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Synergistic effects of particle size distribution on lost circulation control

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Abstract

Lost circulation during drilling is a persistent challenge that can significantly increase operational costs and lead to technical complications. To mitigate this issue, lost circulation materials (LCMs) are employed to seal fractures and reduce fluid losses. This study investigates the application of quartz particles with varying sizes as an LCM additive to improve the sealing efficiency of drilling fluids. The experimental setup utilized a static testing apparatus designed to simulate fractures of different widths under controlled conditions. The drilling fluid tested was a water-based polymer formulation.

Three scenarios were evaluated: (1) the use of quartz particles sized 250–280 microns, (2) particles sized 100 microns, and (3) a combination of these particle sizes. Larger particles demonstrated limited sealing capabilities, achieving a maximum pressure of only 0,7 MPa over 20 minutes, insufficient for effective fracture sealing. Smaller particles showed improved performance, reaching a pressure of 0,8 MPa more quickly, but the most efficient sealing was observed with a mixture of particle sizes. The combination allowed for faster bridge formation and higher sealing efficiency, as indicated by steeper pressure curves and reduced fluid losses.

The findings highlight the importance of particle size distribution in optimizing the performance of LCMs. Smaller particles effectively fill voids within fractures, while larger particles provide structural stability to the sealing layer. This synergy between particle sizes can significantly enhance the performance of drilling fluids in controlling fluid losses. By tailoring the particle size and composition of LCMs, operators can address challenges in a variety of drilling conditions, including high-pressure and high-temperature environments.

These results contribute to the broader understanding of lost circulation mechanisms and provide practical guidance for improving LCM design. This work underscores the need for continued research into advanced materials and innovative approaches to mitigate drilling fluid losses effectively.

Keywords: Lost circulation material (LCM), drilling fluid optimization, quartz particle size distribution, fluid loss mitigation, sealing efficiency, fracture sealing technology

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1. Introduction

Loss of circulation is one of the most challenging issues in drilling oil and gas wells. It leads to significant losses of drilling fluid, increased non-productive time, and higher costs. Circulation losses can also result in complications such as pipe sticking, poor hole cleaning, and well control problems. Traditional methods for controlling circulation losses rely on materials introduced into the loss zone.

These materials are divided into conventional LCMs (without modification) and unconventional LCMs, which are specifically designed to combat fluid loss [1, 2].

Authors in [1] propose an innovative approach using a temperature-activated anionic polymer with a carboxylate complex as a crosslinking agent. This composition forms a gel-like structure that reduces rock permeability to milliDarcy levels and stabilizes the wellbore. The material contains no solid particles, is non-biodegradable, and is resistant to acid dissolution, enhancing its effectiveness.

In [8], two solutions are suggested: 1) a blend of organic polymers and superabsorbent materials that expand within fractures, forming a viscous mass to create a base for a subsequent sealing layer; 2) a high-density composition that quickly dehydrates, leaving a durable "plug" barrier that fills fractures, caverns, and voids.

The study in [9] explores the application of crosslinked polymer solutions for preventing and mitigating circulation losses in complex carbonate reservoirs with unpredictable fracture zones and caverns. Chemical sealing solutions, including crosslinked polymers, provide more reliable and controlled sealing of fractures and voids. The polymer systems discussed are biodegradable and minimally affect the formation, gradually reverting to liquid under the influence of temperature and time.

In [10], an innovative solution is proposed for tackling circulation losses during drilling, particularly in highly fractured carbonate formations, using smart polymer-based materials with shape memory properties (SMPs). The developed LCMs combine various forms and structures, including granules, fibers (1-D), star-shaped and lattice-like (2-D) elements, which restore their shape to form complex 3-D structures for effectively sealing fractures of varying widths and configurations.

The authors of [2] conducted a comparative analysis of the effectiveness of conventional LCMs, such as reed, oak shells, wheat, and mica, when used in water-based drilling fluids in fractured formations. The sealing efficiency of these materials was evaluated under various particle size distributions (PSD) using an experimental setup with adjustable fracture widths. Mixed materials with broad PSDs provided better sealing than individual LCMs, highlighting the importance of selecting the appropriate LCM composition for effective circulation loss control in fractured formations.

In [3], the influence of fiber concentration, fracture roughness, and fiber stiffness on sealing efficiency is evaluated.

Study [4] focuses on the use of granular materials to combat circulation losses during drilling. Granular LCMs are cost-effective and efficient for sealing fractures when the particle size distribution (PSD) is appropriately selected. Large particles should match the fracture size, while the ratio of small to large particles should not exceed 0.67. Optimal performance is achieved when smaller particles make up about one-third of the mixture volume. Thus, precise PSD selection enables reliable and efficient reduction of circulation losses.

The authors of [5] also emphasize that the key factor for effective fracture sealing is the PSD of the LCM.

In [6], the lack of theoretical guidelines for material selection for circulation loss control (LCMs) is identified as a cause of unstable fracture sealing and repeated failures. The authors conducted extensive laboratory experiments, revealing that using LCMs with a single particle size distribution does not provide effective sealing of millimeter-scale fractures.

The study in [7] introduces a new methodology for selecting materials to control circulation losses in formations with multiple natural and induced fractures around the wellbore. The authors use an analytical solution to a geomechanical problem to estimate fracture widths around an inclined wellbore, considering three principal stresses and fracture interactions. Based on these estimates, a "multi-modal" LCM mixture is proposed, consisting of sub-mixtures tailored for specific fracture width ranges.

Article [11] examines factors influencing the strength and stability of the sealed fracture zone. The key parameter for LCM selection is suggested to be the Surface Friction Coefficient (SFC), which determines the stability of force chains in granular material. For effective and durable circulation loss control in fractured reservoirs, the optimization of LCM composition in terms of particle size, combinations, and resistance to thermal, mechanical, and chemical impacts on SFC is critical.

Despite the limitations of traditional lost circulation materials due to the presence of solid particles, which restrict their use in modern bottom hole assemblies (BHAs) and coiled tubing (CT) operations, in our article, we explored quartz as an alternative sealing material.

2. Experimental part

In this experimental study, quartz with various particle sizes was evaluated as a lost circulation material (LCM) additive to mitigate drilling fluid losses.

The static sealing properties of the drilling fluid were examined using a specialized static testing apparatus. A schematic representation of this apparatus is displayed in Figure 1.

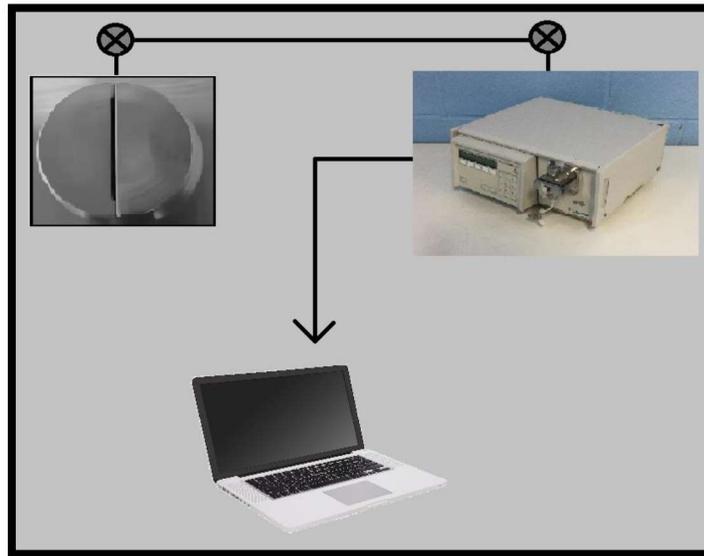


Figure 1. Static testing apparatus

The system comprises a steel cylinder. At the bottom of the cylinder, steel slots were inserted to simulate fractures. These slots can be adjusted to create fractures of various widths. The cylinder is filled with the test fluid and sealed at the top. A high-pressure pump pressurizes the system with water. The apparatus can withstand a maximum pressure of 50 MPa, monitored via a pressure gauge and recorded

on a computer. A flow rate of 2 ml/min was maintained during all experiments, each lasting approximately 60 minutes. After this period, water breakthrough could be observed.

During the first test, a particle concentration of 39 kg/m³ was added to the fluid, equivalent to approximately 2% by weight for the specific drilling fluid.

Particles were sieved to achieve a size range of 250–280 microns. These sorted particles were added to a water-based polymer fluid. The results are illustrated in Figure 2.

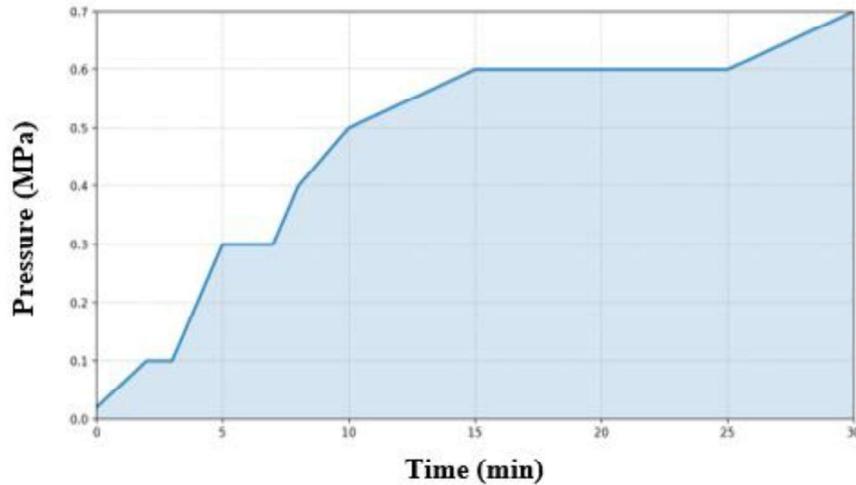


Figure 2. Quartz with particle size range 250–280 microns, 250 micron slot. Polymer fluid

As seen in Figure 2, the particles did not form a seal. The maximum pressure reached only 0,7 MPa, taking around 30 minutes to achieve this value.

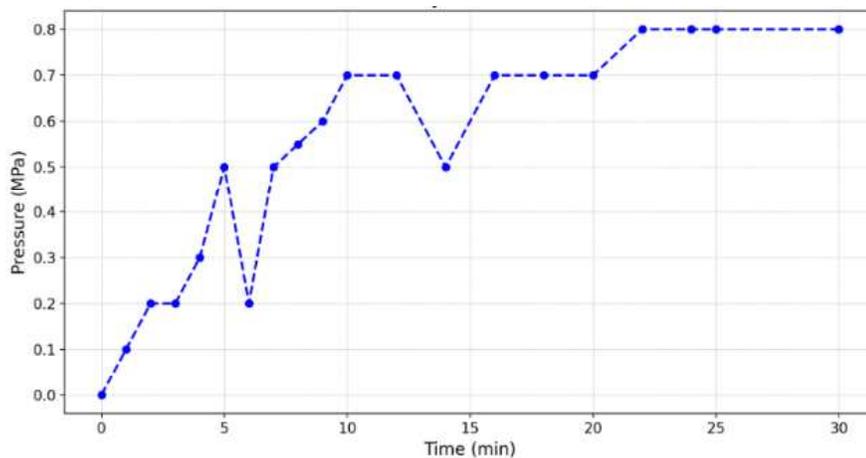


Figure 3. Quartz with particle size 100 microns, 250 micron slot. Polymer fluid

In the second test, a water-based polymer fluid was augmented with 39 kg/m^3 of particles sized 100 microns. The results are presented in Figure 3. When smaller particles were introduced, the sealing properties improved, but the improvement was minimal. The peak pressure achieved was 0,8 MPa, insufficient to seal the fractures. Another notable observation was the shorter time required to reach 0,8 MPa compared to Test №1, indicating that smaller particles enhance sealing efficiency.

For further investigation, a new particle mixture was tested. The experimental results are presented in Figure 4. A blend of particles with a size of 100 microns, along with larger particles in the range of 250–280 microns, was added.

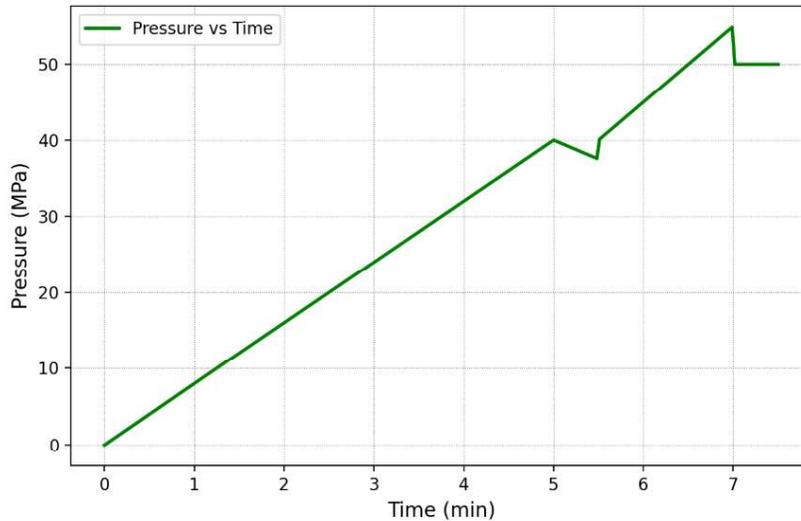


Figure 4. Mixed-size quartz particles. Polymer Fluid

The bridging formation time in Test №3 was shorter, reflecting a greater pressure curve slope. A pronounced slope is indicative of lower filtrate losses through the seal and highlights that the sealing efficiency of the bridge is enhanced by a higher proportion of smaller particles.

Based on the tests described above, it appears that smaller particles in the mixture play a critical role in determining the fluid's bridging properties.

The results of this study provide valuable insights into the role of quartz particles as an additive in controlling fluid losses during drilling.

These results suggest that particle size distribution is critical in enhancing the bridging properties of drilling fluids. Smaller particles play a pivotal role in filling fracture voids, while larger particles contribute to the structural integrity of the seal. By combining these properties, drilling fluids can be tailored to address fluid loss challenges more effectively.

This study highlights the need for a strategic approach to LCM design, taking into account the fracture geometry and the synergistic effects of particle size and composition. The findings contribute to the ongoing development of more effective and efficient lost circulation materials, offering practical applications in the field of drilling fluid engineering.

3. Conclusion

1. Quartz particles sized 250–280 microns alone were unable to form an adequate seal, achieving a maximum pressure of 0,7 MPa over 30 minutes, which is insufficient for mitigating fluid losses effectively.

2. Smaller particles (100 microns) showed slight improvements, reaching 0,8 MPa and requiring less time to achieve this pressure, indicating better initial sealing efficiency.

3. A mixture of both particle sizes demonstrated superior performance, achieving a faster bridging formation and higher sealing efficiency, as evidenced by a steeper pressure curve.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research

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