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ANALYSIS OF THE INTERNATIONAL PRACTICE OF CO^2 INJECTION AS ONE OF THE EOR METHODS

Abstract. CO^2 flooding is currently a popular method employed for enhanced oil recovery (EOR). The initial mention of utilizing CO^2 as an injection gas to enhance oil production dates back to 1916, although its economic feasibility was not established until the 1950s. Initially, alternative gases such as propane, liquefied petroleum gas, and natural gas were utilized, but CO^2 emerged as a more cost-effective and efficient option. The first CO^2 flooding project commenced in 1964, followed by a larger-scale project in 1972. Subsequently, successful CO^2 flood implementations have been witnessed in diverse regions including the United States, Canada, Hungary, Turkey, Trinidad, and Brazil. Among these, the United States stands out with 67 operational CO^2 flood projects, while other countries face challenges such as limited infrastructure and sources. To date, over 100 EOR projects involving CO^2 flooding have been recorded. This publication presents a comprehensive overview of international experiences and methodologies pertaining to the application of CO^2 flooding for enhancing oil production efficiency. Furthermore, it emphasizes the potential projects and applications of this technology within the context of Kazakhstan.

Key words: EOR, CO^2 injection, oil recovery, miscible mode, immiscible mode, Kazakhstan.

Introduction

In the 21st century, the volume of hard-to-recover reserves is increasing. With the development and discovery of new fields, the percentage of hard-to-recover reserves has increased markedly, and a significant number of large deposits have approached the withdrawal threshold from the initial recoverable reserves of 70%, which is the boundary after which the residual reserves become hard-to-recover. In this regard, one has to deal with an increasing number of problems in oil production, the solution of which by applying classical methods of enhanced oil recovery becomes impossible.

A possible extended-term solution to alleviate the adverse impacts of global warming is a technique of infusing CO^2 into geological structures in oil fields, which serves the dual objective of capturing CO^2 and concurrently improving oil retrieval (EOR). This article presents a summary of worldwide investigations and field initiatives concerning EOR-CO^2 procedures.

Oil extraction operations are conventionally divided into primary, secondary, and tertiary phases, as depicted in Figure 1. The primary stage entails initial oil production facilitated by the inherent displacement energy within a reservoir. When primary recovery diminishes, secondary recovery techniques come into play, including gas injection, water flooding, or water-alternating-gas injection. Tertiary recovery, also known as enhanced oil recovery (EOR), is employed to augment oil production beyond what conventional methods can achieve. Traditional oil production typically recovers approximately 35-45% of the original oil reserves, while EOR methods are typically implemented towards the later stages of an oil field's lifespan. These methods involve the utilization of miscible gases (e.g., CH^4, CO^2), chemicals, and/or thermal energy to displace additional oil, typically ranging from 5-15% of the original reserves [1].

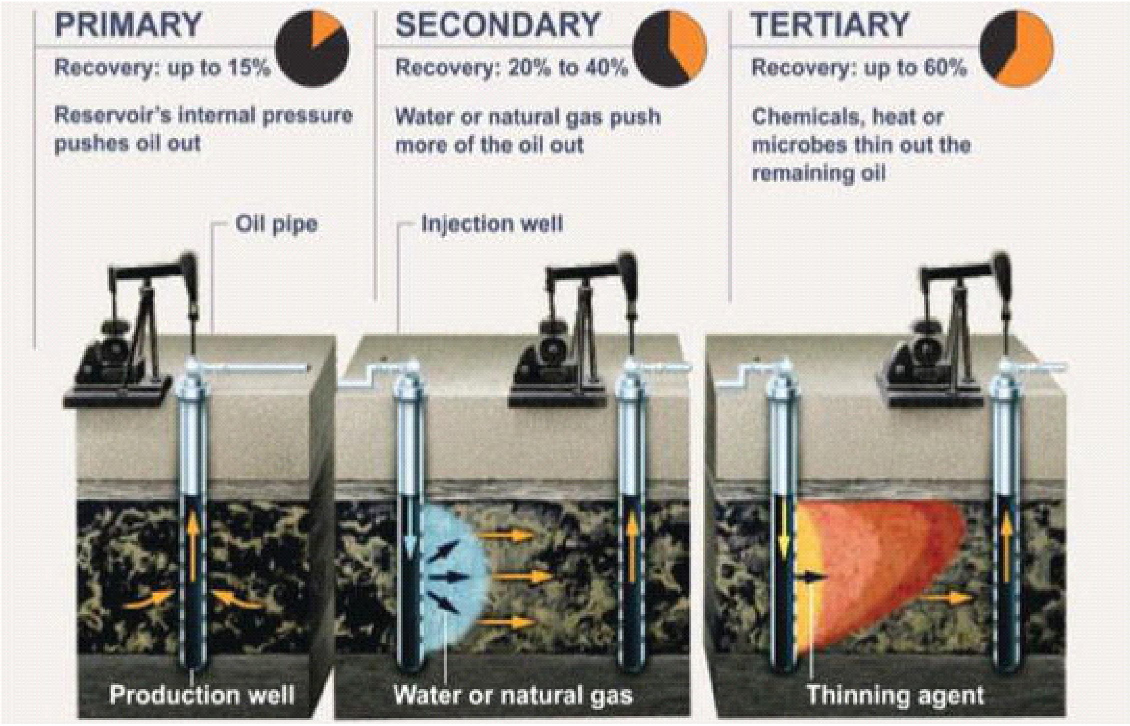

Figure 1 – Oil recovery stages

The injection of CO² into oil fields is one of the methods for improving oil recovery, which uses mixing and immiscible displacement. In mixing displacement, CO² is introduced into the field, mixes with the oil and increases its mobility, which makes it easier to drive it to the well. In immiscible displacement, CO² is introduced into the field without mixing with the oil and pushes it to the well with the help of pressure. In both cases, the injection of CO² helps to increase oil production, because. it provides additional pressure, which helps drive the oil to the well. In addition, CO² injection can also increase the volume of recoverable oil due to the additional solubility of oil in CO², which is the basis of the CO² injection method for recovering additional oil. (Figure 2. Scheme of EOR-CO² operation) [2].

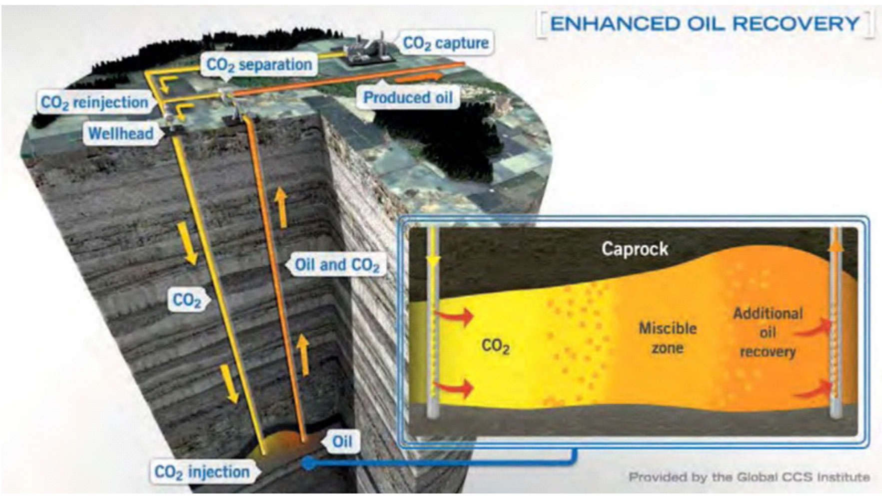

Figure 2 – Scheme of EOR-CO2 operation

The scholarly publication examines the technique of carbon dioxide injection (both miscible and immiscible modes) and evaluates global initiatives associated with this methodology. The potential application of this approach in the oil and gas sector of Kazakhstan will be explored, considering its current relevance and extensive discourse.

Main provisions

The injection of carbon dioxide into oil reservoirs is one of the strategies for increasing oil recovery, using both mixed and immiscible modes. The CO^2-EOR process allows the recovery of residual oil from the reservoir after primary and secondary production by stimulating volume sweep (Ev) and displacement efficiency (Ed). Depending on the pressure, temperature and characteristics of the oil in the reservoir, the injected CO^2 can either mix with the oil or remain immiscible. The miscible CO^2-EOR mode is the preferred choice as it often provides higher recovery rates than the immiscible method [3].

Miscible Mode.

The minimal miscibility pressure (MMP) represents the threshold pressure for achieving miscibility. The MMP corresponds to the pressure level at which over 80% of the original oil-in-place (OIP) is recovered during the breakthrough of CO^2, as stated by Holm and Josendal (1974). Despite being more recent, a general guideline for assessing the MMP is an oil recovery rate of at least 90% when injecting 1.2 HCPV (hydrocarbon pore volume) of CO^2, according to Yellig and Metcalfe (1980). Figure 3 demonstrates the rapid increase in oil recovery with increasing pressure, followed by a plateau once the MMP is reached.

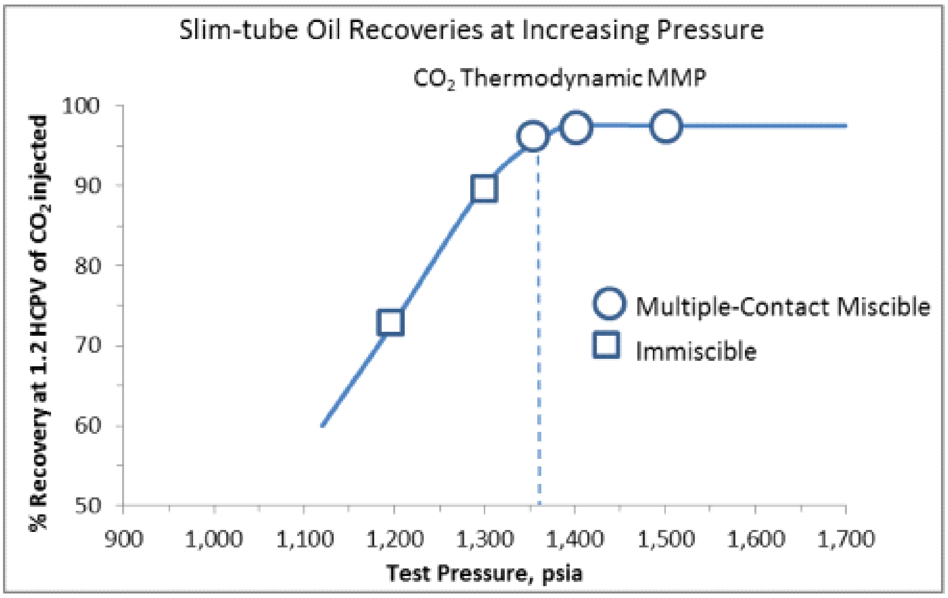

Figure 3 – Oil recovery rates in slim-tube experiments were measured at various pressures, with a constant oil composition and temperature (adapted from Yellig and Metcalfe, 1980). CO^2, referred to as carbon dioxide; psia, representing pounds per square inch absolute; % indicating percent

Three mechanisms of hydrocarbon miscibility are identified, as outlined by Stalkup (1983). The initial mechanism is referred to as first-contact miscibility, where solvents can mix with oil in any proportion and remain as a single phase. However, certain solvents, including CO^2, may not exhibit miscibility upon initial contact but can develop dynamic miscibility with repeated interactions, resulting in a significant enhancement in oil recovery. The second mechanism is the vaporizing gas-drive process, also known as high-pressure gas drive, which achieves dynamic miscibility by vaporizing intermediate-molecular-weight hydrocarbons from the reservoir oil into the injected CO^2 or gas. Lastly, the condensing gas-drive process, or enriched gas drive, achieves dynamic miscibility by transferring intermediate-molecular-weight hydrocarbons or CO^2 (in the case of CO^2-EOR) into the reservoir oil.

In CO^2-EOR, dynamic miscibility occurs when the reservoir pressure exceeds the minimum miscibility pressure (MMP) and displacement takes place. During this process, the intermediate and higher molecular weight hydrocarbons present in the reservoir oil vaporize into the CO^2, a phenomenon known as the vaporization gas-drive process. Additionally, a portion of the injected CO^2 dissolves into the oil, referred to as the condensation gas-drive process. This exchange of mass between the oil and CO^2 leads to complete miscibility without any discernible interface, resulting in the formation of a transition zone that exhibits miscibility with the oil in the front and the CO^2 in the rear, as depicted in Figure 4 (Jarrell et al., 2002; Merchant, 2010).

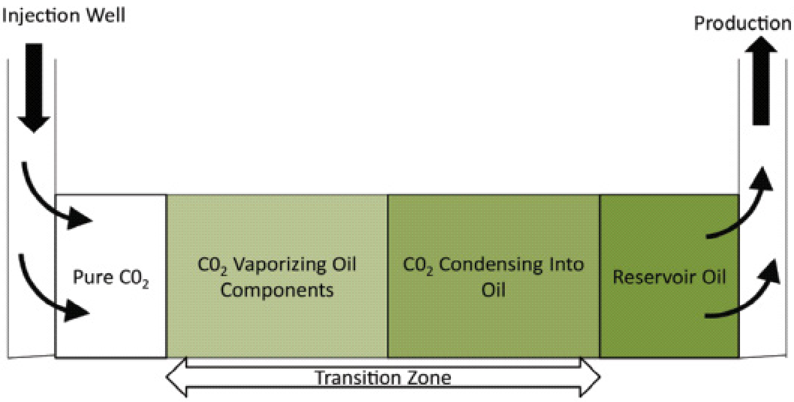

Figure 4 – The transition zone between the injection and production wells is depicted in the schematic of the CO^2 (carbon dioxide) miscible process. (Modified from Jarrell et al., 2002.)

The MMP is measured using slim-tube tests, which are seen to be more trustworthy than mathematical models or correlations. Since slim-tube tests are pricey, there are still two more ways to evaluate MMP: mathematical models and correlations.

Mathematical models, unlike correlations, offer superior findings by utilizing equilibrium data and equation-of-state (EOS), providing a more precise approach to calculating the minimal miscibility pressure (MMP). While correlations are easier to implement, they come with certain limitations and should be relied upon only in the absence of mathematical models or slim-tube tests.

Immiscible Mode.

If the reservoir pressure falls below the minimal miscibility pressure (MMP) or if the composition of the reservoir oil is not conducive to miscibility, the CO^2-oil miscibility will not be attained. However, the presence of CO^2 can still yield positive effects on oil recovery through its dissolution in the oil, resulting in viscosity reduction and oil swelling. These factors contribute to improved sweep efficiency and additional oil recovery. Similar to hydrocarbon gases, the solubility of CO^2 in oil increases with increasing pressure and decreases with decreasing temperature, as depicted in Figure 5, based on research conducted by Simon and Graue (1965) and Welker and Dunlop (1963) [3].

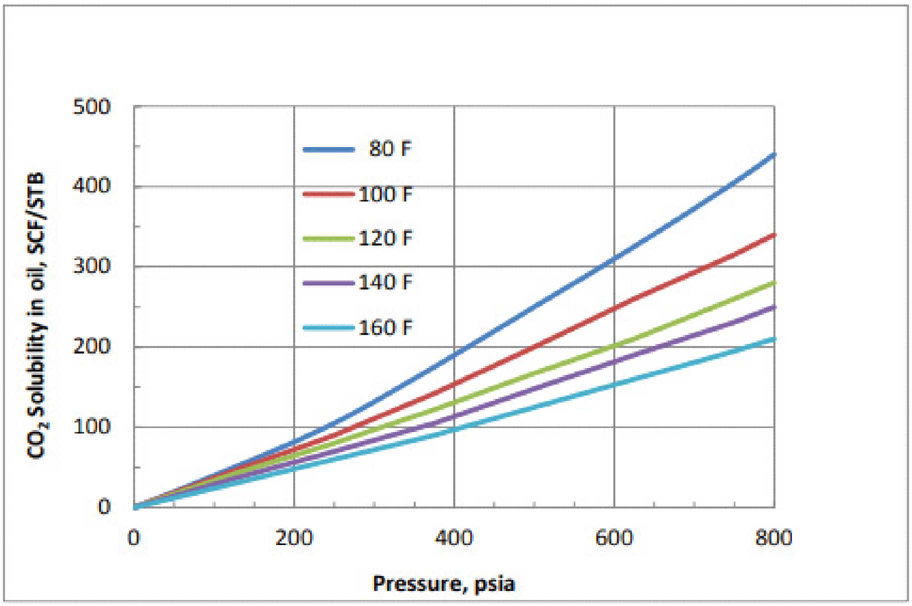

Figure 5 – Solubility of carbon dioxide (CO^2) in crude oil from the Moran field in Kansas is dependent on pressure and temperature, as observed in studies conducted by Welker and Dunlop (1963). The solubility is measured in units of pounds per square inch absolute (psia) and standard cubic feet per stock tank barrel (SCF/STB), while the temperature is indicated in degrees Fahrenheit (F).

Through the process of mixing and non-mixing regimes when CO^2 is injected into the fields, oil production can be improved. the non-mixing method gives fewer production figures because a CO^2-EOR mixing method which, by achieving a minimum mixing pressure (MMP) and obtaining dynamic miscibility, gives higher recovery. Thin tube tests, mathematical models or correlations are used to determine the MWD. Dissolving in oil, reducing viscosity and swelling oil, CO^2 will still have a positive effect on oil recovery, even if the reservoir pressure is below the MMP or the composition of the reservoir oil is not suitable. The amount of oil that can be recovered from reservoirs can increase dramatically as a result of CO^2-EOR [3].

Materials and methods

To analyze the international practice of CO^2 injection, data from scientific articles, oil company reports and other open sources such as the official website were used. Analyzed the experience of injection of CO^2 into oil reservoirs in several fields in different countries, including the United States, Norway and Canada.

Results and discussion

In the 21st century, the surge in carbon dioxide (CO^2) emissions poses a significant challenge to humanity. In this context, globally, initiatives are underway to explore deep reservoir CO^2 infusion as a method to combat climate change and enhance oil recovery. This section examines various CO^2 injection projects and technologies employed to augment oil recovery, including prospects in Kazakhstan.

The Northern Lights venture in Norway commenced in 2020 with the objective of establishing infrastructure for the capture, conveyance, and deep reservoir CO^2 infusion at a depth of 2.5 kilometers. The project leverages refrigeration techniques to attain a stable liquid state of CO^2, subsequently transporting it to deeper strata. Furthermore, a monitoring system has been developed to oversee the process of CO^2 infusion into profound formations. Northern Lights has secured funding from the Norwegian government and anticipates commencing CO^2 injection by 2024 [4].

In Canada, the Quest project, initiated by Shell in 2015, stands as one of the world's largest CO^2 infusion endeavors. Situated in the province of Alberta, the project encompasses CO^2 collection from an oil platform, its transportation, and injection into deep layers at a depth of 2 kilometers. Employing refrigeration technology, CO^2 is liquefied and transported 80 km to the injection site. A monitoring system is also employed to ensure the safety and control of the injection process. The deep reservoir injection of CO^2 has led to a significant decrease of 35% in carbon dioxide emissions [5].

The Petra Nova project in the United States was launched in 2017 as the world's first commercial carbon dioxide separation and storage facility. It is a joint project between NRG Energy and JX Nippon Oil & Gas Exploration, to be installed at the W.A. Parish in Texas.

The project involved the implementation of equipment that effectively separates carbon dioxide from the emissions of a coal-fired power plant. The captured CO^2 is then transported through a pipeline to a designated disposal site located deep underground. As a result, the project has the capacity to annually separate and securely store up to 1.6 million tons of carbon dioxide.

The project implementation involved the utilization of technologies for carbon dioxide liquefaction, compression, well drilling, and gas injection into deep layers. The outcomes of the project indicate its successful operation and its capability to effectively reduce carbon dioxide emissions into the atmosphere. It is important to highlight that the Petra Nova project stands out as one of the world's largest and most triumphant initiatives focused on carbon dioxide separation and storage. Furthermore, it serves as a compelling demonstration of the potential application of similar technologies in various power plants and industries [6,7].

In Kazakhstan, work has also been carried out to inject carbon dioxide into oil and gas deposits to increase their production. The Tengiz Sour Gas Injection project by Chevron was launched in 2008 and was the first large-scale CO^2 injection project in Kazakhstan. It was based on Enhanced Oil Recovery (EOR) technology, which allows for enhanced oil recovery through the introduction of various substances, including CO^2.

The project included the construction of a compressor station for gas compression, as well as a pipeline system for transporting CO^2 from the source to the injection site. According to data obtained from Chevron, CO^2 injection resulted in a 3-5% increase in production and a reduction in greenhouse gas emissions by 3-4 million tons per year [8].

In addition to the Tengiz Sour Gas Injection project, research and development activities in the field of CCS and EOR are being carried out in Kazakhstan. For example, the Kazakhstanmunaigas company is planning to launch a project to inject CO^2 into a field in the Kulsary region, which could potentially result in an increase of 8-10% in production. It is also worth noting that in 2020, the Kazakhstan CCS Association was established, which is responsible for coordinating research and development in the field of CCS in Kazakhstan.[9]

Thus, the analysis of international practice shows that the injection of carbon dioxide into oil and gas deposits is an effective way to increase oil recovery and reduce greenhouse gas emissions. Various projects in Norway, Canada, USA and Kazakhstan show that CCS and EOR technologies can be successfully applied in different conditions and fields. However, it is important to carry out more research and development to improve the efficiency and economic feasibility of these technologies.

Conclusion

In conclusion, the analysis of international practice has shown that CO^2 injection is an effective method of increasing oil recovery. This technology will also help increase production rates at the fields of Kazakhstan. However, the successful implementation of CO^2 injection projects requires taking into account many factors and additional research. Despite this, the prospects for using CO^2 as an injection fluid to increase oil recovery remain high and require further research and development. With the economic benefits of CO^2-EOR proven by many active CO^2-EOR projects, further expansion of its application in oil fields around the world is expected. This indicates the significance and prospects for its use in the future.

References

1 Abdelmalek Atia and Kamal Mohammedi (2018) A Review on the Application of Enhanced Oil&Gas Recovery through CO^2 Sequestration, August 16th.

2 Storing CO^2 through Enhanced Oil Recovery,Combining EOR with CO^2 storage (EOR+) for profit, © OECD IEA, 2015, International Energy Agency,Paris

3 Fundamentals of Carbon Dioxide-Enhanced Oil Recovery (CO^2-EOR)—A Supporting Document of the Assessment Methodology for Hydrocarbon Recovery Using CO^2-EOR Associated with Carbon Sequestration By Mahendra K. Verma, U.S. Geological Survey, Reston, Virginia, 2015

4 Northern Lights Project Concept report RE-PM673-00001, 2019-05-21, http://www.equinor.com.

5 The Shell Quest Carbon Capture and Storage Project, August 2018 Publisher: IEA Greenhouse Gas R&D ProgrammeISBN

6 Petra Nova CCUS Project in USA, June 8, 2018, Noriaki Shimokata, JX Nippon Oil&Gas Exploration Corporation

7 Petra Nova - W.A. Parish Project | Department of Energy.

8 Chevron Corporation website (for Tengiz Sour Gas Injection Project), https://www.chevron.com/projects/tengiz-expansion

9 Darmentaev S., Yessaliyeva A., Yessaliyeva A., Azhigaliyeva A.M., Belanger D. (2010) Tengiz Sour Gas Injection Project, November, DOI: 10.2118/139851-MS.

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Мұнай бергіштікті арттыру әдістерінің бірі ретінде CO^2 кері айдау халықаралық тәжірибесін талдау

Аңдатпа. Қазіргі уақытта CO^2 кері айдау мұнай бергіштікті жоғарылату (EOR) үшін қолданылатын танымал әдіс болып табылады. Мұнай бергіштікті арттыру үшін кері айдау газы ретінде CO^2-ні пайдалану туралы алғашқы тұжырымдар 1916 ж. басталады, бірақ 1950 жылға дейін оның экономикалық тұрақтылығы анықталған жоқ. Бастапқыда пропан, сұйытылған мұнай газы және табиғи газ сияқты балама газдар пайдаланылды, бірақ CO^2 үнемді және тиімді нұсқа ретінде пайда болды. Бірінші CO^2 кері айдау жобасы 1964 ж. басталып, 1972 ж. ауқымды жобаға айналды. Нәтижесінде АҚШ, Канада, Венгрия, Түркия, Тринидад және Бразилия сияқты әртүрлі аймақтарда CO^2 кері айдау сәтті жүзеге асырылды. Басқа елдер шектеулі инфрақұрылым мен көздер сияқты қиындықтармен кездессе, Америка Құрама Штаттары 67 белсенді CO^2 кері айдау жобасымен ерекшеленді. Бүгінгі күні CO^2 кері айдаумен байланысты 100-ден астам мұнай бергіштікті арттыру жобалары тіркелді. Бұл мақалада мұнай бергіштіктің тиімділігін арттыру үшін CO^2 кері айдауды қолданудың халықаралық тәжірибелері мен әдістемелеріне толық шолу жасалады. Сонымен қатар, осы әлеуетті жобаларды және технологияны Қазақстан контекстінде қолдануға ерекше назар аударылады.

Тірек сөздер: МБАӘ, CO^2 кері айдау, мұнай өндіру, араластыру режимі, араласпау режимі, Қазақстан

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Анализ международной практики закачки CO^2 как один из методов увеличения нефтеотдачи

Аннотация. Закачка CO^2 в настоящее время является популярным методом, используемым для повышения нефтеотдачи (EOR). Первое упоминание об использовании CO^2 в качестве закачиваемого газа для увеличения добычи нефти относится к 1916 г., хотя его экономическая целесообразность не была установлена до 1950-х гг. Первоначально использовались альтернативные газы, такие как пропан, сжиженный нефтяной газ и природный газ, но CO^2 стал более экономичным и эффективным вариантом. Первый проект заводнения CO^2 начался в 1964 г., за ним последовал более масштабный проект в 1972 г. Впоследствии успешные реализации заводнения CO^2 были засвидетельствованы в различных регионах, включая США, Канаду, Венгрию, Турцию, Тринидад и Бразилию. Среди них выделяются Соединенные Штаты с 67 действующими проектами по наводнению CO^2, в то время как другие страны сталкиваются с такими проблемами, как ограниченная инфраструктура и источники. На сегодняшний день зарегистрировано более 100 проектов повышения нефтеотдачи, связанных с заводнением CO^2. В данной публикации представлен всесторонний обзор международного опыта и методологий, касающихся применения заводнения CO^2 для повышения эффективности добычи нефти. Кроме того, в нем подчеркиваются потенциальные проекты и применение этой технологии в контексте Казахстана.

Ключевые слова: МӨАӘ, закачка CO^2, добыча нефти, смешиваемый режим, несмешиваемый режим, Казахстан