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Engineered Solid Package Enables Lifting Cement in the Permian Basin

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Abstract

Cementing in the Permian basin has been historically challenging due primarily to highly depleted zones and naturally fractured formations. The problems associated with lost circulation (LC) are well known in drilling and cementing but low cement tops are especially critical due to the exposure of the casing to highly corrosive zones, besides regulatory compliance. Failing to cover such corrosive zones has proven to be expensive to the operators in terms of remediation, lost production and potential liabilities.

It is not uncommon in the Permian Basin to drill and cement wells without mud returns; the Permian lithograph (Chart-1) shows the Upper and Lower Spraberry formations, one of the main thief zones. The average and maximum fracture widths for the Upper and Lower Spraberry formations are shown in (Charts 2 and 3) with 1.35 mm as the largest fracture width for both formations. The upper Spraberry formation is located just below the San Andres formation which needs to be isolated for local regulatory compliance due to its corrosive nature. Lifting cement over the Upper Spraberry formation proved to be quite challenging.

To cement across depleted and corrosive formations it is common to pump specifically designed pills loaded with LCM ahead of the cement slurries which exhibit high viscosities, making difficult to displace them to the thief zone without channeling through.

Due to limitations in the surface equipment volume, LCM pills tend to be smaller than what is needed to fully cure the losses leading to scattered results and ultimately to discontinue its use. The effectiveness of the LCM is further reduced by the contamination suffered at the interfaces with other fluids.

These considerations led to an engineered combination of a placement technique and specifically shaped and sized materials added to cement slurries, that when used in a specific sequence have made it possible to lift cement in the Permian basin to the designed targets. The performance of the new solid package has been validated through laboratory testing, with differential pressures up to 1000psi, and cement bond logs. Other logging tools such as distributed temperature sensing (fiber optics) has been complementary in the identification of thief zones for further job optimization.

The unprecedented results obtained with the new solid/fiber package has made possible lifting cement to the depths specified by regulatory entities, besides providing long term zonal isolation and long term casing protection across the corrosive formations in the Permian basin.

Introduction

Loss Circulation

Despite the technological advancements in drilling and drilling fluid products; lost circulation is still one of the main causes of non-productive time (NPT) throughout the drilling and completion processes. Lost circulation (or lost returns) is defined as the total or partial loss of drilling fluids or cement slurries into highly permeable zones, cavernous formations, and fractures or fractures induced during drilling or cementing operations.

Lost circulation occurs by one of the two mechanisms natural losses and induced losses. Any fluids lost to a highly permeable, unconsolidated, fractured, cavernous or vugular formation are classified as natural losses. Any fluids lost to formation due to excessive induced pressure that hydraulically fractures the formation are classified as induced losses. The solution here proposed addresses primarily natural fractures.

Lost circulation has another classification based on loss rate. The first is seepage losses (1 to 10 bbl/hr) which is the lowest form of lost circulation rate and often gets confused with the volume of formation drilled out. The second is partial losses (10 to 100 bbl/hr) where in some cases drilling operations with partial losses are considered acceptable depending on the cost of the drilling fluid. The third type is severe losses (100 to 500 bbl/hr) which have to be cured in order to continue with drilling or cementing. The forth type is total losses where the return flow completely stops.

Lost circulation can be an expensive and time-consuming problem, which can ultimately lead to losing well control. Depending on the severity it can lead to major consequence for drilling, cementing, completion and work over operations. Such consequences includes but not limited to lost time, loss of mud, reduced safety, stuck drill pipe, formation damage, and lost reserves for drilling and work over operations. It can also lead to reduced annular cement coverage, casing corrosion, poor zonal isolation and receded safety in cementing operations.

Despite what the industry have today, tools that could help in the characterization of loss circulation sections such as FMI for fracture characterization and MDT for pore and frac gradients, those tools are not normally run; therefore, lost circulation treatments are still a hit and miss when treated with single pills. This is why the addition of LCM to the cement slurries has shown to be successful: there are much larger volumes, friction hierarchies are easier to manage, are very effective plugging, and develop compressive strength.

On the other hand the addition of any LCM to the cement slurry may affect the slurry and set cement properties therefore there is only a limited number of materials that can be added, which is even smaller when the addition has to be done on the fly.

Traditional LCM such as granular, lamellar and fibrous types of LCM are primarily added to drilling and cementing fluids. The concentration of the LCM is normally driven by the solid volume fraction of the base cement slurry. Excessive addition of LCM may lead to mixing issues or excessive friction pressure whereas the opposite is ineffective controlling losses.

It has also been found that solids alone, even with different shapes and sizes or ratios are not as effective as when combined with fibers.

An engineered solids package was developed and introduced in the Permian Basin to help lift cement to desired depth, thus meeting regulatory compliance and providing long term zonal isolation while protecting the casing from corrosive fluids. The solids package was used in conjunction with fibrous type of LCM in specific sequence to help achieve the plugging efficiency required which was validated and tested in lab and field applications with unprecedented success.

Engineered Solids Package with Fibers

A new approach to control losses was implemented and applied to successfully place cement across permeable and/or fractured depleted zones in the Permian basin where a variety of alternatives formerly attempted, such as the use of traditional LCM, chemical preflush, light weight cement systems and foam cement have been unsuccessful or not economically feasible.

The new approach consisted of using the cement slurry as the base fluid for the placement of the engineered LCM. The addition of the LCM to the cement slurry instead of pills ahead reduces the friction pressure and density hierarchy differential with the mud and spacer. Also the addition of the LCM to the cement slurry reduces the exposure of deposited materials to erosion form subsequent flow.

The developed LCM as shown in (Fig-1) is an interlocking network of inert fibrous materials and specific sized solids of various sizes and shapes in optimized proportions added at concentrations based on the solids volume fraction (SVF) of the cement slurry (typically 11-12.5ppg) .

Lab Validation

Lab experiments were conducted to validate the plugging efficiency of the LCM package when used for specific cement systems. The test apparatus and equipment used was a modified fluid loss cell as shown in (Fig-2). The cement slurry is mixed, and conditioned to down hole temperature before testing. Then the slurry gets poured into the cell and exerted under pressure applied from the top. The slurry baring LCM is then forced to go through a slot with a set flow area (generally 1–5mm). Multiple tests were performed against different flow areas and LCM concentrations to better evaluate the plugging efficiency.

The criterion for success consist in holding the differential pressure (up to 1000psi) without flowing through the slot.

A successful plugging efficiency test will consist of plugging a slot similar in size to the anticipated fracture width of 1.35 mm and less as shown in (charts 2 and 3). It needs to also hold a similar pressure to the maximum differential pressure across the thief zone during cementing operations. A successful lab plugging efficiency test is shown in (Fig-3).

Job Design and Execution

The engineered LCM package allows for either pre-blending with cement or it can be adjusted on the fly making it possible to place across the thief zone. Another advantage of adding the LCM to the cement slurry is to minimize the need for batch mixing equipment. The LCM chosen is inert, allowing adjusting the concentration without affecting the thickening time of cement which provides flexibility in design and field execution. The concentration of such material can be adjusted based on the solid volume fraction of the carrying fluid or the cementing slurry. It can be applied in drilling and cementing operations in loss circulation environments where fractured, highly permeable, depleted, and/or low pressured formations are present.

The engineered solids package technology can be mixed with cement, spacer fluids and water-based muds. It disperses easily in fluids and does not require special equipment when lab testing the cement slurry because of its inert nature. The solids part of it can be blended with the cement while the fibers can be added to cement while in its slurry phase.

Field Applications

The benefits of the approach above mentioned has been applied in the Permian in more than 100 cement jobs in a span of less than 9 months with unprecedented results. The success rate to date has been over 90% in mitigating losses and over 70% of the wells in achieving the required top of cement. The technology was applied for major operating companies currently drilling in the Permian. Apache Corporation was one of the first operating companies to adopt this approach and managed to achieve the required cement tops in two of their fields in the Permian. While drilling for the production casing on vertical wells in Field-A partial lost circulation were encountered ranging from 30 to 60 bbls/hr. The lost circulation zone was identified to be an unconsolidated weak formation that could have induced fractures as well. Losses were not totally cured with traditional LCM and the decision was made to continue drilling to the final designed total depth (TD) with partial losses. During the cementing operations lost circulation would increase due to extra differential pressure exerted on the lost circulation zone by additional ECD and later the placement of cement slurries. As a result the top of cement was not achieved. In the second field Field-B the production casing was cemented in 2 stages to mitigate losses and to help achieve the required top of cement. On some occasions the multistage tool would fail and result in unplanned cement left in pipe. The solids/fiber technology was applied to the cement slurry in both fields with successful results as illustrated in the following two case histories.

Case History 1 (Apache Corporation)

Wells drilled in Field-A in the Permian normally experience present losses between 30 to 60 bbls/hr . Although the use of conventional LCM mitigates losses during drilling; Data showed that it does not always withstand placement pressures of cement which can negatively affect the bonding quality and achieving the required TOC.

Design

The solids/fiber package approach was selected to mitigate lost circulation and to get the required top of cement. Based on the observed lost circulation zone 50 bbls of the lead cement was treated with the solid/fiber combination to be circulated across the lost circulation zone with fluid sequence as shown in (Table-1). The strategy of the design is to have the LCM curing the loosing section before trying to lift cement in the annulus. The decision to spot the LCM in the first 50 bbls of lead slurry was also based on the fact that the first 50 bbls would be circulated across the entire section to be cemented which can also plug other thief zones along the way as cement is lifted.

Execution

The cementing operation was executed per design. The pumping rates where maintained at 5 (bbl/min) throughout cement placement while minimizing the ECD and maximizing the contact time of the LCM to effectively plug the losing zones.

Circulation was maintained throughout the job and the final lift pressure suggested the TOC was just as per design (Fig-5).

Evaluation

Top of cement was achieved as shown in (Fig-4) with excellent bonding to casing and formation throughout the majority of the production string.

Case History 2 (Apache Corporation)

Wells in Field-B were planned to have production casing cemented in two stages. Leveraging on the results from Field A the cement treatments were reduced to a single stage rather than two, which also yielded to well-known benefits.

Design

The solids/fiber package approach was selected to eliminate the multistage tool that had been needed in offset wells to lift cement to the required depth. Based on the observed lost circulation zones 67 bbl total of the lead cement was treated with the solid/fiber technology circulated across the lost circulation zones. The first part of the lead was treated with 30 bbls then followed by 30 bbls of lead cement as a buffer, and then 37 bbls of cement treated with LCM before switching to tail cement as shown in (Table-2).

Execution

The cementing operation was executed per design with pumping rates of 5 (bbl/min) for cement and displacement slowing down for the last few barrels for bumping the top cement plug. Circulation was maintained through the job and the final lift pressure suggested the top of cement was just as per design (Fig-7).

Evaluation

Top of cement was achieved as shown in (Fig-6) with good bonding to casing and formation throughout the majority of the production string.

Conclusions

- The experience in the Permian Basin has shown that low density fluids alone do not lead to the target top of cement.
- Strategic addition of LCM engineered to the cement slurry has proven to be highly effective in over 100 jobs.
- It is possible to cement in single stages once the performance of the LCM has been optimized
- The addition of LCM to spacer is also a good practice as long as the placement is well understood.

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Nomenclature

BHA = *Bottomhole assembly*
LCM =*Lost Circulation Material*
NPT =*Nonproductive time*
bbl =*Barrels*
SVF = *Solids volume fraction*
hr = *hour*
min =*Minuet*
TOC = *Top of cement*
TD =*Total depth*
ECD =*Equivalent Circulating Density*

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Tables

Fluid Sequence			
Fluid Name	Volume (bbl)	Density lb/gal	Top of Fluid ft
Fresh Water	20	8.32	2206
Lead Slurry	10	11.5	2789
Lead slurry with LCM Package	50	11.5	3080.6
Lead Slurry	127.3	11.5	4347.6
Tail Slurry	133.4	13.2	7521
Displacement fluid	249.2	8.32	0

Table-1 Fluids Sequence for Case History 1

Fluid Sequence			
Fluid Name	Volume (bbl)	Density lb/gal	Top of Fluid ft
Fresh Water	20	8.32	3576
Lead Slurry	10	11.5	4209.6
Lead slurry with LCM Package	30	11.5	4526.4
Lead Slurry	30	11.5	5440.1
Lead slurry with LCM Package	37	11.5	6177.3
Tail Slurry	120	13.2	7093.7
Displacement fluid	261.5	8.32	0

Table-2 Fluids Sequence for Case History 2

Charts

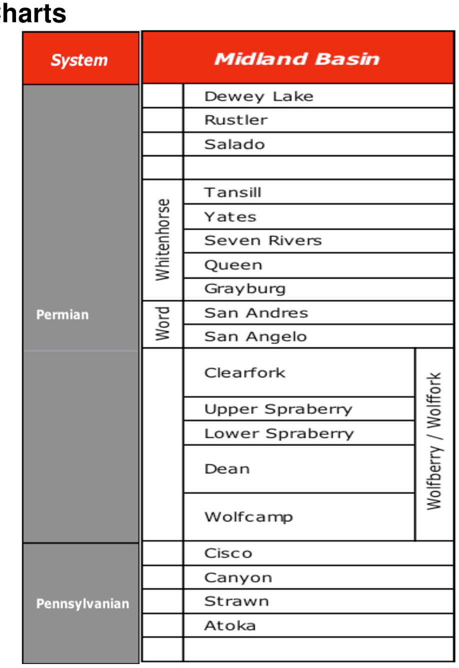

Chart-1 Permian Basin Lithology

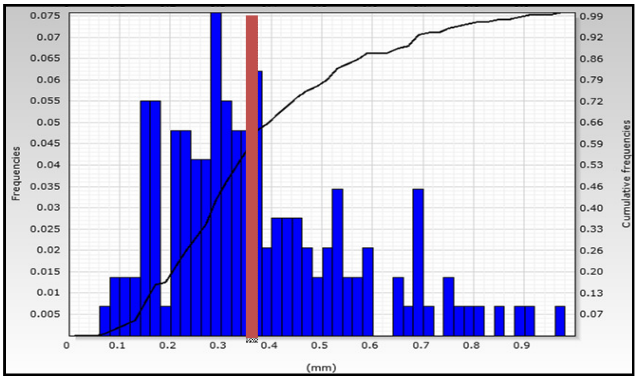

Chart-2 Upper Spraberry Fracture Sizes (Avg 0.39 mm, and 1.35 mm Max) Sandstone/Sandy Dolomite

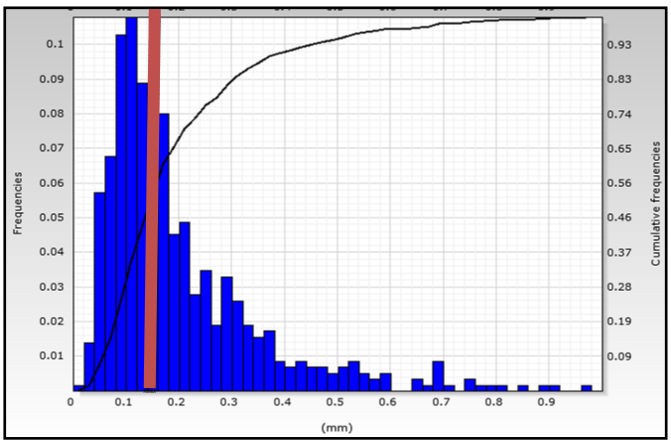

Chart-3 Lower Spraberry Fracture Sizes (Avg 0.21 mm, and 1.35 mm Max) Shale

Figures

Fig-1 Engineered Solids and Fibers Package

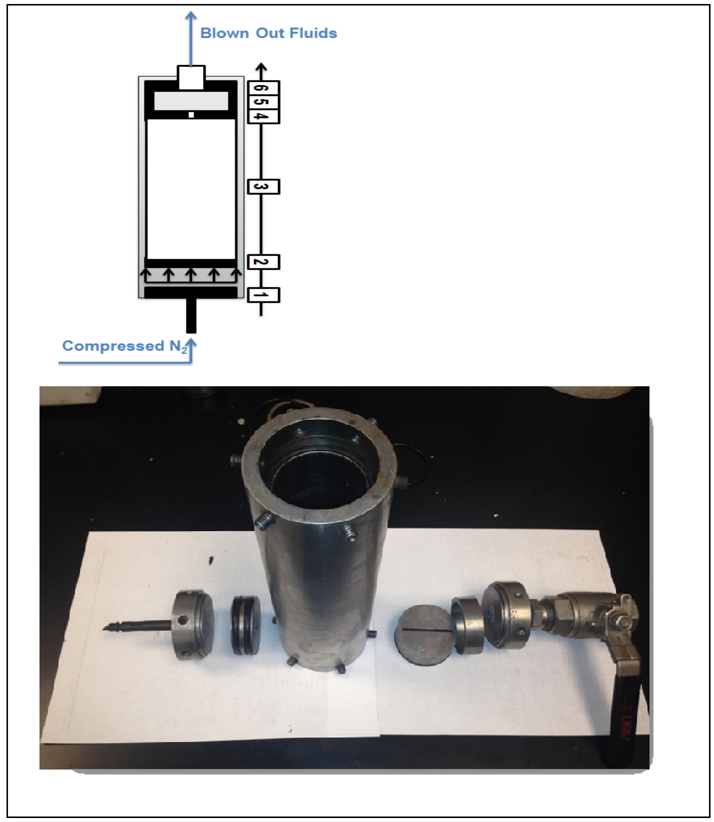

Fig-2 Modified Fluid Loss Cell Testing Apparatus

Fig-3 Successful plugging efficiency test

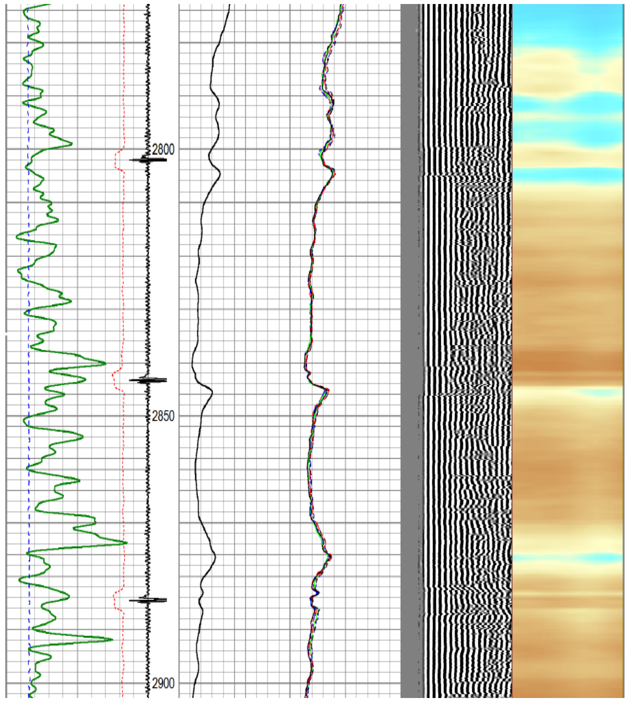

Fig-4 Bond log for Case History 1 in Field-A with estimated TOC at 2,800 ft

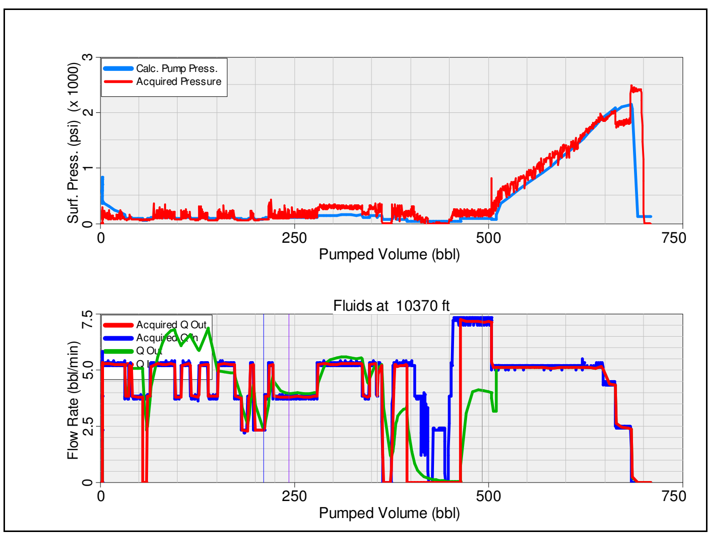

Fig-5 Lifting pressure chart, Pressure match between calculated and acquired pressures for Case History 1

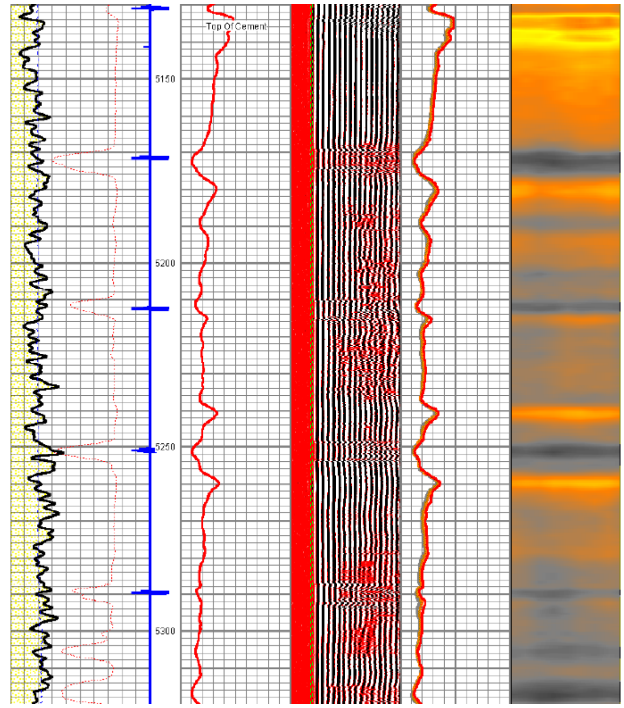

Fig-6 Bond log for Case History 2 in Field-B with TOC at 5,100 ft

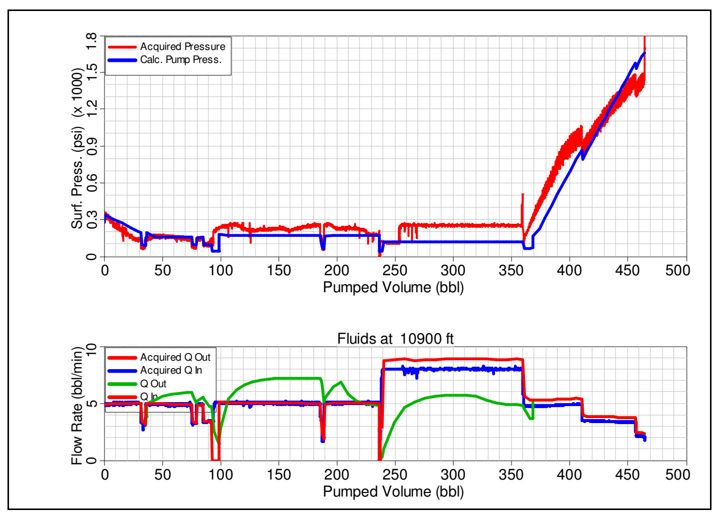

Fig-7 Lifting pressure chart, Pressure match between calculated and acquired pressures for Case History 2