AADE-24-FTCE-070

Shear Activated Cross-linking Lost Circulation Pill

Jeremy Smith, Lynn Foster, Josh Sheldon, Katherine Price Hoelscher, Steve Young, Clint Falgout, and Joseph Powell, SLB

Abstract

When drilling fluid is lost to vugular formations, it can lead to a variety of issues, including increased drilling costs, wellbore instability, and safety concerns. To address this issue, a specialized shear activated cross-linking lost circulation pill was designed.

In this paper we are introducing an innovative shear-activated cross-linking lost circulation pill (LCP) designed to address vugular losses and cut down on drilling fluid expenses. The unique design of the LCP ensures it remains in a liquid state until subject to shearing, resulting in time-saving benefits for rig operations. The feature enables uninterrupted pumping through the existing bottom hole assembly (BHA), eliminating the need for costly trips out of hole to replace BHA. This application fosters a swift and efficient resumptions of drilling operations. The shear activated cross-linking lost circulation pill maintains a low oil-to-water ratio, initially behaving as an oil-continuous phase until it encounters shearing through a nozzle. Upon shearing, it seamlessly transitions into a water-continuous phase, initiating the cross-linking process, and reaches its full gel strength potential within minutes. The system's stability was evaluated through thermal aging up to 250°F and an unconfined compressive strength test was conducted using a load frame analyzer to assess the structural gel strength. This technology was evaluated for universal applications and confirmed to work in variety of oils without compromising gel strength.

The shear activated cross-linking lost circulation pill solution is conveniently packaged in a single kit, facilitating simple field deployment when faced with losses. The palletized kit includes all the necessary chemicals for building one 40 barrel (bbl) LCP. Additional features include is its ability to be mixed on location with a cement batch mixer streamlining the mixing procedure.

Introduction

The drilling of oil and gas involve a complex interplay of geological challenges and engineering solutions. One pervasive challenge faced by the industry is the loss of drilling fluid to vugular formations, a predicament that gives rise to numerous issues with far-reaching consequences; from escalating drilling costs to compromising wellbore stability and raising safety concerns.

Recognizing this challenge, we are developing innovative solutions that can effectively mitigate the adverse effects of lost circulation. A specialized shear-activated cross-linking lost circulation pill was designed. This innovative formulation not only addresses the immediate concerns associated with fluid loss but also seeks to evolve the approach to wellbore stability and drilling efficiency.

What sets the shear activated cross-linking pill apart is its unique ability to be easily mixed on location, offering a “near” real-time and responsive solution to the specific conditions encountered during drilling operations. The procedure includes pumping the pill downhole through the current BHA exactly where the losses occur, where shearing from the drill bit rapidly triggers a cross-linked gel formation. In contrast, other LCPs may necessitate a BHA change or rely on triggers such as temperature or chemical catalysts. This rapid response mechanism ensures a swift and effective sealing of the vugular formations, preventing further fluid loss and its cascading consequences.

This paper delves into the details of the design, development, and application of this shear-activated cross-linking lost circulation pill. It discusses its formulation, deployment, and performance, shedding light on the potential impact of this solution.

Problem

The drilling industry grapples with a persistent and costly challenge of lost circulation, consuming significant time and resources while posing a substantial threat to operational efficiency. The issue stems from prevalent vugular loss zones with 'fracture' sizes ranging from 5mm to ½ meter, rendering traditional lost circulation material (LCM) solutions ineffective. The challenge intensifies in shallower sections with low formation temperatures, where conventional thermal-activated products prove ineffective and potentially hazardous. As drilling operations extend to greater depths, the challenge further escalates with rising temperatures.

Additionally, conventional lost circulation pills rely on external agents to address the issue, with some formulations, like a blend of borate and biopolymers, achieving cross-linking through pH adjustments. Others, utilizing a combination of polymers and a cross-linker, rely on activation through time and temperature. These dynamics highlight the need for innovative solutions tailored to the intricate landscape of drilling in vugular formations.

Discussion and Results

The development of a shear-activated cross-linking (SAC) lost circulation pill is based on reversible emulsion concepts. Initially, the pill takes the form of a high internal phase, oil-based emulsion, constituting 20 percent of the emulsion by volume in the oil phase and 80 percent in the water phase stabilized by carefully chosen emulsifier package that is designed to be responsive to shear. Other components, such as solid polymer, lime, and emulsifier are embedded within the oil phase during the initial pill construction. Additives are designed to be water-reactive but are protected within the oil phase prior to spotting the pill. Once the pill is placed, high shear of the bit nozzles changes the emulsion structure and exposes the additives to the water phase which causes the pill to activate and form stronger gels.

Key feature of the system is to maintain reactive components withing the oil phase to prevent premature setting and allow pill placement. At the same time, stability of the system needs to be carefully balanced to allow the pill to set. An emulsion that lacks stability may lead to premature setting, while an overly stable emulsion may hinder the contact of additives with the water phase, preventing the pill from setting. This involves designing procedures and equipment to sustain oil wettability for all pill components except water. The preservation of an oil external phase is crucial, preventing the activation of the solid polymer and its subsequent hydration and crosslinking. This approach not only enables pumpability but also establishes the ideal rheology to prevent settling of water-based droplets or other materials within the formulation. The resultant pill exhibits remarkable stability, maintaining its emulsion integrity against creaming or coalescence for up to 24 hours when mixed and stored. Therefore, the pill can be mixed ahead of the anticipated losses on a contingency basis.

When the need arises, the pill can be efficiently pumped downhole through the drill string. The high shear encountered during the pumping process through the drill bit prompts a transformation of the emulsion to a water-continuous state. This, in turn, activates the polymer's hydration, initiating crosslinking and the formation of a solid pill. Proper cross-linker chemistry design enhances stability, enabling the sheared material to withstand temperatures up to 250°F. Without these supplementary crosslinkers, the sheared material demonstrates resilience to temperatures upwards of 175°F. Aging studies of the shear activated cross-linked LCP reveal that the oil phase remains encapsulated within the solid pill, mitigating environmental concerns associated with potential oil leaching. This formulation addresses a commitment to environmental responsibility by averting the risk of oil contamination in water zones or from potential hazardous spills.

Initially the shear activated cross-linking pill was developed with diesel as the oil phase due to a specific geographical region request. To address requirements of different regions across the globe, the SAC pill can be formulated using different oils. Following extensive development efforts, an alternative base oil was ultimately chosen, exhibiting comparable strength performance for a more robust and environmentally responsible solution.

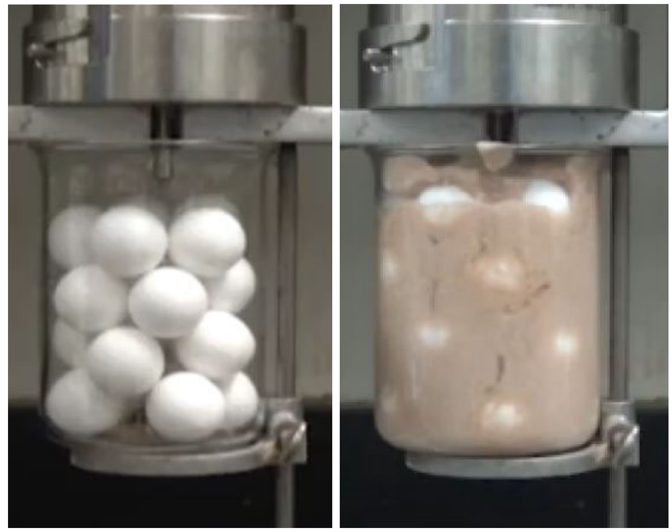

Figure 1 Shear activated cross-linking lost circulation pill showing the ability to fill vugular formations after being sheared through nozzle.

Furthermore, the evaluation of Unconfined Compressive Strength (UCS) played a crucial role in assessing the strength properties of a shear activated cross-linking pull relative to other cross-linking LCMs with similar characteristics. Post-shearing, samples measuring approximately 30mm in diameter and 60mm in length, depicted in Figure 2, were carefully prepared for each test. Then a load frame was employed to record the relationship between the force applied and the corresponding distance during testing. Figure 3 visually captures the pill during this evaluation process.

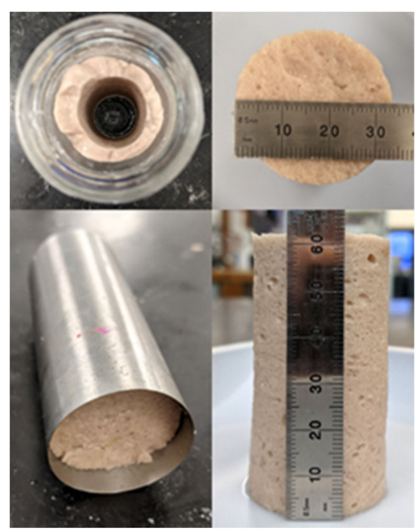

Figure 2 Shear activated cross-linking LCP sample being prepared for UCS testing.

Figure 3 Shear activated cross-linking LCP during UCS testing.

Figure 4 provides a comprehensive overview of the UCS results for the shear activated cross-linking LCP, prepared in two distinct base fluids, alongside the results for FORM-A-PLUG II and FORM-A-SET AK. FORM-A-PLUG II, achieves cross-linking through pH adjustments, while FORM-A-SET AK relies on a blend and is activated by time and temperature. The graph illustrates that both formulations of shear activated cross-linking (SAC) pill with diesel and paraffin oils exhibit a compressive strength approximately twice as high as the existing technologies. Noteworthy is the fact that the SAC pills accomplish this strength with a reduced set time compared to FORM-A-PLUG II, and it achieves this without the need for precise temperature-adjusted formulations as required by FORM-A-SET AK. The UCS testing results highlight the enhanced performance and efficiency of the SAC LCP, positioning it as a promising advancement in the field of cross-linking LCMs.

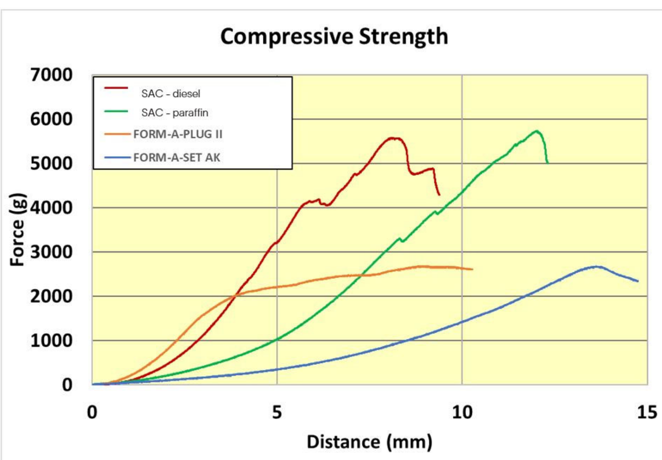

Figure 4 UCS results for SAC LCP with diesel and paraffin vs other cross-linking LCMs

From Lab to Large Scale and Field Readiness

The emulsion's strength plays a pivotal role in determining the performance of the pill, with the choice of mixing equipment exerting a significant influence on this important factor. In the initial stages of laboratory testing, it became evident that a low RPM, high surface area mixing paddle (refer to Figure 5 below) was essential for constructing the pill effectively. Using a standard overhead or blender-style mixer posed challenges, as it generated excessive shear in localized areas, leading to premature activation of the pill. Conversely, when the mixer was set to a slow speed to prevent premature activation, there was insufficient mixing energy to effectively emulsify the water. Striking the right balance in mixer design and operation proved imperative in achieving optimal emulsion strength for the desired performance of the shear-activated cross-linked loss circulation pill.

Figure 5 Lab scale mixing in jar with high surface area mixer.

Progressing to the next phase of pill mixing evaluation involved upscaling from 1 lab barrel (350mL) to 5 true barrels (210 gallons). To accomplish this, a medium-scale mixing flow loop was constructed. An IBC Tote was integrated with a centrifugal pump, induction hopper, and an agitator, as depicted in Figure 6. The design of this equipment, in terms of geometry and proportions, aimed to replicate a standard mud pit commonly found on various rigs. The intention was to create equipment readily available on a larger number of rigs capable of building the pill. However, similar challenges were observed in the medium-scale setup when using an overhead mixer. The agitator either triggered premature activation of the pill during mixing or proved insufficient in keeping solids suspended and emulsifying the water. This observation was further validated through a full-scale field mix, yielding identical outcomes to those observed in the lab and medium-scale evaluations.

Figure 6 Mixing tote for medium scale mixing with centrifugal pump,

hopper, and agitator.

After analyzing successful lab practices, it became evident that the mixing tank's size needed to be significantly smaller in proportion to the paddle dimensions and should adopt a rounded shape to prevent solids from accumulating in the corners' dead zones. This observation led us to explore the use of a cement batch mixer. Thus, a second mixing flow loop was constructed, featuring a 50-gallon cylindrical tank with a conical bottom, as illustrated in Figure 7. While utilizing the same centrifugal pump and hopper, new agitator paddles were specifically manufactured to mimic the size and shape of the paddles found in a cement batch mixer, as depicted in Figure 8. Applying this replicated mixing equipment ensures the consistent preparation of a 1-barrel pill with behavior similar to what is observed at the laboratory scale. All subsequent development stages were carried out using this equipment, and the insights gained, along with the procedures followed, were distilled into the creation of comprehensive Engineering Guidelines for the product.

Figure 7 Large-scale batch mixer to replicate field conditions.

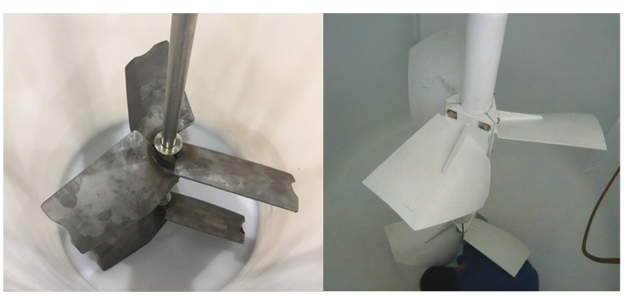

Figure 8 Agitators were manufactured to replicate the size and shape of cement batch mixers.

Studying the details of its design, the shear-activated cross-linked loss circulation pill emerges as a carefully crafted solution tailored for seamless application in the field. Each facet of its composition and packaging has been carefully considered to enhance user convenience and operational efficiency. The product is thoughtfully presented in palletized kits, an organized assembly of essential chemical additives crucial for constructing the shear activated cross-linking pill, as visually represented in Figure 9. The palletized kit is designed with the capacity to generate 40 barrel LCM pills, offering compatibility with cement batch mixers. This setup provides a substantial and efficient quantity to effectively address lost circulation challenges in drilling operations. This on-location pill production capability not only simplifies logistics but also enhances the adaptability and responsiveness of the solution in addressing lost circulation concerns in real-world drilling scenarios.

Figure 9 EMS-8650 HT, shear activated cross-linked lost circulation pill packaged in palletized kits.

Conclusions

The introduction of the shear-activated cross-linking lost circulation pill represents a significant leap forward in addressing the operational and costly issues of lost circulation in vugular, cavernous, fractured and/or highly depleted formation zones during drilling. This innovative solution boasts several distinctive features such as, the pill's ability to transition from an oil-continuous to a water-continuous phase upon shearing, coupled with its rapid gel formation, demonstrates its efficiency in sealing vugular formations and preventing further fluid loss. The robust stability of the system, evaluated through thermal aging and UCS testing, positions it as a reliable and resilient solution.

Addressing the industry's commitment to global environmental stewardship, the paper also highlights the testing of alternative base oils to meet regulatory requirements. This highlights the system's adaptability to various oils without compromising its gel strength. The seamless integration of the shear-activated cross-linked loss circulation pill into field operations, using existing BHA and drill string, its palletized packaging, and compatibility with cement batch mixers, enhances the efficiency and responsiveness of addressing lost circulation challenges in real-world drilling scenarios.

In summary, this paper provides a thorough exploration of the shear-activated cross-linking lost circulation pill, offering insights into its formulation, deployment, and performance. The shear activated cross-linking lost circulation pill not only tackles immediate drilling challenges but also holds promise for enhancing overall drilling efficiency, safety, and cost-effectiveness. As the industry continues to grapple with the complexities of drilling operations, this shear-activated pill emerges as a transformative tool which can allow operators to achieve some of the sustainable targets contributing to the evolution of drilling practices in the dynamic landscape of the oil and gas sector.

Nomenclature

LCP = lost circulation pill
LCM = lost circulation material
SAC = Shear activated cross-linking
BHA = bottom hole assembly
°F = degrees Fahrenheit
RPM = revolutions per minute
UCS = unconfined compressive strength
mL - milliliters