WEP Warwick Evans Publishing

International Journal of Natural Resources and Environmental Studies

ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 8, Number 3, Year 2026
DOI: https://doi.org/10.62051/ijnres.v8n3.07
Journal homepage: https://wepub.org/index.php/IJNRES/index

# Optimization of Drilling-Fluid Lost-Circulation Control in the Mesozoic Yanchang Formation of Zhengning Oilfield

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## ABSTRACT

Lost circulation is a major engineering problem that restricts the safe and efficient drilling of oil and gas wells. Reservoirs of the Mesozoic Yanchang Formation in Zhengning Oilfield are generally characterized by low porosity, low permeability, strong heterogeneity, and seepage jointly controlled by fractures and microfractures, which makes the types of lost-circulation channels encountered during drilling highly complex and the plugging operation difficult. On the basis of reviewing the research status of commonly used lost-circulation materials and plugging technologies, this paper combines the reservoir characteristics and lost-circulation background of the Yanchang Formation in Zhengning Oilfield to analyze the block adaptability of existing plugging systems. Drawing on previous studies on lost-circulation optimization in the Yanchang Formation—especially the findings related to particle-size analysis, D90 adaptability evaluation, rheology and filtration tests, and composite-formulation optimization—Chapter 4 is rewritten as an experimental evaluation and optimization of lost-circulation materials. The study shows that lost-circulation control in the Yanchang Formation of Zhengning Oilfield should emphasize a multi-stage synergistic concept of "coarse-particle bridging–medium-particle filling–fine-particle compaction." A broad particle-size-distribution composite system should be preferentially adopted so that the pressure-bearing and anti-erosion capacity of the sealing layer can be ensured while maintaining stable drilling-fluid rheology and filtration performance.

## KEYWORDS

Zhengning Oilfield; Yanchang Formation; Lost Circulation; Drilling Fluid; Lost-Circulation Materials; Plugging Optimization; Experimental Evaluation.

## 1. INTRODUCTION

Lost circulation is one of the most common and hazardous downhole complexities in drilling engineering. It not only causes substantial loss of drilling fluid, prolongs the drilling cycle, and increases engineering costs, but may also induce wellbore instability, pipe sticking, and well-control risks. For tight reservoirs with low porosity, low permeability, and developed fractures, lost-circulation channels usually exhibit large scale differences, complex geometries, and a high risk of repeated losses; therefore, conventional experience-based plugging measures often fail to achieve stable results.

The Mesozoic Yanchang Formation in Zhengning Oilfield is an important exploration and development interval on the southern margin of the Ordos Basin. Previous studies have shown that the reservoir lithology in this area is dominated by feldspathic lithic sandstone and lithic feldspathic sandstone. Overall reservoir properties are poor, and fractures as well as diagenetic microfractures play an important role in fluid migration. For drilling engineering, this means that lost circulation is

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usually not limited to simple pore seepage, but is more likely to show a composite character in which pore seepage, microfracture losses, and fracture losses coexist [1-2].

At present, many studies have focused on plugging for lost circulation, but most of them emphasize the performance evaluation of general-purpose materials, while block-specific summaries targeted at the geological characteristics and loss background of the Yanchang Formation in Zhengning Oilfield remain relatively insufficient. Based on this, and on the basis of reviewing the research status of drilling-fluid plugging technology, this paper combines the reservoir characteristics of the Yanchang Formation in Zhengning Oilfield and incorporates the achievements of related studies on material gradation, performance evaluation, and composite design in the Yanchang Formation, so as to systematically summarize the optimization direction of lost-circulation control for this block.

## 2. LOST-CIRCULATION BACKGROUND AND PLUGGING REQUIREMENTS IN THE YANCHANG FORMATION OF ZHENGNING OILFIELD

### 2.1. Reservoir and Fracture Characteristics of the Study Area

The Yanchang Formation in Zhengning Oilfield belongs to a typical tight-reservoir interval and is characterized overall by low porosity, low permeability, and strong heterogeneity. The lithology is dominated by feldspathic lithic sandstone and lithic feldspathic sandstone. Pore types are mainly secondary pores, including intergranular dissolution pores, feldspar dissolution pores, and lithic dissolution pores, while a certain number of tectonic fractures and diagenetic microfractures are also developed. On the one hand, fracture development improves reservoir seepage capacity; on the other hand, it provides preferential channels for drilling-fluid losses [1-2].

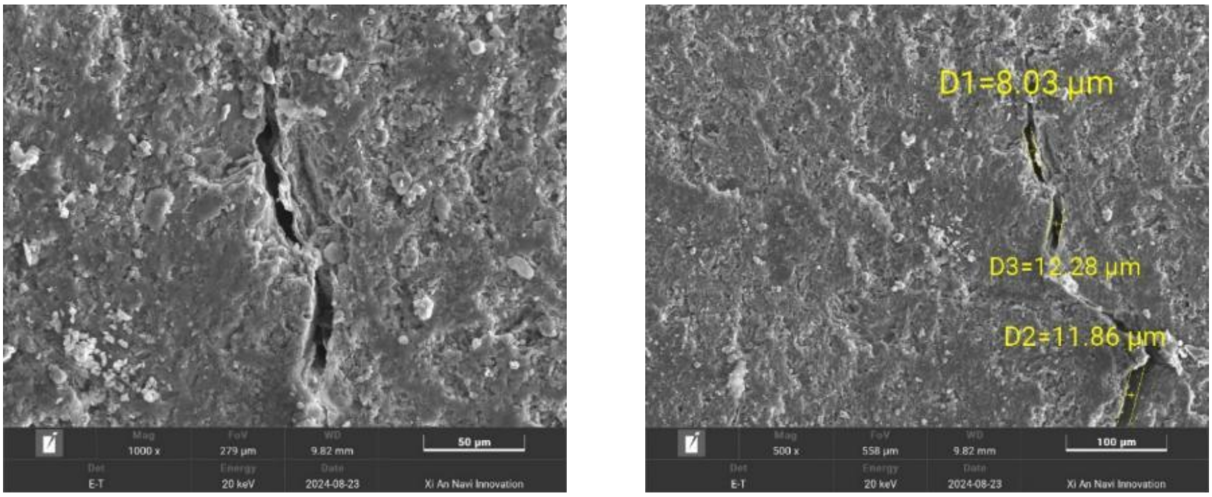


**Fig. 1** SEM images of the Yanchang Formation

From an engineering perspective, the reservoir mechanical properties and pressure-bearing capacity vary greatly across the area, and local high-rate loss channels are likely to form once the wellbore is exposed. Fracture scales are not completely consistent, and lost circulation often presents a composite feature of "main-fracture diversion plus supplementary seepage through microfractures," which is also an important reason why conventional single lost-circulation materials can hardly achieve a stable effect.

### 2.2. Main Factors Affecting Lost Circulation

Lost circulation in the Yanchang Formation of Zhengning Oilfield is jointly controlled by multiple factors. First, the development of fractures and microfractures makes the formation prone to local high-rate loss channels. Second, the sandstone–mudstone assemblage is complex and the formation is strongly heterogeneous, resulting in significant differences in pressure-bearing capacity among different intervals. Third, when the window between drilling-fluid column pressure and formation fracture pressure is narrow, differential-pressure-induced losses are easily triggered. Fourth, local wellbore intervals may have poor wall stability, and borehole enlargement and rock fragmentation may further aggravate fluid losses.

According to the characteristics of the loss channels, lost circulation in this area can be roughly divided into three types: pore-seepage type, microfracture type, and fracture type. Among them, pore-seepage losses usually occur at relatively low rates but persist for a long time; the microfracture type requires a high degree of particle-size matching for the materials; and the fracture type generally exhibits high loss rates, great plugging difficulty, and a high risk of repeated losses.

### 2.3. Plugging Optimization Requirements

Combined with the formation conditions and lost-circulation characteristics of the Yanchang Formation in Zhengning Oilfield, plugging optimization in this block needs to solve three problems simultaneously: establishing a material gradation system suitable for multiscale fracture channels, improving the pressure-bearing and anti-erosion capacity of the sealing layer, and avoiding obvious damage to drilling-fluid rheology and filtration performance caused by lost-circulation materials. Therefore, plugging design in this block should not simply copy a generic formulation; instead, it should be customized around the characteristics of the block.

## 3. STUDY ON PLUGGING TECHNOLOGIES FOR THE YANCHANG FORMATION IN ZHENGNING OILFIELD

### 3.1. Common Lost-Circulation Materials and Their Mechanisms

At present, drilling-fluid lost-circulation materials mainly include bridging materials, high-fluid-loss materials, solidifiable materials, gel materials, and adaptive plugging materials. Bridging materials are mainly rigid particles, flaky materials, and fibers. They are low in cost and widely applied in the field, but are sensitive to particle-size matching. High-fluid-loss materials rely on rapid filtration to form a sealing layer and act quickly, but they carry a risk of reservoir damage. Solidifiable and gel materials have relatively high pressure-bearing capacity and are suitable for severe losses, but they require a stricter operational window and better compatibility. Adaptive materials show great application potential in complex channels, although their field maturity is still limited [3-10].

In recent years, plugging research has gradually shifted from the development of single materials to a more integrated path of "loss-channel identification–material matching–experimental evaluation–field optimization." Especially under fracture-loss conditions, increasing attention has been paid to material gradation and the integrity of the sealing structure, and composite plugging systems are gradually replacing single-agent systems as the main research direction.

### 3.2. Methods for Evaluating the Adaptability of Lost-Circulation Materials

In addition to traditional evaluations of plugging effectiveness, recent studies have paid more attention to the analysis of the matching relationship between particle-size composition and fracture scale. Studies related to the Yanchang Formation indicate that, during the preliminary screening of materials, the theoretically matched fracture width can be roughly estimated from particle-size distribution, the proportions of coarse, medium, and fine particles, and the D90 criterion. However, D90 can only be used as a preliminary screening basis; the actual sealing effect still needs to be verified by subsequent plugging experiments.

According to particle size and function, lost-circulation materials can generally be divided into three categories. The first is coarse-particle-dominated materials, which have strong bridging capacity and are suitable as skeleton materials at the entrance of larger fractures. The second is medium- and fine-particle-dominated materials, which are better at filling the interior of fractures. The third is broad-gradation materials and composite systems, which are more conducive to forming a synergistic sealing structure featuring "coarse-particle bridging–medium-particle filling–fine-particle compaction."

### 3.3. Adaptability Analysis for the Yanchang Formation of Zhengning Oilfield

The characteristics of low porosity, low permeability, and seepage jointly controlled by fractures and microfractures in the Yanchang Formation of Zhengning Oilfield determine that lost-circulation channels often exhibit a multiscale distribution. A single lost-circulation material cannot simultaneously satisfy the needs of large-fracture bridging, internal fracture filling, and fine-channel compaction. Therefore, lost-circulation control in this block requires more a stable sealing structure formed through the synergy of multilevel particles.

From the perspective of engineering applicability, granular lost-circulation agents and their composite systems have a relatively small effect on drilling-fluid rheology and are therefore more suitable as the main field plugging system. Polymer materials can reduce filtration to some extent, but they also increase viscosity markedly, so the dosage must be controlled in practical application. For the Yanchang Formation in Zhengning Oilfield, it is clearly more meaningful in practice to optimize a broad-gradation composite system than to rely on a single plugging agent.

## 4. EXPERIMENTAL EVALUATION AND OPTIMIZATION OF LOST-CIRCULATION MATERIALS

### 4.1. Experimental Scheme and Formulation Systems

According to particle-size composition and functional role, the experimental systems were divided into two categories: single-agent systems and composite systems. The single-agent systems included coarse-particle bridging type, medium-coarse-particle type, medium-fine-particle filling type, and polymer filtration-reduction type; the composite systems included a dual-bridging-skeleton system, a bridging–filling system, and a broad-gradation composite system.

**Table 1** Formulation systems and functional positioning

| Formulation No. | System Type | Main Functional Characteristic |
|---|---|---|
| Formulation 1 | Coarse-particle bridging single agent A | Dominated by coarse particles; suitable for forming a skeleton at the fracture entrance |
| Formulation 2 | Coarse-particle bridging single agent B | Strong bridging capacity with good pressure-bearing potential |
| Formulation 3 | Medium-coarse-particle single agent | Provides both bridging and filling functions to a certain extent |
| Formulation 4 | Medium-fine-particle filling single agent | Easily enters the fracture interior and is conducive to in-fracture filling |
| Formulation 5 | Polymer filtration-reduction single agent | Strong filtration-reduction capacity, but obvious viscosity increase |
| Formulation 6 | Formulation 1 + Formulation 2 (1:1) | Dual-bridging-skeleton composite system |
| Formulation 7 | Formulation 1 + Formulation 2 (1:2) | Strong-bridging composite system |
| Formulation 8 | Formulation 3 + Formulation 4 (1:2) | Bridging–filling composite system |
| Formulation 9 | Formulation 1 + Formulation 2 + fine-particle component | Broad-gradation composite system |
| Formulation 10 | Broad-gradation filling system | Suitable for filling and compacting microscale channels |

## 4.2. Experimental Methods

The base slurry was prepared with water and bentonite. Rheological properties were measured with a six-speed rotational viscometer, and the evaluation indices included apparent viscosity, plastic viscosity, yield point, and gel strength. Filtration performance was tested with an API medium-pressure filter press. Fracture-plugging capability was evaluated using a lost-circulation simulation device, with the simulated fracture-width range set at 0.5–5 mm. The adaptability to microscale seepage channels was additionally evaluated by sand-bed experiments. Particle-size testing combined laser particle-size analysis with sieving, and particle-size intervals, the proportions of coarse, medium, and fine particles, and D90 were used as preliminary evaluation indices.

**Fig. 2** Lost-circulation simulation experimental apparatus

### 4.3. Experimental Results and Analysis

Particle-size gradation analysis showed that Formulations 1, 2, and 3 were dominated by coarse and medium-coarse particles and had strong bridging capability, making them more suitable as skeleton materials at the entrance of relatively large fractures. Formulations 4 and 5 were dominated by medium and fine particles and were more beneficial for entering fracture interiors and microscale channels for filling and compaction. Formulations 6 to 10 belonged to broad-gradation or composite systems and combined skeleton, filling, and compaction functions. Overall, the theoretical fracture-width adaptability range of single-agent materials was limited, whereas broad-gradation composite systems were more suitable for loss conditions in which multiscale fractures coexist.

The rheological test results indicated that after adding Formulations 1, 2, 3, and 4 to the base slurry, the overall effect on system rheology was small and the system still retained good fluidity and pumpability. The composite systems represented by Formulations 6, 7, 8, and 9 were close to single-agent particulate materials and also did not show obvious viscosity increase. In contrast, the rheological parameters increased markedly after adding Formulation 5, indicating that it behaved more like a polymer filtration-reduction treatment agent.

Filtration tests showed that with increasing dosage of lost-circulation materials, the filtration volume of each system generally decreased, but the differences among formulations were obvious. Formulation 5 exhibited the most significant filtration-reduction effect, indicating that polymer components can quickly improve the water-loss performance of the system; however, combined with the rheological test results, this system also showed an obvious viscosity-increase problem. By comparison, the filtration-reduction capacity of single-agent particulate systems was generally limited, whereas broad-gradation systems such as Formulations 9 and 10 reduced filtration more steadily while maintaining good rheological performance, indicating that the synergy of multilevel particles is more conducive to forming a dense filter cake and a low-permeability sealing layer.

Fracture-plugging experiments showed that under simulated fracture conditions of 0.5–10 mm, the adaptability range of single-agent systems was generally limited. Formulations 1 and 2 had strong bridging capability at the entrance of medium-sized fractures, but when used alone they did not adequately fill the remaining channels inside the fracture. Formulation 4 was favorable for in-fracture filling, but it was difficult for it to form a stable skeleton at the entrance of larger fractures. After compounding, the plugging capacity of all systems improved significantly. Among them, Formulation 7 performed best under medium to relatively large fracture conditions, and Formulation 8 also showed good plugging potential, although it was slightly weaker overall than Formulation 7.

Sand-bed experiments showed that Formulations 4 and 10 had good entry and filling capacities in microscale channels and could effectively reduce the permeability of residual microchannels after skeleton formation. Because it combines coarse, medium, and fine particle components, Formulation 9 also showed good stability in the evaluation of microscale channels. This demonstrates that in formations such as the Yanchang Formation of Zhengning Oilfield, where microfractures and matrix seepage channels are jointly developed, a bridging skeleton alone is insufficient to form a long-term stable sealing layer; filling and compaction components must also be used for secondary reinforcement.

**Table 2** Comprehensive experimental performance evaluation of the main formulations

| Formulation No. | Particle-Size Compatibility | Rheological Impact | Filtration Control | Fracture Plugging | Overall Evaluation |
|---|---|---|---|---|---|
| Formulation 4 | Well suited to medium and fine channels | Low | Moderate | Average | Suitable as a filling and compaction component |
| Formulation 5 | Well suited to medium and fine channels | High | Excellent | Average | Not suitable as the main plugging system alone |
| Formulation 7 | Best suited to medium and large fractures | Low | Moderate | Excellent | Recommended as the main skeleton plugging system |
| Formulation 9 | Well suited to multiscale channels | Low | Good | Good | Has potential as a composite plugging system |

### 4.4. Optimization Results

Based on the experimental results for particle-size gradation, rheological performance, filtration performance, fracture-plugging capacity, and microscale-channel filling capacity, Formulation 7 showed strong bridging capability for medium and large fractures and is suitable as the main skeleton plugging system; Formulations 4 and 10 performed well in filling and compacting microscale channels and are suitable as auxiliary filling components; and Formulation 9 exhibited relatively balanced overall performance and has the potential to serve as a composite plugging system. In contrast, although Formulation 5 had outstanding filtration-reduction capability, its viscosity-increase effect was obvious, making it unsuitable for independent use as the main plugging system.

Therefore, for the Yanchang Formation in Zhengning Oilfield, the experimentally optimized results can be summarized into two application strategies. One is to target medium- and large-fracture losses with Formulation 7 as the main system so as to strengthen bridging at the fracture entrance. The other is to target microfracture and composite losses by adding Formulation 4 or Formulation 10 on the basis of Formulation 7 to improve in-fracture filling and compaction capacity and form a synergistic plugging structure of "bridging–filling–compaction."

## 5. CONCLUSIONS AND RECOMMENDATIONS

(1) The Yanchang Formation reservoirs in Zhengning Oilfield are characterized by low porosity, low permeability, strong heterogeneity, and seepage jointly controlled by fractures and microfractures. Lost-circulation types are therefore complex, among which microfracture and fracture losses are the key targets for plugging optimization.

(2) Common lost-circulation materials currently include bridging materials, high-fluid-loss materials, solidifiable materials, gel materials, and adaptive materials. However, for fractured tight reservoirs such as the Yanchang Formation in Zhengning Oilfield, the adaptability range of single-agent materials is limited, whereas broad-gradation composite systems are more suitable for engineering application.

(3) Experimental results show that Formulation 7 exhibits good bridging and pressure-bearing potential under medium to relatively large fracture conditions and can be used as the main skeleton plugging system. Formulations 4 and 10 have strong filling capacity in microscale channels and are suitable as auxiliary filling and compaction components. Although Formulation 5 shows a certain filtration-reduction effect, it also causes obvious viscosity increase, so its use mode must be strictly controlled.

(4) For the Yanchang Formation in Zhengning Oilfield, it is recommended to adopt a composite plugging concept of "Formulation 7 as the main skeleton + Formulation 4 or Formulation 10 as the filling and compaction component" so as to balance bridging capability for medium and large fractures, filling capability for microfractures, and the post-plugging stability of the system.

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