

Cementing Process Control and Performance Tracking to Decrease Cost and Improve Operations in the Permian Shale

Jessica McDaniel and Travis Baughman, CSI Technologies, LLC

Copyright 2016, AADE

This paper was prepared for presentation at the 2016 AADE Fluids Technical Conference and Exhibition held at the Hilton Houston North Hotel, Houston, Texas, April 12-13, 2016. This conference is sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individual(s) listed as author(s) of this work.

Abstract

With the decreasing price per barrel of oil, US shale operators must significantly reduce drilling costs for production to remain commercially viable in these areas. This project focuses on reducing cost while increasing the efficiency of Permian Basin cementing operations. With multiple cementing service companies that provide varying design philosophies and technologies, and using varied nomenclature, consistency is hard to find. Consequentially, analysis and comparison of cementing options is difficult and time consuming. To remedy this, a standardized process of engineering oversight and operations control was implemented with one goal in mind: Pumping the best cement slurry for the lowest price.

This process started at the design phase, analyzing each component of the cement systems in place and ensuring each fluid performed as needed to provide isolation. Using carefully designed, simple cement systems led to significant savings in cementing materials. Standardized designs optimized performance and value, simplifying the comparison of cementing options. This allowed the drilling team to make informed decisions comparing cementing systems side by side, knowing that each will deliver the performance needed for the specific well. Field implementation of these systems was monitored to confirm the success of the new systems. These changes resulted in an average cost savings of \$130,000 per well in cementing materials alone. The additional benefit of this control system is the improved clarity when analyzing cementing proposals and performance. As the quality of the cementing operations improves, the cost associated with cementing will decrease.

Introduction

From the summer of 2014 through the winter of 2015, crude oil has plummeted from around \$100/bbl to under \$40/bbl. This has resulted in a severe downturn in the oil and gas market. Specifically in the Permian Basin where the rig count has dropped 59% from 565 rigs in November 2014 to 234 in October 2015 (1). Along with the rig count dropping, the activity in the region has also diminished; resulting in cost cutting, thousands of lay-offs and millions of dollars of equipment lying inactive. This has painted a fairly grim picture of the future of the industry. As a result of this downturn, emphasis has shifted to operating cost reduction.

This particular cost reduction project focuses wholly on cementing operations and design. While the actual cost of primary cementing is only a small percentage of the cost each well, typically around 5%, the financial ramifications of poor primary cement work can be much greater. A poor cement job can result in difficulty with completions, delayed production, and potentially millions of dollars in remediation. Often, if communication from lower zones is present, many state and federal entities will require extensive remedial work to fix the well either before or after completions. With this in mind, it is very important to achieve adequate zonal isolation during the primary cementing operations to keep costs low during the life of the well. When remedial cementing becomes a necessity, the cost increases considerably. This happens initially as the simple increase in number of cement jobs, as they are not planned. Additionally, the service company will often charge significantly more per unit volume of slurry than if it were a primary job.

The cost benefit of eliminating remedial work is obvious, yet there are also opportunities to intelligently reduce the cost of primary cementing. Using the techniques outlined in this study, carefully engineering the cementing process, it is possible to decrease the cost of cementing operations as well as increase or maintain the performance of the cemented annulus. This is achieved through intelligent selection of performance criteria, standardizing the performance across each service company, and simplifying the systems and process where possible.

Background

Cement technology has advanced over the years, resulting in a large spectrum of options from low cost conventional approaches to ultra-high cost, high performance technology previously unavailable. With this has developed a need to optimize the cementing performance (technology) necessary for sound well construction with the associated cost considered. Several cementing companies operate in the Permian Basin. Each company has preferred designs they have created for each string in the area. It can be difficult to identify if these preferred designs and techniques are best suited to a particular well/string. When comparing multiple service companies, it is vital to analyze slurry performance and associated cost. Drilling engineers can feel rushed and

overwhelmed with their options when looking at these systems. This lack of clarity results in considerable time spent analyzing each option, to accurately determine the cost versus performance value. Working with multiple service companies is not unique to the Permian Basin; this is standard in every field with most operating companies.

The issue specific to the Permian Basin is the pressure gradients. The pressure required to fracture the formations being drilled is very low, which can result in massive losses while drilling and cementing the intermediate strings. At the same time, the pore pressure in some zones in the same string may be close to the pressure to fracture, which creates a very narrow window to work in. Preventing gas or fluid influx may require taking losses in other zones. Cementing on losses is never recommended, and there are many methods and materials to heal the losses prior to cementing. As a last resort, cement can be used to cure or at least lessen severe losses and aid in bringing cement to surface. Unfortunately, this method does not always work, and it can be difficult to achieve the objective with cement alone. Current methods to ensure state and federal regulations are met are time consuming, cost prohibitive, or not effective. These methods include extra casing strings, multiple stage jobs, and costly lightweight materials.

The Process

This project was initiated as oil prices began to drop, the drilling team needed to find ways to cut costs. Faced with wells that had a narrow pressure window, the cement systems were ultralight, and still would induce losses to a point that most jobs were performed in two stages, or required remediation. A solution using a heavier conventional cement system coupled with low cost lost circulation techniques was implemented to improve cementing operations while reducing costs. During the implementation of this technique it was identified that of the cement companies involved in the region little standardization of cement properties and performance existed, though many of the job objectives were the same. In addition, a number of cementing services and systems appeared to have less than desirable job success rate. Without knowing what performance properties to request, it was difficult to understand the performance/cost (the value balance). This was addressed using a proven method to standardize and optimize cementing operations across all providers.

Implemented properly, this process of technical guidance in combination with performance standardization will result in cost benefits over time. The process starts with collecting all data related to cementing design, operations and implementation through close observation. This requires a three pronged approach incorporating a focus on cementing engineering, operations, and lab testing. After all data have been collected, the major issues can be easily identified. Each will need a proposed solution that will be practical and effective. With this three pronged approach, it is possible to produce solutions that will work well in the field, as the engineering, operations, and laboratory testing teams are

working closely. Those solutions are formed into recommendations for the field and design teams.

This method has been employed in other fields prior to this project (2) (3). Previous studies have taken place in the Haynesville and in the Marcellus, both with different primary goals, and both met with success by using this approach which is outlined in Figure 1.



Figure 1 – General approach used in this project (2)

The focus in every area should be standardization of performance criteria with an emphasis on balancing cost versus performance. With many service companies across several drilling teams and with the variety of methods available it can be difficult to achieve standard cementing performance well to well. Standardization can be an effective approach to decrease the cost and time spent on each cement job while increasing clarity regarding cementing performance. Standardization should include design, operations, and testing procedures.

Implementation will require continuing to work closely with the engineering, field and laboratory teams. After the official recommendations are identified, they must be shared and agreed upon with the entire drilling team and all cementing companies that will be involved. This will allow for the changes to be executed as quickly as possible. The continued oversight ensures that each recommendation is correctly applied to every subsequent cement job. This allows for an easier comparison when comparing previous cement jobs to ones with the new recommendations and to compare progress on all future jobs. Additionally, any new deficits that are identified can be quickly addressed as the infrastructure is already in place for making quick, effective changes. This process relies heavily on careful design and planning. Once this is established, the implementation phase can fully go into effect.

The obvious benefit of this process is directly addressing any major deficits in a quick and effective manner. An additional benefit to this process, once the standardized designs and procedures are in place is the increased understanding and clarity experienced by the drilling team. All cement jobs will be performed in a similar manner with cement that performs similarly, making it easier to intelligently evaluate available cement vendor options.

This entire process requires significant effort and focus on the cementing work, especially in the first few months. This effort will come to a peak around the halfway point, usually 3-6 months, after that, each service company and the drilling team should have the tools needed to continue the efforts in a more self-sustaining manner. For this project, engineering time peaked at about 6-7 months into the project

averaging about 18 hours per week. The average over the entire project is around 12 hours/week. For continued success, the time spent each week will decrease to 1 or 2 hours, with more in-depth spot checking every quarter or so. At this point the knowledge base of drilling team now includes the basic cementing performance parameters needed for each string, as well as the application of various fluids needed for a cement job to achieve the final objective.

The general trend is shown in the figure below. This shows a peak around 3-6 months into the project.

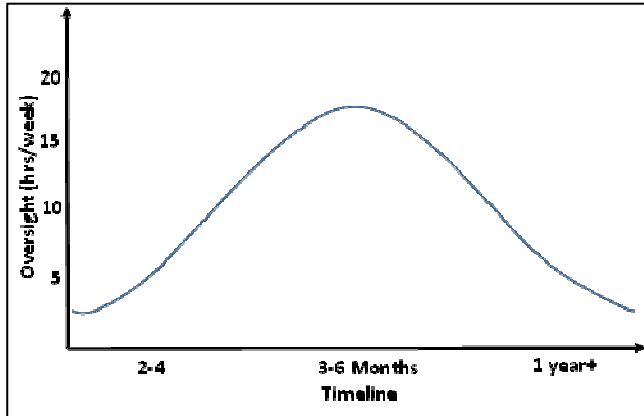


Figure 2- Planned time dedication needed for project

For this particular project, the field days were heavier up front, while implementing the new recommendations. The engineering work was heavier toward the middle of the project at 6-7 months while working on a secondary round of recommendations and special projects. From there, the hours dropped off steeply. At this point, the drilling engineers and the service companies working together were able to successfully use the recommendations and uphold all new requirements while still able to identify new areas of improvement.

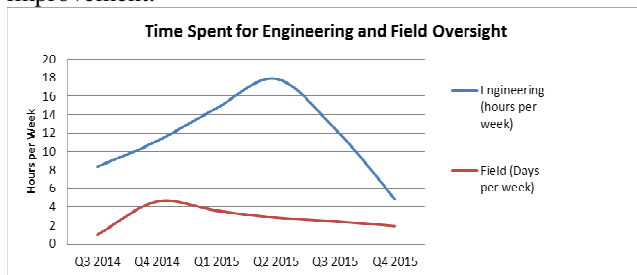


Figure 3 – Actual time dedicated to this project

The cost associated with this oversight is low in comparison to cementing costs, and especially low when considering the cost of remediation. The chart below shows the average cost per month of the engineering and field oversight required to implement this process. This will vary dependent on rig count and throughout this project there were 4-6 rigs. Average cost per month was around \$40,000. The average cost of a single cement job during this project is \$85,000, with several performed each month. With that in mind, the cost for oversight is relatively low, and decreases further with each month as adoption of process becomes

naturally ingrained into operator culture.

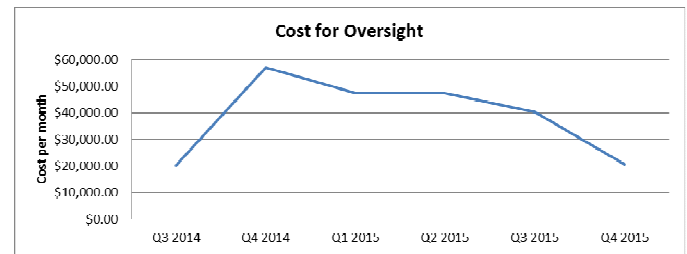


Figure 4 – Actual cost for engineering and field oversight

Compared to the savings during this project, cost is very low. The graph below shows the comparison between the savings and the cost of oversight.

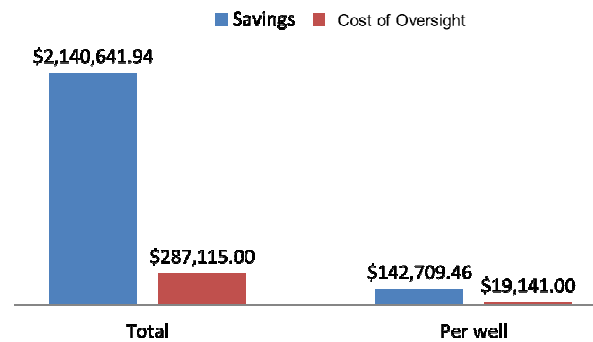


Figure 5 – Cost savings versus cost of oversight

Method of Observation

Identifying the major issues is the first step in this process. This is achieved through collecting data; the approach had three fronts: engineering analysis, laboratory testing, and field observation. Through experienced observation and expert analysis of this field from all three perspectives, it allows the team to quickly pinpoint the issues and determine recommendations in a way that allows the team to implement them seamlessly. Without balanced, robust engineering, constant product performance management, and sound execution techniques the system would lose both its effectivity and efficiency.

Initially, the drilling team must identify and define issues they are having. Additional teams to include would be completions and production teams, as not all issues in cementing occur during the pumping stage. Many issues occur after the cement has set, or even after completions and during production. It is also beneficial to meet with the cementing service teams as well to analyze the cement systems. During this time data should be collected on:

- Well data
 - Information such as depth, casing size and set points, hole size, zones of interest, pressure and temperature gradients, washout/excess, loss zones and salt zones.
- Design
 - Gather information on cement system design, planned cement heights, federal and

state regulations, and perform a full cost analysis of proposals.

- Testing
 - Look at current testing and sample collection procedures of all service companies.
- Operations
 - Determine the current service quality provided, the information that is readily provided prior to each job, and current field practices.
- Problems
 - Identify issues with placement, problems seen during and after the completion phase and any remedial work common in the area.

This data set highlights areas need to be focused on and identifies the intentions regarding design and placement. A full cost analysis allows the team to determine a balance between cost and performance. Cement systems and implementation should be designed specifically for the area and objectives. Intelligently identifying areas that can be optimized may help lower the total cost either directly, by implementing a more economic material, or indirectly through improved long term performance.

Once the data have been collected on cost versus performance, testing and field observation can take place. Using the data and areas of interest identified in the engineering step, field observation can take place with a focus on the highlighted concerns. Field evaluation should include the following sections:

- Pre job preparation – This covers the pre job laboratory testing, operational timing, and documentation.
- Common practices – Before, during and after operations, what typically goes on. Often, a fresh set of eyes, can shed light on underlying issues. This step will also help increase communication with the office concerning any problems at the wellsite.
- Equipment – Evaluation of the equipment should occur prior to the job. Ensuring the equipment is on a regular maintenance schedule and is functioning properly for the job by starting it and running it. If some equipment issues occur during the job, it is important to document those issues and request they be remedied prior to the next job. This step is important for both electrical and mechanical equipment.
- Personnel – Evaluation of personnel should take place before, during and after the job. Ensuring necessary information is available to complete the job and is able to present that documentation to the company representative is very important to assess job readiness and service quality.
- Post Job – The evaluation after the job is as important as any other step, and possibly more important. This

includes everything from rig down and clean up to the delivery of the job report to action item completion. Careful and thorough documentation of a job is the key to continuous improvement.

Goals for lab testing will also be targeted. While typically a general panel of tests is administered to each cement system, the specific goals and criteria established in the engineering step can refine the laboratory focus for a more specific analysis, to reduce the number of tests needed. It is important during this step to test pilot samples as well as field blends. Any inconsistencies between the pilot testing and field blend testing can help to identify areas to improve in blending and loading operations. The information collected from this will include:

- Mixability and pumpability of cement
- Consistency of designed system vs field blend
- Gel strength development
- Test repeatability
- Fluid loss performance
 - Lower fluid loss is not always better
- Stability of system
 - If it is a foamed system, check foam stability both set and unset
- Compressive strength development
- In gas zones a more aggressive testing panel should be employed to determine gas tightness of the slurry
- Foamed slurries should also have a more aggressive testing panel to identify any stability issues

Identifying Deficits

Once all of this information has been collected, a series of recommendations can be made to the client to start on the path of improvement. Specific goals in each area are going to be different, however the general outline of these recommendations are always similar as shown below:

- Simplify where possible
 - Multiple cement systems
 - Too many additives
- Standardize service provided
 - Dictate performance
 - Do not dictate products
 - Understand high cost additive inclusion
 - Identify standard procedures and practices to implement across the field
 - Laboratory testing
 - Field operations
- Increase clarity through the process
 - Understand the reason for additives
 - Understand performance criteria for slurries
- Decrease cost when possible
 - Identify additive options and set thresholds for cost and performance according to well conditions.
 - Determine where most unanticipated costs may be found.

- Improve or maintain quality
 - Adequate cement placement
 - Long term durability of cement and incidence of backside pressure
 - Displacement practices
 - Look at methods used for counting displacement, rate of plug bump, and if completions encounter debris on cleanout.

Making Standard Recommendations

Standardization

Standardizing the cementing process is the most important recommendation in any field. With the numerous cementing companies and options available, it is vital for each member of a drilling team to be on the same page and understand why they are utilizing certain practices. The standardization process should apply to the following:

- Formations covered by each string/generally casing set points
- Casing size and hole size
- Cement performance properties
 - Free water, fluid loss, compressive strength and other special objectives
- Laboratory testing procedures
- Cementing operational procedures
 - Use of spacers, typical rate of pumping

By standardizing the above criteria, it allows the engineers to have a better understanding of how small changes affect the cementing operations and introduces a new level of clarity to the situation. This also reduces the time spent making these decisions, and allows the engineer more time to focus on any specific problems the well may be having. That being said, oftentimes, there are certain problems associated with the well that may lead to needing to alter the cementing or casing programs. This is much more easily handled when the typical casing and cement designs are well established and understood. This makes the process of altering the design or procedure easier as typically just small adjustments need to be made to account for additional performance.

Simplification

In addition with standardizing cement systems, simplification of the systems is also desirable. This will limit the amount of excess additives that are included in the system. Some specific areas to focus on are:

- Density – Density is one of the most important aspects of any cement system. Each of the Portland cements has an API density, or the density it performs best at. These densities vary, however if the target density is low, a class C cement may be the best suited for the job, if the density is very high, a class H blend will work best. By using the cement that naturally works better at a higher or lower density, it is easier to reduce the amount of

specialized lightweight or heavyweight additives. Mixing cement at the density it will work best at will reduce the need for stability aids; it will have improved compressive strength, and will mix better in the field reducing the need for frequent shutdowns. The API densities of the most commonly used oilfield cements are shown below (4).

- Class A: 15.6 ppg
 - Class C: 14.8 ppg
 - Class G: 15.8 ppg
 - Class H: 16.4 ppg
- Fluid loss – fluid loss additives are typically some of the higher cost materials in a cement system. Therefore, setting specific and intelligent fluid loss criteria is important. Typically, low fluid loss requirements are set for reasons such as a high permeable formation or to aid in gas tightness. If these are the reasons for setting the fluid loss criteria, then ensure the specific goals are met by requiring testing of the pilot and field blends. However, if gas tightness is the requirement, ensure that extra testing is performed to ensure that all gas tight criteria are met.
 - Gas mitigation – when gas risks exist, specific testing is required to understand the true gas mitigation performance of a slurry.
 - Stability – adequate suspension of solids is necessary for placement and mechanical property development

Implementation

When implementing any changes, consistency is the key to success. In this project, an engineer was available to review each cementing program and all cement tests to ensure all performance criteria was adhered to. In the field, all jobs were attended by a field advisor who could help transition the crews into the new operational procedures and ensure all were followed correctly.

The additional benefit of this method of implementation is that as problems arise, they are easily caught. Careful observation from both engineering and field perspectives makes it much easier to catch small problems before they become larger. This level of observation creates a feedback loop for continuous improvement. This will further help reduce costs and improve cementing quality.

Results

The results from this study showed that on average, the savings per well was around \$140,000. This project has lasted 15 months with very dramatic improvement near the beginning of the project.

Prior to beginning this project, the cement systems implemented were very high cost. They included many of the specialized products needed to create light weight cement resulting in expensive materials, and adding complication to materials handling operations. The first major change to the intermediate system in this project happened toward the end of

2014 and decreased the cost per barrel of slurry by about half. This cost per barrel was calculated by adding the total cost of the cement job, including materials, blending, shipping and equipment and dividing it by the number of barrels of cement pumped on the job. That helped ensure all aspects of the cement job were considered when running a cost comparison. From the end of 2014 through the first quarter of 2015, much of the time and energy spent was ensuring all service companies were meeting the specific performance criteria on every cement system pumped. This resulted in very little change during that time period. As April 2015 approached, the price per barrel of oil continued to plummet. Cost cutting was necessary in all areas of drilling including cementing. This resulted in the next drop in cost from the first quarter to the second quarter of 2015. During this time, it was imperative that the cement systems and operations were still held to the established performance criteria even with the decrease in cost. Close engineering and field oversight ensured the Over the rest of 2015, costs continued to stay low, and performance was closely tracked to ensure each cement job would be implemented correctly. In the third and fourth quarter of 2015, other service companies came into play. This meant extra time analyzing each option to ensure the cement and operational performance would meet the standards set forth. This resulted in a modest drop in price toward the very end of the year as competition between cementing companies increased. Again, using a new cementing company required that their performance be closely tracked to ensure proper implementation of the cement systems.

The value of field and engineering oversight is less concrete, but still can be recorded and monitored over time. Engineering oversight in the beginning of the project helped with redesigning a lower cost cementing system, implementing said system, and ensuring all components were used correctly. Field oversight allowed for a closer look at each job. Early in the project, the field oversight was primarily to ensure the new cement systems were implemented correctly. As the project went on, and the cement was successfully implemented, the field advisors were able to provide more value in identifying issues prior to a cement job such as incorrect cement on location, insufficient materials to complete the job, and equipment issues, all of which arose multiple times during this project. Additionally, chronic issues that arose were easier to evaluate and determine the root cause by having a person in the field studying each job closely. One of the issues was full displacement. It is difficult from the office to determine the cause when a plug does not land at the end of a job. However, a field attendant can carefully evaluate cement plugs, darts, and displacement practices to ensure that the proper measures are being taken for each cement job. During this project, it was determined that often, the dart used to pass through multiple sleeves in the horizontal section was not providing adequate separation of fluids, allowing some mud to bypass the plug during displacement resulting in no plug bump.

These costs are more difficult to assess without

speculating on time spent and cost associated with remediation. However, of the cementing operations that utilized the engineering and field oversight, intervention by either the engineering or field teams occurred in about 50% of jobs saving anywhere from \$2000-3000 for small field ticket variances to major issues such as loading out cement without adequate retarder, which, when caught, may save an entire well. Examples of problems identified during this project include:

- Invoicing/accounting mistakes
- Cement performance criteria not met
- Materials missing from location (cement, spacer, etc.)
- Incomplete cement blends (missing additives such as retarder)
- Incorrect cement blends (cement from another job)
- Poorly working equipment/ assist in troubleshooting issues
- Better mixing and pumping practices
- Poor displacement practices

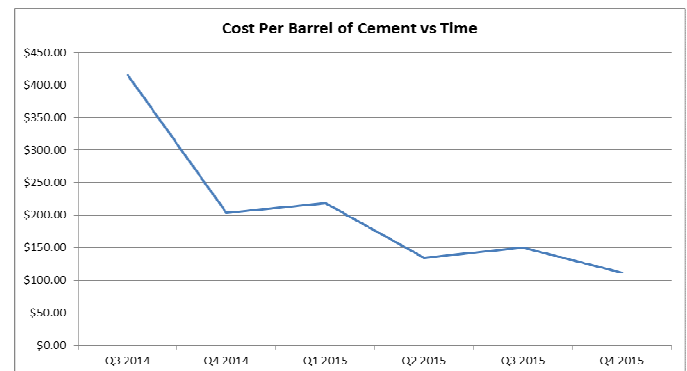


Figure 6 – Per barrel of cement cost decrease over time, shown per quarter

The next chart shows the service quality over time. The cement system performance was held strictly, not allowing for much change from job to job. Service quality must be upheld to ensure operational performance does not slip along with a decrease in cost. This was especially important toward the last half of 2015 as many workforce reductions were taking place. In this case, excellent service quality was delivered along with a decreased cost for materials and services. The service quality issues noticed most often were small issues that, alone did not pose a lot of risk to a job, but in combination with several other issues could have contributed to an issue. During this time, very few service quality incidents were observed. Events tracked include density control, equipment problems, missing paperwork, and personnel issues.

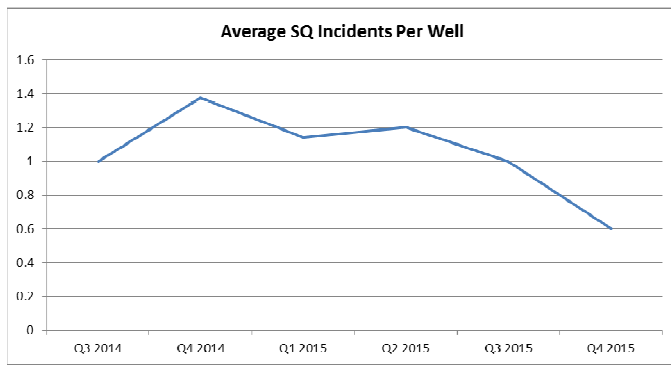


Figure 7 – Average service quality incidents per well shown per quarter

The major area of improvement for this project was increasing wellbore strength over weak zones for successful cement placement. The technology developed through the process detailed in this report allowed for successful cement placement through weak zones that could barely hold the mud column needed for drilling. The mud was typically around 9-9.5 ppg, while the cement and other fluids needed to be placed in those zones was 11.5-12ppg. Typically, cement needed to be brought to surface. Prior to this project, this would inevitably result in losses, and no cement to surface. After this project was implemented, nearly all cementing operations allowed for cement to surface and this greatly reduced the need for remedial work in the area.

Conclusions

Through this project, the major goal has always been to decrease cost without compromising the integrity of wells in the Permian basin. This required some technical work in altering the cement design and close oversight in planning and execution stages of cementing operations. With the engineering, field and laboratory oversight and expertise, this close monitoring was possible, resulting in an overall savings for the client.

While industry dictated some of this savings, the close oversight allowed for a simplified and easier transition to reducing the costs.

The major conclusions from this project are that

- Close oversight in engineering, laboratory and field operations, can result in significant savings over time.
 - Consistent oversight will allow for a feedback loop and continuous improvement as issues arise, they can be dealt with quickly and efficiently
 - The continuous improvement/feedback loop leads to further cost savings and cement performance improvement
- Standardizing the cementing designs and implementation will reduce cost and time spent analyzing each cement job.
 - Allows engineers to compare cement jobs in an “apples to apples” fashion versus having to factor in the differences between each service company’s design and operations.

- Inconsistencies are more easily recognized as performance parameters are standardized.
- Lastly, this standardization and oversight will lead to further cost savings over time as the teams involved will become more experienced with understanding cementing performance, placement and design. This will:
 - Reduce the amount of time needed to analyze cement proposals, laboratory results, and designs.

References

1. "Permian Basin Report Data." *Drilling Productivity Report*. US Energy Information Administration, 8 Feb. 2016. Web. 12 Feb. 2016.
2. Bassett, J. A., Watters, J. T., Sabins, F. L., & Febraro, A.: "Focus on Cement Design and Job Execution Increases Success for Shale Cementing Operations." SPE155757, SPE Americas Unconventional Resources Conference, Pittsburgh, June 5-7.
3. McDaniel, J., Watters, L., & Combs, N. K.: "Zonal Isolation Assurance: Relating Cement Mechanical Properties to Mechanical Durability." SPE1913405, SPE/AAPG/SEG Unconventional Resources Technology Conference, Denver, August 25-27, 2014.
4. Nelson, Erik B., Dominique Guillot. *Well Cementing*. Sugar Land: Schlumberger, 2006. Print.