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Research on Control Technologies for Hydrogen Sulfide Bearing Shale Oil Wells in China's Shengli Oilfield

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ABSTRACT

Pyrite is abundant in some shale oil blocks of the Shengli Oilfield, China. During the development process, the high-temperature and high-pressure formation environment induces a thermochemical reaction between pyrite and hydrocarbons, generating and releasing hydrogen sulfide (H_2S). This poses a serious threat to safe production, environmental protection, and crude oil quality. This paper provides an in-depth analysis of the formation mechanism of hydrogen sulfide in shale formations, identifying the high-temperature pyrolysis of pyrite in a closed system as the primary sulfur source. To address this issue, a high-temperature desulfurizer suitable for shale oil wells has been developed. This desulfurizer exhibits excellent characteristics, including high-temperature resistance (adaptable to formation temperatures), rapid reaction, high desulfurization efficiency, large sulfur capacity, and partial regenerability. By injecting the desulfurizer into the formation alongside fracturing fluid during the fracturing process, source control and treatment of hydrogen sulfide are achieved. Successful field applications in five wells demonstrate that this technology significantly reduces hydrogen sulfide concentrations during well opening and production, yielding effective treatment results. It provides an efficient technical approach for the safe and high-efficiency development of similar hydrogen sulfide-bearing shale oil reservoirs.

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Introduction

With the increasing strategic significance of unconventional hydrocarbons, shale oil has become a key target for reserve growth and production enhancement in China's Shengli Oilfield. However, hydrogen sulfide (H_2S) is frequently detected during the development of several shale oil reservoirs. Hydrogen sulfide is a highly toxic and strongly corrosive acidic gas; its presence poses severe threats to the safety of field personnel, accelerates corrosion of downhole tubulars and surface facilities, and ultimately leads to equipment failure and increased operational costs [1]. In addition, H_2S-bearing crude oil suffers quality degradation, and its emissions can cause substantial environmental harm.

Unlike conventional reservoirs, the occurrence of H_2S in the shale oil intervals of the Shengli Oilfield is closely linked to their distinctive geological and geochemical characteristics. Previous investigations have shown that the shale formations in this region are enriched in pyrite. As one of the most widely distributed sulfide minerals in the Earth's crust, pyrite can serve as a substantial sulfur source for H_2S generation under specific geological and geochemical conditions. Therefore, elucidating the mechanisms responsible for H_2S formation in shale oil wells and developing targeted prevention and mitigation technologies are of critical importance for ensuring the safe, environmentally responsible, and efficient development of shale oil resources in the Shengli Oilfield [2-8].

Mechanisms of Hydrogen Sulfide Generation in Shale Oil Formations

The generation of hydrogen sulfide in shale oil reservoirs is governed by a set of complex geochemical processes. Current consensus suggests that H_2S detected in shale oil wells of the Shengli Oilfield primarily originates from the thermochemical reduction of pyrite.

Sulfur Source: Pyrite

Pyrite is a common authigenic mineral in shale formations and is particularly well developed in organic-rich intervals, where it provides a major sulfur source for H_2S production. Experimental and geochemical studies indicate that pyrite reacts with hydrocarbons under closed-system high-temperature pyrolysis to yield hydrogen sulfide and a suite of organosulfur compounds (OSCs) [9]. The resulting organic products include diverse OSCs as well as significantly altered hydrocarbons, such as n-alkanes, cycloalkanes, alkanes, alkenes, and aromatic hydrocarbons.

Formation Mechanism: Thermochemical Reactions Between Pyrite and Hydrocarbons

Extensive laboratory simulations and geological–geochemical analyses demonstrate that, in closed systems, pyrite undergoes complex redox reactions with formation hydrocarbons (crude oil, kerogen, etc.) during high-temperature thermal decomposition [9]. Under elevated temperatures, pyrite and hydrocarbons generate H_2S and various OSCs, and the abundance of OSCs formed under hydrothermal pyrolysis conditions is significantly higher than that produced during anhydrous pyrolysis. When temperatures exceed approximately 450 °C, markedly higher H_2S concentrations are observed. A representative reaction, using n-pentane as an example, can be expressed as [9]:

$$\text{n-}C_5H_{10} + FeS_2 \xrightarrow{H_2O} H_2S + OSCs + Fe_7S_8 + \text{altered hydrocarbons} \quad (1)$$

The organosulfur compounds produced in these reactions—such as thiols and thiophenes—are themselves corrosive and toxic, and constitute undesirable heteroatomic impurities requiring removal during subsequent processing. This mechanism also explains the sustained generation and release of H_2S following well initiation, as changes in formation fluid composition, temperature, and pressure conditions continue to drive these reactions.

Development of High Temperature Scavengers and Source Control Technologies

Conventional approaches for hydrogen sulfide mitigation primarily focus on wellhead or surface desulfurization, representing end-of-pipe treatments that do not address corrosion of downhole equipment and tubulars, and are associated with high operational costs. To enhance intrinsic safety, this study proposes a "source-control" strategy, wherein H_2S is eliminated directly within the reservoir.

Conceptual Framework

During the volumetric hydraulic fracturing of shale oil wells, the newly developed high-temperature desulfurization agent is introduced as an additive to the fracturing fluid and injected into the formation along with the large fluid volumes used to create the artificial fracture network. As hydrocarbons in the shale matrix react with pyrite and generate H_2S, the released gas migrates into the fracture system, where it immediately reacts with the pre-placed scavenger. This in situ reaction effectively immobilizes and removes H_2S before it can migrate into the wellbore.

Development and Performance Characteristics of the High Temperature Scavenger

In response to the high-temperature, high-salinity, and chemically complex conditions characteristic of shale formations, a novel high-temperature H_2S scavenger for oilfield applications—designated LY-1—was successfully developed. The molecular structure of the scavenger is shown in Figure 1.

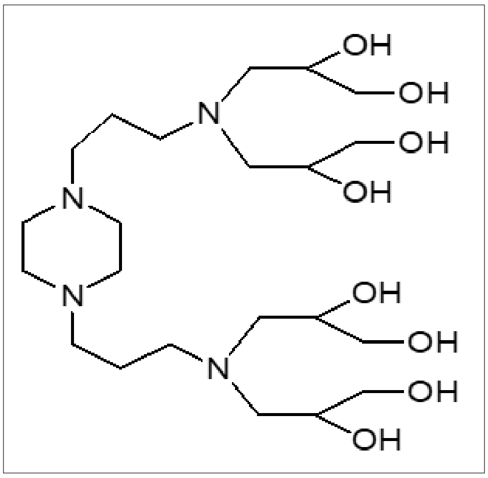


Figure 1: Molecular Structure of Desulfurizer LY-1

The LY-1 scavenger exhibits several key performance attributes:

- **High-Temperature Stability:** The scavenger remains chemically stable within the high-temperature environment of the Shengli shale oil reservoirs (150–180 °C or higher), without decomposition or loss of reactivity.
- **Rapid Reaction Kinetics and High Scavenging Efficiency:** LY-1 reacts swiftly with hydrogen sulfide, enabling effective removal within the short residence time of fluids flowing through fractures. The H_2S removal efficiency exceeds 99%.
- **High Sulfur Capacity:** A relatively small mass of the scavenger can capture a substantial amount of sulfur, thereby reducing injection volume and operational costs.
- **Partial Regenerability:** The scavenger can recover a portion of its reactivity under specific conditions, extending its effective lifespan within the formation and improving the overall techno-economic performance.
- **Excellent Compatibility:** LY-1 is compatible with fracturing fluids and other chemical additives, and does not impair key properties such as proppant-carrying or fracture-creation performance. When blended with the fracturing fluid and subjected to shear at 180 °C for 2 h, the residual viscosity remains above 100 mPa·s. The rheological behavior is shown in Figure 2.

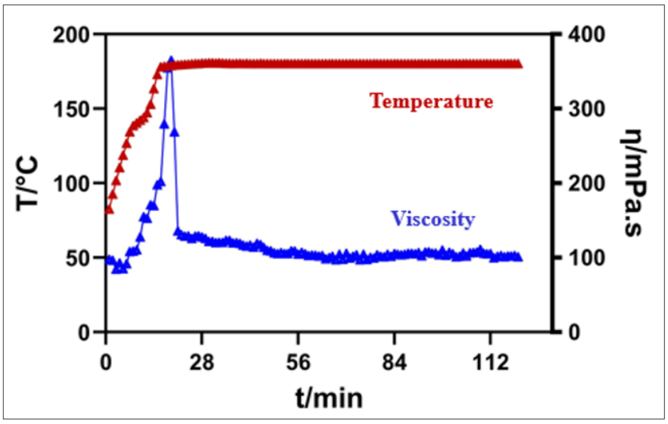
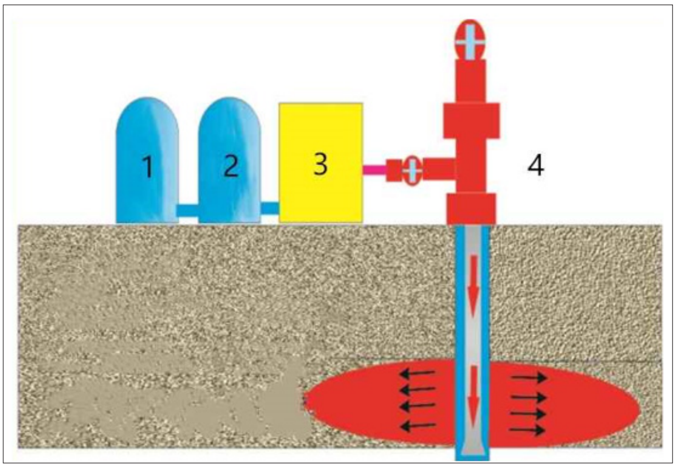


Figure 2: Rheological Curve of the Fracturing Fluid Blended with the LY-1 Scavenger at 180 °C

Source Control Technology

This study proposes an innovative in situ formation desulfurization concept, as illustrated in Figure 3. The core strategy involves co-injecting an efficient high-temperature scavenger with the fracturing fluid, allowing it to enter the reservoir simultaneously during the hydraulic fracturing operation. Once placed within the formation, the scavenger reacts directly with hydrogen sulfide as it is generated, converting H_2S in the mid- to deep reservoir zones into stable, nonhazardous solid products before the fluids return to the wellbore.

This approach substantially reduces the release of H_2S during well testing and subsequent production, mitigating operational safety risks and environmental burdens at the wellsite. Moreover, the technology provides critical support for the safe and efficient development of high-sulfur shale oil wells.



1. Fracturing Water Supply; 2. Desulfurization Treatment; 3. Fluid Mixing
4. Fracturing Well

Figure 3: Schematic Illustration of In Situ Formation Desulfurization Achieved by Co-injecting the Scavenger with the Fracturing Fluid

Field Application and Performance Evaluation

To systematically assess the practical effectiveness of the high-temperature scavenger–based source-control technology, five pilot wells with similar geological conditions and elevated baseline H_2S concentrations were selected for field trials.

Operational Procedure

During hydraulic fracturing, the concentration of the scavenger (0.5%–2.0%) was designed in advance based on the predicted formation H_2S levels. The high-temperature scavenger was uniformly blended into the fracturing fluid system. As the fracturing fluid was injected, the scavenger was effectively transported deep into the formation and retained within the complex fracture network created by the fracturing operation.

Application Performance

A six-month comparative monitoring program was conducted between the five pilot wells and three adjacent production wells in the same interval that did not employ the new technology. The evaluation focused on three aspects: H_2S control performance, operational safety, and overall economic benefits. The key findings are summarized below.

Significant and Persistent H_2S Control Efficiency

The initial production period poses the highest risk of H_2S release. Monitoring data show that within the first 24 hours after production, the peak concentrations of gaseous H_2S at the wellhead of the pilot wells were consistently within 5–15 mg/m³. In sharp contrast, the untreated comparison wells exhibited peak H_2S concentrations of 150–280 mg/m³ during the same period. On average, the pilot wells achieved a 94.7% reduction in H_2S concentration, far exceeding the 90% benchmark typically considered highly effective. More importantly, the long-term stability of the technology was clearly demonstrated. Throughout six months of continuous monitoring, H_2S concentrations in produced fluids from the pilot wells remained within the low range of 10–25 mg/m³, consistently below the national and industry safety threshold of 30 mg/m³. No significant increases were observed with fluctuations in production rate or pressure. By contrast, H_2S concentrations in the comparison wells fluctuated between 80–200 mg/m³, posing persistent operational and safety challenges. These findings indicate that the scavenger, when co-injected during fracturing, forms a long-lasting "protective zone" within the formation capable of continuously neutralizing newly generated H_2S during production—representing a fundamental shift from short-term treatment to long-term prevention.

Substantial Reduction in Operational Safety Risks and Improved Working Environmen

The application of the source-control technology fundamentally transformed the risk-management approach at the wellsite. Because H_2S is largely removed within the reservoir prior to fluid return, the exposure risks at the wellhead and surface facilities were drastically reduced. Consequently, the pilot wells were able to simplify—or even eliminate—the large, complex temporary or mobile surface desulfurization units traditionally required, along with their associated chemical-injection systems and high-frequency maintenance of monitoring and alarm interlocks. This not only avoided several million RMB in upfront equipment investment but also significantly reduced the operational risks associated with maintaining and operating such high-hazard systems. The on-site working environment improved markedly, and emergency response planning became less intensive and complex. Risk management priorities shifted from reactive emergency handling toward proactive risk prevention, reflecting a genuine implementation of the "safety-by-design" philosophy.

Enhanced Overall Economic Benefits and Improved Product Value

Beyond safety improvements, the technology also delivered substantial economic benefits. First, the savings in capital and operational costs previously associated with surface desulfurization—such as equipment investment, chemical consumption, energy usage, waste-agent disposal, and dedicated labor—constitute direct financial gains. Second, by mitigating H_2S-induced corrosion on tubulars, valves, and surface processing facilities, the technology is expected to extend the service life of key equipment and reduce maintenance and replacement costs. In addition, the source-control approach prevented secondary interactions between H_2S and produced crude oil during surface handling, reducing sulfur contamination of the product. Preliminary laboratory analyses indicate that crude oil from the pilot wells exhibited lower sulfur content and improved stability. These enhancements contribute to higher crude-oil quality and market value, thereby increasing the overall commercial recovery and economic performance of the shale-oil resource.

Conclusions and Outlook

The abundant pyrite present in the shale oil formations of the Shengli Oilfield serves as the primary sulfur source for hydrogen sulfide generation during production, with its high-temperature reactions with hydrocarbons constituting the core formation mechanism. The newly developed high-temperature scavenger exhibits excellent thermal stability, rapid and efficient H_2S removal capability, high sulfur capacity, and partial regenerability—properties that fully meet the technical requirements for source-control desulfurization in shale reservoirs.

By integrating the scavenger with the hydraulic fracturing process, the proposed source-control technology establishes a "chemical barrier" within the fracture network, enabling effective interception of hydrogen sulfide. Field applications in five wells have demonstrated the reliability, safety, and economic advantages of this approach.

Looking ahead, further optimization of injection parameters (e.g., concentration, slug design), in-depth investigation of the scavenger's long-term stability and reaction mechanisms within the reservoir, and the development of a refined life-cycle economic evaluation model will enhance the technology's reliability, adaptability, and economic performance. These advances will support the transition of the technology from pilot-scale trials to broader industrial deployment, providing a replicable and scalable solution for efficient shale-oil development in the Shengli Oilfield and similar domestic reservoirs. This work is expected to exert a profound impact on national energy security and the sustainable supply of cleaner energy resources.

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