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Unconventional Reservoir Depletion Generates the Need for a Dissolvable Cased Hole Sealant

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Abstract

In unconventional reservoirs, infill drilling and field development has created a unique relationship between parent and child wells that is often accompanied by fracture network connectivity and depleted zones. These depleted zones not only affect well production, but they also create an increasing number of challenges in cased hole operations during frac plug drill-outs and workovers. During these operations, an inability to maintain full circulation and effectively remove wellbore debris can cause more costly issues such as stuck pipe and formation damage. As operators continue to develop their acreage, these problems will only continue to become more common and severe.

Traditionally, the use of nitrogen or a more robust, permanent sealant have been used to seal off depleted perforations. Both costly and unreliable, these traditional options also impart a significant amount of formation damage that further restricts production.

This paper discusses the development of a removeable sealant specifically designed to remediate lost circulation in low-pressure perforations. In addition, the paper discusses a newly designed testing apparatus that effectively simulates a sealant's application, removal, and a demonstration of return permeability of the reservoir in a laboratory setting. The high-pressure cell can be loaded with a variety of proppant beds, it allows for both forward and reverse flow, and it demonstrates the effect of a solvent flush across the face of the filter cake without disturbing the proppant bed, similar to the expected downhole flow pattern. Case studies in several North American basins will also be presented and discussed to show field applications.

Introduction

In unconventional reservoir development, oil and gas operators will typically drill, complete, and produce a single well on a portion of their leased acreage. This is often done due to contractual obligations and allows them to hold onto this leased acreage as well as develop an understanding of their expected production in that area. At a later time, they will return to the pad to develop the remainder of the acreage by drilling and completing additional "child" wells offset of the original "parent" well. However, the reservoir conditions while developing the child wells are no longer the same due to the reservoir depletion and overall stress changes in the formation caused by the production of the parent well.

The changes in the reservoir can be seen throughout each phase of the well development including increased mud losses while drilling, frac hits visible in parent wells while stimulating the child well, and an overall lower production of the newly completed well. While stimulating the well, the evidence of frac hits in the offset parent well is a direct indicator of the stimulation fluid and proppant penetrating a depleted portion of the reservoir and connecting to the offset fracture network (Teran, Fontenot, Khodabakhshnejad 2019). In fact, studies have shown that the hydraulic fractures from these "child" wells not only grow preferentially towards the depleted "parent" well but also that it can reduce the extension into the virgin rock by more than 60% (Defeu et al. 2018). This in turn can cause isolated perforation intervals within the child well to be low-pressure and depleted.

Industry experts continue to explore this relationship between parent and child wells and how to mitigate the effects. Although the ultimate concern is a lower production and a loss of recoverable reserves, these depleted intervals can cause several operational consequences prior to even putting the well on production. These depleted intervals can cause a loss in circulation when drilling out frac plugs and attempting to clean the wellbore free of debris. Ultimately, the inability to maintain an adequate circulation rate through the perforated interval will cause delayed operations, loss of drill out fluid and chemicals into the reservoir, and potentially a stuck work string due to debris buildup around the plug mill. Therefore, in these operations it is imperative to deal with these depleted intervals both effectively and efficiently to minimize cost and get the well on production as soon as possible.

As these unconventional reservoirs continue to mature and operators continue to develop their acreage, fracture network connectivity will only increase leading to more and more low-pressure and depleted perforation intervals.

The Plug Drill Out Operation

Prior to putting the well on production, the operator must run in and mill out any frac plugs set during completions all the while circulating out any debris. The typical frac plug is made of a rubber composite material with a few metal or ceramic pieces. Figure 1 below shows a composite frac plug as well as the same frac plug after being drilled up.

Figure 1: Composite Frac Plug and the Plug Debris after Drill Out (Bruseth and Shaffer 2020)

To remove the plug debris from the wellbore, the operator must rely on one of two mechanisms: viscosity or velocity. By utilizing a fluid viscosifier, the operator can send viscous sweeps to collect, suspend, and transport the plug debris to surface. Alternatively, by maintaining a higher pump rate the operator can utilize turbulent flow in the annulus to successfully carry the debris. Although both methods each have their respective advantages and disadvantages, they both rely on the ability to maintain an adequate circulation rate to facilitate the transportation of wellbore debris to surface.

Current Method of Sealants

Although previously not as common, encountering low-pressure perforations while drilling out plugs is not a brand-new issue in the oil and gas industry. Operators have used several different methods to help control these losses and maintain circulation during drill outs. These methods and their potential benefits as well as drawbacks are examined below.

Nitrogen

Nitrogen has long been a staple in the oil and gas industry due to its inert qualities and abundance. For that reason, many operators will elect to have a nitrogen unit on site during plug drill outs in the event they do encounter a low-pressure zone. By pumping nitrogen, they can lighten the fluid column thus reducing the hydrostatic pressure on the perforations and allowing them to regain circulation. However, one of the major draw backs is that the low-pressure zone is not actually being sealed off. Therefore, they will have to continue to pump nitrogen from the time the zone is encountered until the entire well has been cleaned out. This in turn can lead to an exorbitant amount of nitrogen used in addition to the standby cost of having units and personnel on site for precautionary measures. With the average lateral length continuing to increase, it is not uncommon to use several million cubic feet of nitrogen on a drill out. These high volumes, in addition to the associated rental and service fees, can carry a cost in excess of $500,000 per well; leading to substantial AFE overages.

Lost Circulation Materials (LCM)

Alternatively, various types of granular, fibrous, and/or polymer lost circulation materials and diverters are deployed to seal off the trouble zone prior to proceeding to the next plug. Once sealed and full returns are established, the operator can then resume normal operations and proceed with the drill out as planned. There is a wide variety of products on the market including sized salt, ground calcareous material, granular graphite, mineral fibers, and polymers. As an operator there are several considerations when selecting a lost circulation material including compatibility with the fluid system and downhole tools, wellbore temperatures, and the possibility of formation damage from particles left behind in formation.

The first consideration is the compatibility with the fluid system and internal flow restrictions of the downhole tools. Some sealants on the market require specific fluid systems to effectively seal off the perforation and remain intact. For example, if running sized salt, the remaining lateral will have to be drilled with a saturated brine to prevent the salt from prematurely dissolving. Additionally, not all sealants are compatible with the various chemicals in a typical drill out fluid system. An adverse reaction could cause rapid gelation potentially causing tool plugging and increased circulation pressures. Even if there is no adverse reaction, it is also important to understand the particle size of the material to be sure it can safely pass through the downhole tools. For example, large amounts of a course fiber may effectively seal off a set of perforations but there is also a high risk of plugging off the work string prior to exiting the mill bit.

One often discussed drawback of using currently available lost circulation materials is the long-term effects it may have on production. Although the goal of the LCM is to shut off the set of perforations taking fluid, the alternative effect is that when the well is put on production the sealant will also restrict production from the zone. Theoretically, the LCM particles only travel to the low-pressure zone, but it is also highly likely it interacts with other exposed zones, possibly reducing permeability.

To counteract this, using a dissolvable material helps remove the debris left across the formation and returns the wellbore to its original post-frac permeability. One of the most common base materials used in degradable diverters is a polylactic acid (PLA) which degrades over time when exposed to water and heat. There is a wide variance in these polymers as many can be designed to degrade in temperatures from 120°F - 300°F over the course of a few hours or up to several weeks (Cookson 2020). The upside of this is that over time the polymers should degrade and the wellbore will naturally return to its original state without intervention. However, an unexpected variance in wellbore temperature, product manufacturing, or the correct PLA selection can lead to an inconsistent and uncontrollable degradation of the polymer. From a purely operational standpoint, the variability in degradation time can disrupt an operation as a premature degradation can open up a set of low-pressure perforations while still attempting to drill out the remaining lateral over the course of several days. On the other hand, if a tool were to get stuck from a build up of the diverter around the mill, operations would have to come to a halt until enough time had passed for the PLA to dissolve and be jarred free. Additionally, the lack of particle size range and differentiation of materials can cause an inconsistent and unreliable seal at the perforation. And finally, it has also been proposed that if a single set of perforations is acting as a thief zone, some operators may wish to not have these perforations open right away as to not steal production from the other zones.

A Single Sack Acid-Soluble Sealant (SSASS)

As previously mentioned, there is a variety of different materials and techniques currently used in the oil and gas industry to remediate lost circulation during frac plug drill outs and workover operations. Each technique has some positive attributes but also carry some noteworthy drawbacks as outlined above. To further technological advancement in this area, the goal was to develop a lost circulation solution that expands upon the desirable qualities of alternative solutions and be able to deliver it to the operator in a single sack, cost effective solution. The sealant will effectively close off low-pressure zones while minimizing the overall impact on the operation. The following sections discuss the development, laboratory testing, and field applications of what is believed to be the simplest and most effective solution in the market today.

Broad Scope of Development

The first goal of development was to minimize the actual impact on operations and eliminate the need for additional equipment or personnel on location. With that in mind, the use of nitrogen or any sort of specialty chemical that required additional equipment was quickly eliminated from the process. Next, the product had to be effective in a broad scope of completion designs and wellbore conditions. Depending upon the basin, the wellbore temperature, pressure, and frac sand proppant loading can vary significantly. Therefore, the product was designed with a broad range of particle shapes, sizes, and types while all taking into consideration the ability to flow through downhole tools at high concentrations. Lastly, with the ever-present risk of damaging the formation, the sealant had to be highly soluble in acid to eliminate any residual particles and return full formation permeability after the job was complete. During the development phase, a specific testing apparatus was created to have the ability to test all of the above qualities of the proposed SSASS.

Laboratory Testing

Outlined in Figure 2 is a model of the testing apparatus that was constructed during the development of the sealant.

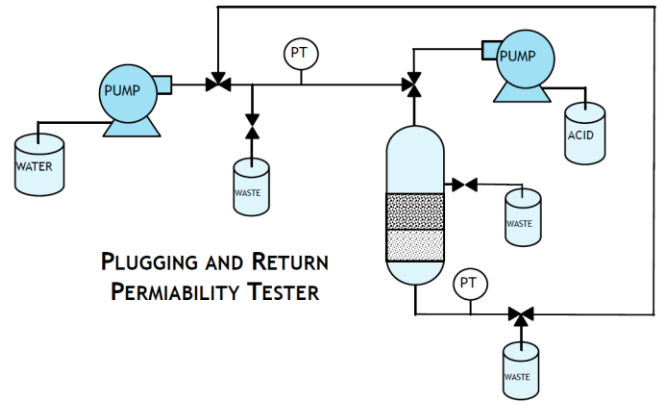

Figure 2: Diagram of Testing Apparatus Used in Development of SSASS

The apparatus was constructed to utilize a high-pressure pump capable of pumping at a constant rate through a high-pressure cell. The cell can then be loaded with a variety of different proppants to effectively simulate a near wellbore post-frac proppant bed. Water was then pumped forward and reverse through the proppant bed to determine the baseline frictional pressures of the system. Next, a pill was created by taking a 50 sec/qt base fluid with 40 ppb of the sealant and was then loaded into the cell, above the proppant bed. Pressure was then applied above the pill at a constant rate until the desired pump pressure was achieved; in which that pressure was held for 1 hour. After the 1 hour, flow was reversed from below the proppant bed to determine if it was possible to backflow through the LCM pill above. Next, a secondary valve was opened, and an acid flush was pumped across the face of the proppant bed for 30 minutes to accurately simulate the pumping of an acid flush across the face of a perforation. At the end of the flush, water was once again pumped forward and reverse through the proppant bed to determine any increases in the baseline frictional pressure.

This apparatus and the above outlined procedure were used to test hundreds of combinations of materials at varying concentrations within the blend. As mentioned, the primary objective was to ensure the sealant created an effective seal across the proppant bed that prevented continual fluid loss over time, and it had to be both acid soluble and allow for a full return of permeability to the proppant pack. Table 1 below shows several of the higher performing combinations as well as the final performance of the SSASS.

Table 1: Sealing of Proppant Bed in Simulated Perforation

Sample Name	1 hr Fluid Loss (mL)	Acid Solubility	Return Permeability
JF003-54-8	23	Fail	Fail
JF003-54-9	33	Fail	Fail
JF003-64-1	79	Pass	Pass
JF003-64-2	65	Pass	Pass
JF003-64-3	20	Pass	Fail
JF003-64-3	19	Pass	Fail
JF003-64-5 (SSASS)	17	Pass	Pass

A graphical representation of these pressures and stages of the procedure can be seen below in Figure 3 for the SSASS.

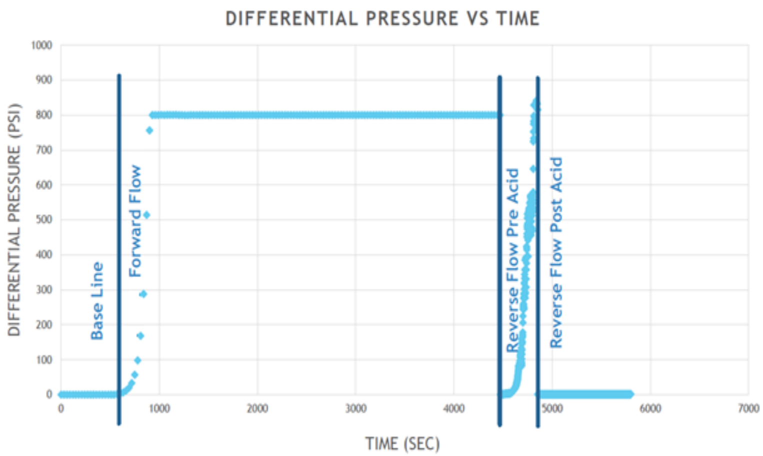

Figure 3: Differential Pressure vs Time Final SSASS Development

The results of the testing show that the desired pressure was achieved and held for 1 hour with minimal fluid loss. The milliliters of fluid loss that were displayed in Table 1 can largely be attributed to spurt loss and once sealed, the fluid loss over that hour was negligible as seen by the steady pressure profile in Figure 3. Prior to the acid treatment, back flow through the proppant bed was not achieved showing the sealant held when exposed to both forward and reverse flow. After the acid treatment, reverse flow was achieved, and it was in line with the base line pressure prior to any treatment; thus demonstrating a full return of permeability to the proppant bed.

Field Applications

Case History #1-Permian Basin-Plug Drill Out

A Permian operator traditionally encounters severe lost circulation while drilling out–frac plugs in the Midland Basin. It is not uncommon to encounter complete loss of returns during drill-out operations on wells drilled in the Jo-Mill and Lower Spraberry targets. To mitigate the losses, an aphron-based fluid system was utilized while deploying a variety of different lost circulation materials; with inconsistent and unacceptable results. After extensive lab testing of the SSASS, the lab determined the plugging capabilities, solubility in acid, and compatibility with their current fluid system outperformed all of the other products they had tested and a decision was made to trial it in the field. After drilling out the kill plug and the first frac plug, the well went on a vacuum. The bit was positioned just above the next plug and a 10 bbl sweep was pumped containing 40 ppb of the SSASS. After exiting the bit and moving across the exposed set of perforations, 80% returns were established. The operator decided they wanted to regain full returns before proceeding to the next plug and decided to pump another 10 bbl sweep successfully regaining full returns. Satisfied with the effectiveness and ease of application; the operator continued to use the product across eight different wells in the area that had approximately 55 plugs in each. The average cost of product across all eight wells was $24,780/ well; a significant decrease compared to previous options. In addition, the ability to seal off the losses and effectively regain circulation allowed the operator to cut off roughly 2-3 days/well on drill outs on this pad.

Case History #2-Bakken-ReFrac Plug Drill Out

An operator had conducted a refrac on one of their existing wells in Dunn County, North Dakota in which they cemented a 3-1/2” liner inside their existing 4-1/2” production casing. While milling out the plugs, low wellhead pressure in conjunction with semi-mobile plugs made it difficult to bring the plug debris to surface; resulting in 9 plugs (17,837’ – 19,285’) being left behind. With the mill positioned at 11,792 ft a 40 bbl 20 ppb SSASS pill was picked up and circulated with fresh water while observing no noticeable changes in pressure or returns at surface. The SSASS concentration was then adjusted to 40 ppb and a 30 bbl pill was circulated with the mill positioned at 12,000 ft resulting in a 50% gain in returns at surface. The operator then ran in and tagged the first plug while maintaining a 5 bbl - 25 ppb SSASS sweep regimen to combat any diminish in returns. Once the last plug was milled up a final 5 bbl sweep was pumped and at this point full returns were established. The operator was able to reach TD and circulate four bottoms up with full returns and effectively clean out the well before tripping.

Conclusion

An increase in technological efficiency and reservoir familiarity has led to a rapid increase in the development of unconventional reservoirs. This development has and will continue to alter reservoir characteristics and lead to new challenges in well development and production. Although a lot is still unknown about the relationship between parent and child wells, one tangible consequence is the connection of fracture networks from offset wells that have led to low pressure production zones after completing the well. The ability to effectively deal with these zones by sealing them off is imperative to maintain an efficient operation without drastically altering the budget. Although there are multiple options on the market, the single sack acid soluble sealant with a broad particle size distribution can effectively seal off low pressure perforations at a relatively minimal cost without the need for additional equipment or personnel. In addition, the option to completely remove the sealant with an acid flush if desired gives the operator the ability to return the wellbore to the original post-frac permeability. The industry is just starting to see the effects of the full-scale development of unconventional reservoirs, and it is fully expected these issues will only continue to grow over time.

Conclusions

- Current industry practices with pad development in unconventional reservoirs has led to an increase in low-pressure perforation intervals through fracture network connectivity.
- Effectively sealing these low-pressure zones during plug drill out and workover operations is imperative to effectively clean debris from the wellbore prior to production.
- Conventional methods on the market such as nitrogen, graphitic lost circulation material, and polylactic acids have shown to be operationally challenging, ineffective, and costly.
- A Single Sack Acid Soluble Sealant allows operators to create an effective seal with minimal operational impact and to mitigate any potential long term formation damage.

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