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Evaluation of CO2 Sealing Effectiveness in Balixi Buried Mountain of Huabei Oilfield

Sun Honghua[1] Zhang Mingyang[1] Fan Wei[1] Guo Sujie[1] Zhang Wenping[1]
1 No.2 Mud Logging Company, BHDC
(Corresponding Author:sunhonghua@cnpc.com.cn)

ABSTRACT

Carbon Capture, Utilization, and Storage is a greenhouse gas emission reduction . To achieve a win-win target of improving oil recovery and carbon sequestration through gas injection, Huabei Oilfield has conducted carbon dioxide-enhanced oil recovery and carbon sequestration pilot tests in the Balixi Buried Mountain Oil Reservoir. With a increase in gas injection wells, CO2 was detected in Dongying Formation and Shahejie Formation of the upper strata of the buried mountain in new drilled wells. A carbon isotope investigation was conducted on those wells to further clarify the source of CO2 and evaluate the effectiveness of the buried mountain closure,. Based on this investigation, an novel method evaluating the CO2 storage and injection capacities of the heterogeneous carbonate reservoirs in Balixi Buried Mountain was established. A total of 4000 sampling points of 3 wells are used to establish the new model. From the results, it was clarified that the isotope in the active sections of CO2 gas measurement is lighter in the Dongying Formation of Balixi Buried Mountain. Meanwhile, the composition in those sections is dry, showing the characteristics of mainly biogenic gas. In contrast, the carbon isotope of the active sections of CO2 gas measurement is heavier in the Shahejie Formation had a heavier carbon isotope weight and higher Meanwhile, the composition in those sections is humidity, showing the characteristics of thermogenic gas. Therefore, CO2 in the Dongying Formation and Shahejie Formation of the upper strata of Balixi Buried Mountain is self-generated in the strata, further confirming the effective closure of the buried mountain.

Keywords: CCUS, Balixi Buried Mountain, Carbon Isotope Technology, Effectiveness

NONMENCLATURE

Abbreviations	
APEN	Applied Energy
Symbols	
n	Year

1. INTRODUCTION

1.1 Research Background

With the aggravation of global climate change, greenhouse gas emissions have become a focus of international concern. Carbon Capture, Utilization, and Storage (CCUS) technology is an effective means to reduce atmospheric carbon dioxide concentrations and plays a significant role in mitigating climate change[1]. The CCUS project in the Bayi Lishan oil reservoir of the Huabei Oilfield aims to achieve efficient exploitation of oil and gas resources and dual goals of environmental protection through carbon dioxide-enhanced oil recovery and storage.

1.2 Purpose and Significance of the Research

The main purpose of this study is to use carbon isotope technology to clarify the source of carbon dioxide in the Bayi Lishan oil reservoir, evaluate the effectiveness of the buried hill closure, and establish an evaluation method for the non-homogeneous carbonate reservoir's CO2 injection and storage capacity. This is crucial for optimizing the application of CCUS technology, improving oil recovery rates, and ensuring environmental safety.

1.3 Research Methods and Materials

This study employed geological exploration, experimental analysis, and numerical simulation

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methods. By collecting geological data from the Bayi Lishan oil reservoir and combining field test data with carbon isotope analysis techniques, the sources of carbon dioxide were systematically studied and analyzed.

1.4 Domestic and International Research Status

Research on CCUS technology has made progress in various countries, but its application in non-homogeneous carbonate reservoirs still faces challenges. The innovative aspect of this study lies in the application of carbon isotope technology in the CCUS project of the Bayi Lishan oil reservoir[2], providing a new research perspective and technical path for similar geological conditions.

2. CCUS TECHNOLOGY OVERVIEW

2.1 Definition of CCUS Technology

Carbon Capture, Utilization, and Storage (CCUS) technology involves capturing carbon dioxide (CO2) produced during industrial processes, utilizing it in various ways, or storing it long-term to reduce atmospheric concentrations of greenhouse gases. It is considered a key route to achieving low-carbon economic development and has a significant impact on mitigating global climate change.

2.2 Classification of CCUS Technology

CCUS technology mainly includes three components: carbon capture, carbon utilization, and carbon sequestration. Carbon capture involves directly capturing CO2 from large emission points such as fossil fuel power plants and steel mills through chemical absorption, physical adsorption, or membrane separation methods. Carbon utilization encompasses converting captured CO2 into valuable products or services, such as using it as a raw material in chemical production or promoting plant photosynthesis to enhance crop growth. Carbon sequestration stores captured CO2 in underground rock layers, deep oceans, or through mineralization to isolate it from the atmosphere over long periods. Underground rock layer storage is the most mature and widely used carbon sequestration method currently[3].

2.3 Application Areas of CCUS Technology

CCUS technology is widely applied in sectors including fossil fuel power generation, steel manufacturing, cement production, and other heavy industries. Moreover, it is utilized in the petroleum extraction industry by injecting CO2 to enhance oil recovery while achieving carbon sequestration.

2.4 Trends and Challenges of CCUS Technology Development

With the global consensus on reducing greenhouse gas emissions growing, CCUS technology has developed rapidly. However, high costs, technological complexity, legal and regulatory inadequacies, and public acceptance remain major challenges to its promotion. Future innovation and policy support will be key factors driving the development of CCUS technology.

3. OVERVIEW OF THE BAYI LISHAN OIL RESERVOIR IN THE HUABEI OILFIELD

3.1 Geographical Location and Geological Structure

Located in the central area of the Huabei Oilfield, the Bayi Lishan oil reservoir boasts advantageous geographical positioning and convenient transportation. Geologically, it features a typical buried-hill structure composed of complex fault blocks formed by multiple tectonic movements, providing excellent conditions for hydrocarbon accumulation.

3.2 Type and Characteristics of the Oil Reservoir

The Bayi Lishan oil reservoir is a deep, high-pressure, high-yield oil field characterized by non-homogeneous carbonate rock formations. Despite strong reservoir properties within the reservoir, complex geological conditions make hydrocarbon distribution uneven, presenting certain difficulties to development.

3.3 Development History and Current Status

Since its discovery, the Bayi Lishan oil reservoir has undergone initial exploration evaluation, intermediate development adjustment, and advanced deepening development stages. Currently, as the reservoir enters a high water cut period, oil recovery rates are gradually decreasing, necessitating the adoption of new technologies to enhance oil recovery and extend the lifespan of the oilfield.

3.4 Problems and Challenges

Despite the abundant oil and gas resources in the Bayi Lishan oil reservoir, its development process also faces a series of problems and challenges. Firstly, the high-temperature and high-pressure conditions of deep reservoirs make conventional development techniques difficult to apply[4]. Secondly, the reservoir's internal non-homogeneity and complex geological structures complicate hydrocarbon distribution predictions. Additionally, as water cut increases and recovery rates drop during development, how to effectively enhance recovery rates becomes an urgent issue. Finally, stricter environmental protection requirements necessitate green development while ensuring development efficiency.

4. CARBON DIOXIDE-ENHANCED OIL RECOVERY AND STORAGE PILOT TEST

4.1 Test Purpose and Methods

To improve oil recovery rates and achieve carbon emission reduction targets in the Bayi Lishan oil reservoir of the Huabei Oilfield, a pilot test of carbon dioxide-enhanced oil recovery and storage was conducted. The primary aim was to verify the feasibility and effectiveness of the carbon dioxide-enhanced oil recovery technique and to evaluate the effectiveness of the buried hill closure system. The test included designing injection wells, constructing and monitoring systems to accurately record and analyze test data[5].

4.2 Test Results Analysis

Analysis of data collected during the test period indicates that oil production significantly increased after CO2 injection, demonstrating good application prospects for the carbon dioxide-enhanced oil recovery technique in this oil reservoir. Monitoring data also showed that CO2 distribution in the reservoir matched expectations, without evident leakage, preliminarily proving the effectiveness of the buried hill closure system.

4.3 Problems and Solutions

During the test, some injection wells experienced higher injection pressures than anticipated, potentially increasing the risk of formation fractures. To address this, injection parameters were adjusted, and the layout of injection wells was optimized to reduce risks and enhance injection efficiency. Additionally, to monitor CO2 migration and distribution more accurately, the number of monitoring wells was increased. These measures ensured smooth testing and accurate data collection.

5. STUDY ON CARBON ISOTOPE TECHNOLOGY

5.1 Basic Principles and Applications of Carbon Isotope Technology

Carbon isotope technology is based on different isotopic ratios (13C/12C) of carbon dioxide from various sources. Analyzing these ratios in samples allows for tracing the origin of carbon dioxide, determining whether it is biogenically or thermogenically produced. This technology plays a crucial role in petroleum exploration, environmental monitoring, and the assessment of CCUS projects.

5.2 Establishment of Evaluation Methods for Non-Homogeneous Carbonate Reservoir CO2 Injection and Storage Capacity in Bayi Lishan

A set of evaluation methods for CO2 injection and storage capacity tailored to the geological characteristics of non-homogeneous carbonate reservoirs in the Bayi Lishan oil reservoir was established[6]. This method integrates knowledge from geology, geochemistry, and engineering by analyzing the physical properties, porosity, permeability of reservoir rocks, and carbon isotope data comprehensively to assess storage capacity.

5.3 Analysis of Carbon Isotope Test Results

Carbon isotope tests on CO2 from the Dongying and Shaxi formations of the Bayi Lishan oil reservoir revealed that CO2 from the Dongying formation had lighter isotopes, indicating biogenic gas characteristics; whereas CO2 from the Shaxi formation exhibited heavier isotopes, suggesting thermogenic gas properties. These results demonstrated the autogenic nature of carbon dioxide in the strata, providing a scientific basis for further application of CCUS technology.

5.4 Verification of Buried Hill Closure Effectiveness

Combining carbon isotope test results with other geological data verified the effectiveness of the buried hill closure system in the Bayi Lishan oil reservoir. The results showed that the buried hill closure system could effectively prevent upward CO2 migration, confirming its sealing performance in CCUS projects. This discovery is crucial for guiding subsequent CCUS operations and optimization designs.

6. CONCLUSIONS AND OUTLOOK

6.1 Research Achievements

Through the carbon dioxide-enhanced oil recovery and storage pilot test combined with carbon isotope technology applications in the Bayi Lishan oil reservoir of the Huabei Oilfield, this study successfully established an evaluation method for non-homogeneous carbonate reservoir CO2 injection and storage capacity. Research findings indicate that the

CO_2 in the Dongying formation primarily exhibits biogenic gas characteristics, while that in the Shaxi formation shows thermogenic gas traits, both derived autogenously from strata. Furthermore, the effectiveness of the buried hill closure system was verified, providing a scientific basis for applying CCUS technology in this oil reservoir.

6.2 Limitations and Shortcomings of Research

Although this study achieved positive results, it still has certain limitations and shortcomings. For instance, the limited number of carbon isotope test samples may not fully represent the entire oil reservoir. Additionally, the long-term stability and safety of the buried hill closure system require further monitoring and study. Future work needs to expand sample sizes to enhance data representativeness and reliability.

6.3 Suggestions for Future Research and Practice

Given the limitations of current research, it is suggested that future studies should increase the number of sample points to cover a wider area, thus more accurately assessing the storage and injection capacity of CCUS technology as well as the effectiveness of buried hill closure. Additionally, it is recommended to initiate long-term monitoring programs to evaluate the environmental impacts and economic benefits of CCUS projects. Furthermore, interdisciplinary collaboration is encouraged, integrating the latest research findings from geology, geochemistry, engineering, and other fields to continuously optimize the application strategies of CCUS technology.

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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