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Analysis of the Long-term Benefits and Drawbacks of Carbon Dioxide EOR in Offshore Oilfields

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Abstract: *This article examines the benefits and drawbacks of using carbon dioxide for enhanced oil recovery (EOR) in offshore oil fields. The process of injecting carbon dioxide into subterranean oil reservoirs not only increases crude oil production but also reduces carbon emissions and cuts extraction costs, thereby playing a crucial role in promoting the sustainable development of the petroleum industry. However, the method is not without its challenges, including the potential for environmental harm to marine life and aquatic ecosystems, as well as significant economic expenditures and the risk of carbon dioxide leakage. To optimize the benefits of this technology, the article recommends a range of measures, such as enhancing the recycling and utilization of carbon dioxide, developing robust safety and monitoring technologies, increasing financial investment, and seeking government support. Through the collaborative efforts of all stakeholders, the full potential of this technology can be harnessed to achieve a critical balance between profitable oil recovery and the priority of environmental stewardship.*

Keywords: *Carbon Dioxide Oil Recovery, Benefits, Drawbacks, Suggestions, Offshore Oil Fields*

1. Introduction

Carbon dioxide offshore oil field recovery technology is a technology with both long-term benefits and drawbacks. The principle of carbon dioxide offshore oil recovery technology is based on specific pressure, temperature, and crude oil characteristics, allowing carbon dioxide to mix with the crude oil in the reservoir. At the initial contact, carbon dioxide does not mix with crude oil, but under certain conditions, carbon dioxide can interact with compounds in crude oil to create a mixed phase state, which in turn drives the crude oil towards the production well[1]. It can increase crude oil production and reduce carbon emissions by injecting carbon dioxide[2]. However, this technology is not without its flaws, and it also faces a series of difficulties and challenges, which require us to conduct more profound analysis and thinking. Especially at present, the global climate change issue is becoming increasingly severe, and governments and businesses around the world are actively seeking ways to reduce carbon emissions. In the petroleum industry, carbon dioxide flooding is a feasible solution.

Many countries began exploring methods for improving oil recovery through CO2 flooding in laboratories and on site in the 1950s, with the United States being the earliest country to study and apply them. In the 1970s, the United States began conducting on-site experiments on carbon dioxide oil recovery and achieved certain success. The main innovation lies in the discovery that carbon dioxide can physically and chemically interact with crude oil, thereby improving its fluidity and increasing recoverable reserves. However, this method has some problems, such as the injection of carbon dioxide forming a large number of bubbles in the reservoir, leading to a decrease in reservoir stability, and even causing serious consequences such as blowout. As research progressed, insights into the advantages of carbon dioxide (CO2) flooding technology were gradually unveiled. For instance, CO2 can undergo chemical reactions with petroleum molecules in the reservoir, leading to the formation of stable compounds that act as solid cores, enhancing reservoir stability. Moreover, CO2 can also be injected to regulate reservoir pressure, enabling more precise control over oil production. During the 1980s and 1990s, CO2 flooding technology underwent rapid development, spurred by the adoption of advanced injection techniques and control methods, such as high-temperature and high-pressure CO2 injection to enhance oil production. Additionally, new flooding technologies were developed, including CO2-water mixed flooding, which can more effectively manage reservoir pressure and boost oil production. In the 21st century, CO2 flooding technology saw widespread adoption. This period saw the deployment of CO2 flooding in offshore oil fields, which are typically located in deep waters where traditional extraction techniques are impractical. Offshore CO2 flooding primarily involves the injection of CO2

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and water, leveraging the solubility and reactivity of CO2 to elevate reservoir pressure and increase oil production.

This technology has developed rapidly in recent years, especially with the increasing demand for offshore CO2 storage, the application of CO2-EOR has expanded from land to sea. Internationally, significant progress has been made in the application of CO2-EOR. For example, the United States has a considerable scale and technological process in this field, and is in a dominant position globally[3]. The United States currently operates 11 large-scale industrial projects for carbon capture, utilization, and storage (CCUS) and enhanced oil recovery (EOR). The annual capture capacity of these projects ranges from 16.28 million to 18.64 million tons, of which over 90% of carbon dioxide is used for oilfield development, such as oil recovery to enhance oil recovery. In China, the first offshore carbon dioxide storage demonstration project is located in the eastern waters of the South China Sea, which is the largest offshore oil production platform in Asia. This project has successfully achieved a complete set of technology and equipment system for capturing, treating, injecting, storing, and monitoring carbon dioxide at sea, filling the gap in China's offshore carbon dioxide storage technology. The Enping 15-1 platform is expected to store 300000 tons of carbon dioxide annually during peak periods, with a cumulative capacity exceeding 1.5 million tons.

Overall, carbon dioxide offshore oil recovery technology has been widely applied and developed globally, especially in regions such as the United States and China. While improving oil recovery, this technology has also achieved effective utilization and storage of carbon dioxide[4].While the technology has met with some success, it still faces challenges, including high costs associated with CO2 capture and transportation, safety concerns, and environmental implications.

2. Analysis of Long term Benefits of Carbon Dioxide Offshore Oil Field Flooding

2.1 Increase oilfield production

CO2 can be used to increase oil recovery to increase value of CO2 sequence[5]. Oilfield production is a key indicator of oilfield development, which directly affects the economic benefits of petroleum enterprises. Carbon dioxide oil recovery technology is prone to mixed phase reactions with formation crude oil, resulting in oil volume expansion and viscosity decrease. After mixing with formation water, the viscosity of water increases, the migration speed accelerates, the interfacial tension between oil and water decreases, the oil sweep area increases, and the oil recovery rate is improved. For example, Daqing Oilfield has improved crude oil recovery by utilizing carbon dioxide flooding technology, while achieving the capture and burial of carbon dioxide. It is expected to increase the recovery rate by 9 to 12 percentage points, enabling petroleum enterprises to develop the oilfield more efficiently and thereby improve the oilfield recovery rate.

Carbon dioxide offshore oil recovery technology can reduce the difficulty of oilfield development[6]. This technology dissolves the oil in the oilfield into carbon dioxide by injecting it, and takes it out of the oilfield, thereby reducing the difficulty of oilfield development. The solution of CO2 in petroleum helps to recover the expanded oil and improve the flow rate in small pores and throws[7]. The use of this technology can reduce the risks during oilfield development, enabling petroleum enterprises to develop oilfields more safely, thereby reducing the cost of oilfield development.

2.2 Reducing carbon emissions and greenhouse gas emissions

Carbon dioxide offshore oil field displacement technology, as an effective means of reducing carbon emissions and greenhouse gas emissions, has significant application value in the oil extraction process. Firstly, the basic principle of this technology is to inject a certain amount of carbon dioxide into the oilfield, reduce the internal pressure of the oilfield, and occupy the pore space originally occupied by oil with carbon dioxide, thereby increasing crude oil production. During this process, the emission of carbon dioxide has been significantly reduced compared to traditional oil extraction technologies. Moreover, this technology can effectively reduce greenhouse gas emissions during oil extraction, contributing to the mitigation of global climate change issues.

Secondly, carbon dioxide offshore oil field displacement technology has significant environmental advantages in practical applications. Carbon dioxide is a renewable resource that can be used in various fields such as agriculture, industry, and energy. Moreover, carbon dioxide oil displacement technology can effectively reduce carbon emissions and greenhouse gas emissions during oil extraction, contributing to the mitigation of global climate change issues and aligning with current international environmental standards.

In summary, carbon dioxide offshore oil field displacement technology has significant environmental benefits in the oil extraction process and contributes to mitigating global climate change issues. By continuously optimizing and improving carbon dioxide oil displacement technology, we can better leverage its environmental advantages and achieve a win-win situation between oil extraction and environmental protection.

2.3 Reducing Oil Extraction Costs

Carbon dioxide offshore oil field recovery technology, as a new type of oilfield development technology, has been widely applied in recent years. This technology can effectively reduce energy consumption, material consumption, and other costs during the oil extraction process, thereby improving the competitiveness of petroleum enterprises.

Carbon dioxide offshore oil field displacement technology offers significant cost advantages over traditional oilfield development techniques, which primarily rely on chemical flooding and thermal recovery methods. These methods require substantial chemical and thermal energy consumption, resulting in high costs and environmental pollution. In contrast, carbon dioxide flooding technology consumes no chemicals or thermal energy and only utilizes existing production facilities, leading to lower costs.

This technology can effectively reduce energy and material consumption during the oil extraction process. Traditional oilfield development techniques require large amounts of energy and chemicals to sustain production, whereas carbon dioxide flooding technology can utilize existing production facilities and employ carbon dioxide as an oil displacement agent, thereby reducing energy and material consumption.

CO2 EOR is an economically effective method for enhancing oil extraction. This technology not only enhances the recovery rate of low-permeability oil fields but also reduces greenhouse gas emissions, aligning with national requirements for addressing climate change and carbon reduction. Specifically, carbon dioxide flooding technology enhances oil recovery by capturing, purifying, and injecting carbon dioxide underground for oilfield displacement, achieving significant economic and social benefits. According to research and practice, carbon dioxide flooding can increase oilfield recovery by 10% to 20%. The adoption of this technology enables oil companies to develop oil fields more efficiently, achieving higher economic benefits.

In summary, carbon dioxide offshore oilfield recovery technology, as a new type of oilfield development technology, has significant cost advantages. Therefore, it is necessary to use and manage it scientifically and reasonably to achieve its maximum benefits.

2.4 Promoting Sustainable Development of the Petroleum Industry

Carbon dioxide offshore oil field recovery technology, as a new type of oil extraction technology, has attracted widespread attention for its long-term benefits and drawbacks. This article will analyze in detail the promoting effect of this technology on the sustainable development of the petroleum industry.

Firstly, carbon dioxide offshore oil field recovery technology helps to achieve sustainable development of the petroleum industry. The study results show that there is significant potential for enhancing oil recovery and storage CO2 in oil fields in the North Sea[1]. Traditional oil extraction technologies, such as water flooding, gas flooding, chemical flooding, etc., have problems such as high energy consumption, serious pollution, and resource waste. Carbon dioxide oil recovery technology can effectively solve these problems. The carbon dioxide oil recovery technology utilizes the physical and chemical properties of carbon dioxide to inject it into the oil reservoir, causing the crude oil in the reservoir to form a solution soluble in carbon dioxide, thereby improving oil recovery efficiency. Compared with traditional extraction techniques, carbon dioxide oil recovery technology can reduce energy consumption, reduce pollution, improve oil recovery, and has significant sustainability advantages.

Secondly, this technology provides a guarantee for energy security. With the rapid development of the economy and the increasing demand for energy, the supply-demand contradiction of petroleum resources is becoming increasingly prominent. The development and application of carbon dioxide oil recovery technology can effectively improve oil recovery rate, alleviate the shortage of oil resources, and ensure national energy security.

In summary, as a new type of oil extraction technology, this technology has significant sustainability advantages and can provide guarantees for energy security.

3. Analysis of Disadvantages of Carbon Dioxide Offshore Oil Field Flooding

3.1 Impact on the environment

Carbon dioxide offshore oil recovery technology is a new type of oilfield development technology that utilizes the solubility of carbon dioxide to increase oilfield production by injecting a large amount of carbon dioxide into the seabed[8].

This technology may have an impact on the marine environment. Carbon dioxide is a greenhouse gas that can absorb the heat reflected off the Earth's surface, leading to global warming. Offshore CO2-EOR may face groundwater pollution, salt water treatment challenges, high CO2 injection rate risks, and offshore leakage issues, which may increase operational risks. In addition, the dissolution and release of carbon dioxide in the ocean may also have an impact on the chemical equilibrium of the ocean, leading to changes in marine chemical reactions.

In summary, while increasing oilfield production, this technology may also have certain impacts on the marine environment. Therefore, when applying carbon dioxide oil recovery technology, it is necessary to consider these impacts and take corresponding measures to reduce them.

3.2 Damage to underwater ecosystems

While providing energy for humans, the carbon dioxide offshore oil displacement technology may also cause damage to the seabed ecosystem and affect marine ecological balance.

In practical applications, this technology may cause certain degrees of damage to the seabed ecosystem. On the one hand, the injection of large amounts of carbon dioxide into the seabed by carbon dioxide oil recovery technology may lead to an increase in carbon dioxide content in seabed sediments, thereby affecting the acid-base balance of the seabed ecosystem. On the other hand, the dissolution and diffusion of carbon dioxide in seabed sediments may alter the acquisition of oxygen by benthic organisms, thereby affecting their survival and reproduction.

The destruction of underwater ecosystems by this technology may further affect the balance of marine ecology. The marine ecosystem is a complex biosphere, where organisms depend on and constrain each other. If the underwater ecosystem is damaged, it may lead to the interruption of the marine food chain, which in turn affects the stability of the entire marine ecosystem.

In addition, the destruction of underwater ecosystems may exacerbate global climate change, affecting human survival and development. Therefore, in the process of promoting the application of this technology, full consideration should be given to its potential impact on the seabed ecosystem, effective measures should be taken to reduce its negative impact, and sustainable development of marine oil and gas development should be achieved. At the same time, efforts should also be made to strengthen the protection of underwater ecosystems, enhance human understanding and attention to marine ecosystems, and jointly maintain marine ecological balance.

3.3 High cost risk

The economic feasibility of offshore carbon dioxide oil recovery is a multifaceted issue. CO2 EOR technology can improve oil recovery by injecting carbon dioxide into the reservoir, while achieving the utilization and storage of carbon dioxide. This is an important component of Carbon Capture, Utilization and Storage (CCUS) technology. Despite its enormous potential, there are still some challenges, including limitations in technological level, small market size, unstable oil recovery effects, and low transportation capacity.

The cost of carbon dioxide oil recovery technology is high and requires a large amount of investment and technical support. Offshore CO2-EOR faces challenges such as high costs, reserve uncertainty, CO2 supply limits, lake of business models, and regulatory uncertainty. In addition, the capital intensive nature and challenging environment of offshore operations increase the financial risks

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and uncertainties of the project[9].

Overall, offshore carbon dioxide oil recovery technology has enormous economic potential, but it still needs to solve a series of technical problems and improve its technological level in order to achieve its commercial application and large-scale development. Meanwhile, government policy support and investment in CCUS technology are also important factors driving the development of this field.

3.4 Risk of carbon dioxide leakage

Offshore carbon dioxide enhanced oil recovery and storage technology is a crucial means to achieve the "dual carbon" objective, but its potential leakage risk cannot be ignored[10]. The primary risk associated with subsea CO2 geological storage is the potential geological disasters triggered by CO2 leakage, such as submarine landslides, posing a threat to marine engineering safety. Therefore, environmental geological monitoring of storage areas is essential to ensure the safety of marine carbon storage.

In shallow water environments, the integrity failure of CCUS (Carbon Capture, Utilization, and Storage) wellbore may have severe consequences. minor issues may shorten the lifespan of the wellbore and equipment, increasing maintenance and renovation costs. In more severe cases, the integrity failure of the wellbore may lead to CO2 leakage, posing a threat not only to the safety of personnel but also to the marine environment. Therefore, when storing and utilizing CO2 in offshore oil and gas fields, the integrity and sealing of the wellbore are essential for achieving efficient utilization.

Currently, the main safety risks faced by offshore oil and gas fields during CCUS projects based on CO2 enhanced oil recovery include: unstable geological storage space due to pressure changes, which may cause geological deformation or earthquakes; geological bodies may leak through wellbore, faults, or fractured overlying layers; The uneven displacement process may affect the recovery rate. Once CO2 leaks, it not only leads to a large amount of greenhouse gas emissions into the atmosphere but may also pose a serious threat to human safety, such as the 1986 Nios Lake CO2 leak in Cameroon, which resulted in at least 1200 deaths.

From the perspective of wellbore integrity, the main causes of carbon dioxide leakage may include: corrosion of cement rings in high carbon dioxide content environments, corrosion of wellbore columns and key downhole equipment, sealing issues of traps, and wellbore blockage.

4. Suggestion

This article proposes some suggestions to better utilize carbon dioxide offshore oil field displacement technology and maximize its long-term benefits. Firstly, we need to strengthen the recovery and utilization of carbon dioxide, as carbon capture, utilization, and storage (CCUS) technology can achieve its goals. CCUS includes geological utilization, chemical utilization, and biological utilization. For example, using carbon dioxide for oil recovery, producing chemicals or fuels, and using microalgae plants for biotransformation. CCUS technology has significant benefits in improving oil recovery and reducing carbon emissions, thereby reducing environmental pollution. Secondly, we need to strengthen the research and development of technology and risk control. The integrated technology of carbon dioxide geological storage and enhanced oil and gas recovery can achieve large-scale carbon dioxide storage while improving oil and gas recovery. However, the injected carbon dioxide continues to migrate underground, which may pose a risk of leakage. Therefore, while studying the improvement of storage efficiency, attention should be paid to the development of carbon dioxide leakage safety monitoring technology to achieve long-term and safe storage. In addition, we also need to strengthen financial investment, such as funding for scientific research projects. Many research on carbon dioxide leakage safety monitoring technologies are funded by national or local scientific research projects. There is also enterprise investment. The Energy Conservation and Emission Reduction Monitoring Center of China National Offshore Oil Corporation and the Key Laboratory of Low Carbon Transformation Science and Engineering of the Chinese Academy of Sciences Shanghai Institute of Advanced Research have all participated in relevant research. Finally, there is government support, with governments of various countries providing financial support for research on carbon dioxide leak monitoring technology through national budgets and special funds.

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5. Conclusion

Carbon dioxide offshore oil field recovery technology can increase oilfield production, reduce carbon emissions, and lower production costs, playing an important role in promoting sustainable development of the petroleum industry. However, this technology also has the potential to cause damage to the marine environment and underwater ecosystems, as well as high costs and leakage risks. In response to these drawbacks, this article proposes some suggestions, including strengthening the recycling and utilization of carbon dioxide, developing safety monitoring technologies, increasing investment and government support, etc., to achieve the maximization of long-term benefits of carbon dioxide offshore oil field recovery technology.

In summary, carbon dioxide offshore oil field recovery technology has significant long-term benefits, but there are also certain drawbacks. By taking corresponding measures, the advantages of this technology can be fully utilized to achieve a win-win situation between oil extraction and environmental protection. This requires joint efforts from the government, enterprises, and research institutions to promote the healthy development of this technology.

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