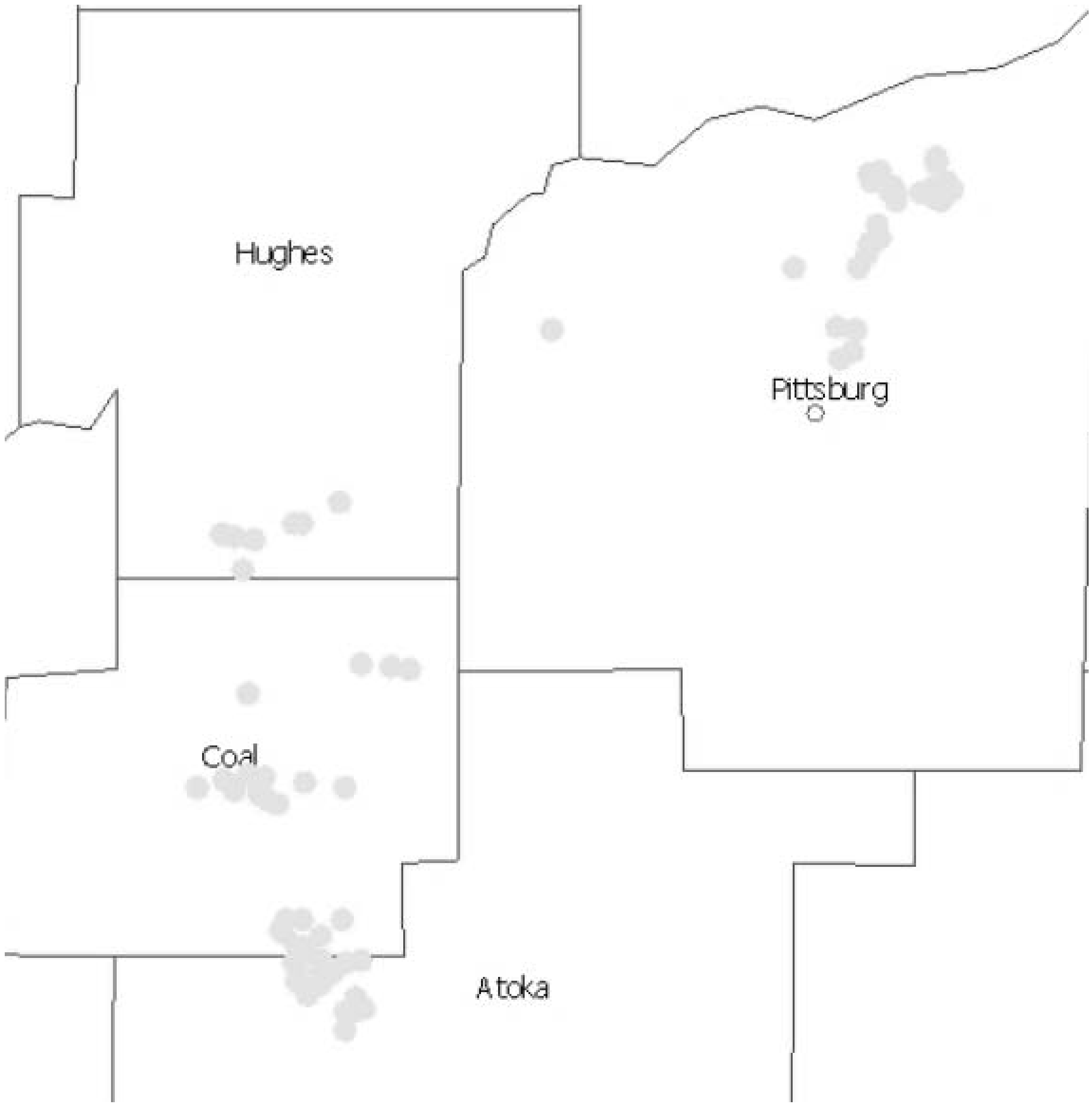

Figure 1- Study Area With Well Locations