

The Application of Comprehensive Well Logging Technology in Evaluating the Effect of CO₂ Injection

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ABSTRACT

In the face of escalating global climate change, Carbon Capture, Utilization, and Storage (CCUS) technologies have become indispensable for climate change mitigation. The application of carbon dioxide in geological fields, such as Enhanced Oil Recovery (CO₂ - EOR) and geological sequestration, presents both promising prospects and significant challenges. There are potential risks of leakage during geological sequestration, which can threaten groundwater and soil environments. Moreover, the long - term impact of carbon dioxide injection on geological structures and their stability remains uncertain. Comprehensive well logging technology has emerged as a powerful tool to address these issues. By continuously monitoring key parameters like formation pressure, temperature, and gas composition in real - time and integrating modern data analysis methods, it can precisely evaluate the effects of carbon dioxide injection, predict and monitor its migration and distribution, and ultimately reduce leakage risks and ensure the safety and long - term stability of geological applications.

Keywords: Geological sequestration, Comprehensive well logging, Injection effect

NONMENCLATURE

Abbreviations

APEN Applied Energy

Symbols

n Year

1. INTRODUCTION

The global climate change issue has reached a critical juncture. Rising global temperatures, melting ice caps, and extreme weather events are all clear manifestations of the urgent need to reduce greenhouse gas emissions. Among these greenhouse gases, carbon dioxide is the most significant contributor. Carbon Capture, Utilization, and Storage (CCUS) technologies have thus emerged as a set of comprehensive solutions to this pressing problem^[1].

In geological fields, the application of carbon dioxide offers a two - fold benefit. On one hand, Carbon Dioxide Enhanced Oil Recovery (CO₂ - EOR) can increase the recovery rate of oil and gas reservoirs. As traditional oil and gas resources become increasingly scarce, maximizing the extraction of existing reserves is of great economic importance. On the other hand, geological sequestration can effectively reduce the amount of carbon dioxide in the atmosphere, which is crucial for mitigating global climate change. However, these applications are fraught with challenges. The potential leakage of carbon dioxide during sequestration and the impact on geological structure stability are two major issues that need to be addressed. This paper will comprehensively explore the applications and challenges of carbon dioxide in geological domains and highlight the crucial role of comprehensive well logging technology in overcoming these challenges.

2. APPLICATIONS OF CARBON DIOXIDE IN GEOLOGICAL FIELDS

2.1 Carbon Dioxide Enhanced Oil Recovery (CO₂-EOR)

The principle of CO₂ - EOR is based on the unique physical and chemical properties of carbon dioxide. When carbon dioxide is injected into oil reservoirs, it dissolves in the crude oil. This dissolution leads to several important effects. Firstly, it causes the oil to expand. The expanded

oil occupies a larger volume in the reservoir pores, which helps to displace the oil more effectively towards the production wells. Secondly, carbon dioxide reduces the interfacial tension between oil and water. In an oil reservoir, the presence of water can create a barrier that hinders the flow of oil. By reducing the interfacial tension, carbon dioxide makes it easier for the oil to flow through the porous rock formations.^[2]

This technology has been widely adopted in many countries and regions around the world. In the United States, for example, CO₂ - EOR has been used in mature oil fields in Texas and Wyoming. These fields have already produced a large amount of oil, but with the application of CO₂ - EOR, additional oil reserves can be extracted, extending the economic life of the fields. In China, some oil fields in the Ordos Basin and the Tarim Basin have also started to experiment with CO₂ - EOR technology, showing promising results in improving oil recovery rates^[1].

2.2 Geological Sequestration

Geological sequestration is a long - term solution for reducing atmospheric carbon dioxide levels. The basic idea is to inject carbon dioxide into deep underground reservoirs where it can be stored for an extended period. There are several common methods of geological sequestration.

Deep - sea sequestration involves injecting carbon dioxide into the deep ocean floor. The cold temperature and high pressure at great depths can keep the carbon dioxide in a stable liquid or super - critical state. However, this method also raises concerns about the potential impact on the marine ecosystem. For example, the increased acidity of the surrounding seawater due to carbon dioxide dissolution may harm marine organisms, especially those with calcium carbonate shells^[2].

Saline aquifer sequestration is another option. Saline aquifers are underground layers of porous rock filled with saltwater. These aquifers are widespread and have a large storage capacity. Carbon dioxide can be injected into these aquifers, where it will dissolve in the saltwater or be trapped by the geological structure.

Depleted oil and gas fields are also suitable for carbon dioxide sequestration. After the extraction of oil and gas, these fields have existing infrastructure, such as wells and pipelines, which can be reused for carbon dioxide injection. Additionally, the geological structure of these fields has already been studied in detail during the oil and gas exploration process, reducing the uncertainty associated with sequestration.

3. CHALLENGES IN GEOLOGICAL APPLICATIONS OF CARBON DIOXIDE

3.1 Leakage Risks

Leakage is one of the most significant challenges in geological sequestration of carbon dioxide. There are multiple potential leakage pathways. Faults and fractures in the geological formation can act as conduits for carbon dioxide to escape from the storage reservoir. If the seal rock above the reservoir is not intact, carbon dioxide can migrate upwards and reach the groundwater system.

Once carbon dioxide enters the groundwater, it can react with water to form carbonic acid. This acidification can change the chemical composition of the groundwater, affecting the solubility of various minerals. For example, it may dissolve heavy metals such as lead and mercury, which are normally present in the soil or rock in an insoluble form. The contaminated groundwater can then pose a threat to human health if it is used for drinking or irrigation.

If carbon dioxide leaks back into the atmosphere, it will undermine the purpose of geological sequestration and exacerbate the greenhouse effect. Therefore, continuous monitoring and effective prevention of leakage are essential for the success of carbon dioxide geological sequestration projects. *Real-time Monitoring and Data Analysis*

3.2 Geological Structure Stability

The injection of carbon dioxide can have a profound impact on geological structures. When carbon dioxide is injected into the reservoir, it increases the formation pressure. This pressure increase can cause the rocks to deform or fracture. In some cases, it may trigger micro - seismic events.

The long - term stability of geological sequestration is closely related to the integrity of the geological structure. If the structure is weakened due to carbon dioxide injection, there is a risk of large - scale leakage in the future. Moreover, the complexity and uncertainty of geological structures make it difficult to accurately predict and assess the long - term impact of carbon dioxide injection. Different geological regions have different rock types, sedimentary histories, and stress fields, which all need to be considered when evaluating the stability of carbon dioxide storage^[3].

4. APPLICATION OF COMPREHENSIVE WELL LOGGING TECHNOLOGY IN GEOLOGICAL APPLICATIONS OF CARBON DIOXIDE

4.1 Overview of Comprehensive Well Logging Technology

Comprehensive well logging technology is a multi-disciplinary and advanced monitoring technique. It combines various sensors, such as pressure sensors, temperature sensors, and gas composition sensors, to continuously collect data on key parameters in the wellbore and the surrounding formation. These sensors are designed to work in harsh underground environments, with high precision and reliability.

The data collected by these sensors are then analyzed using modern data analysis methods. Machine learning algorithms, for example, can be used to identify patterns and trends in the data. By analyzing historical data from similar projects and real-time data from the current well, these algorithms can predict the behavior of carbon dioxide in the reservoir, such as its migration path and distribution^[4].

This technology not only provides a real-time picture of the current state of the carbon dioxide injection process but also helps to make informed decisions about future operations. For example, if the data indicate that the injection rate is causing excessive pressure increase, the injection rate can be adjusted to ensure the safety of the project.

4.2 Real-time Monitoring and Data Analysis

Real-time monitoring is a key feature of comprehensive well logging technology. By continuously measuring formation pressure, temperature, and gas composition, it can detect any abnormalities in the carbon dioxide injection process promptly.

For instance, an abnormal increase in formation pressure may indicate that the carbon dioxide is not being properly absorbed by the reservoir or that there is a blockage in the injection well. Similarly, a change in gas composition may suggest that carbon dioxide is reacting with the surrounding rocks or that there is a leakage in the system.

Once an abnormality is detected, an alarm can be triggered, and relevant personnel can take immediate action. Data analysis techniques play a crucial role in this process. By analyzing the collected data, experts can understand the root cause of the problem and develop appropriate solutions. For example, if the data show that the carbon dioxide is migrating towards a potential leakage pathway, measures can be taken to block the pathway or adjust the injection strategy.

Moreover, data analysis can also be used to optimize the injection scheme. By analyzing the relationship between injection parameters (such as injection rate, pressure, and gas composition) and the response of the formation, the injection process can be fine-tuned to improve the efficiency of carbon dioxide sequestration and oil recovery.

4.3 Geological Structure Monitoring and Assessment

Comprehensive well logging technology can also be used to monitor changes in the geological structure. By measuring formation pressure variations and rock deformations, it can detect any signs of geological structure instability.

For example, if the pressure in a certain part of the reservoir suddenly drops, it may indicate that a fracture has occurred in the rock. By continuously monitoring these parameters, potential risks can be identified at an early stage.

In addition to real-time monitoring, comprehensive well logging technology can also be combined with geological models and simulation analyses. These models can simulate the long-term behavior of the geological structure under the influence of carbon dioxide injection. By comparing the simulation results with the real-time data, the accuracy of the models can be improved, and more reliable predictions of geological structure stability can be made. This provides a scientific basis for decision-making in carbon dioxide geological sequestration projects, such as determining the optimal injection location and rate.

4.4 Case Study

In a CO₂ - EOR project in a large oilfield, comprehensive well logging technology was fully utilized. During the project, the well logging sensors continuously monitored formation pressure, temperature, and gas composition.

One day, the sensors detected an abnormal increase in formation pressure in a particular area of the reservoir. The data analysis team immediately analyzed the data and found that the increase was due to a blockage in one of the injection channels. Based on this analysis, the engineering team quickly took corrective measures, such as adjusting the injection rate and flushing the blocked channel. This prevented the pressure from rising further and avoided the potential risk of leakage.

Furthermore, through long-term data analysis, the team was able to predict the migration and distribution of carbon dioxide in the reservoir. They optimized the injection scheme by adjusting the injection points and

rates in different parts of the reservoir. As a result, the oil recovery efficiency was significantly improved, and the carbon dioxide was more effectively sequestered in the reservoir.

5. CONCLUSION AND OUTLOOK

The application of carbon dioxide in geological fields, including CO₂ - EOR and geological sequestration, holds great potential for both economic development and climate change mitigation. However, the challenges of leakage risks and geological structure stability cannot be ignored.

Comprehensive well logging technology has proven to be an effective solution to these challenges. By real-time monitoring of key parameters and integration with modern data analysis methods, it can precisely evaluate the effects of carbon dioxide injection, predict and monitor its migration and distribution, and ensure the safety and long-term stability of geological applications.

In the future, further research and development are needed to improve the accuracy and reliability of comprehensive well logging technology. New sensors with higher sensitivity and better durability need to be developed to adapt to more complex geological environments. Moreover, more advanced data analysis algorithms should be explored to handle the large-scale and complex data generated by well logging systems. With continuous improvement, comprehensive well logging technology will play an even more important role in the safe and sustainable implementation of carbon dioxide geological applications..

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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