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CARBON CAPTURE, UTILIZATION AND STORAGE IN TENGIZ OIL FIELD

Abstract

Carbon capture, utilization, and storage (CCUS) technologies have become critical tools in mitigating anthropogenic greenhouse gas emissions and achieving global climate targets. This study investigates the potential for CO_2 sequestration in the depleted gas reservoirs of the Tengiz field, a unique site characterized by deep reservoir conditions and a history of extensive hydrocarbon extraction. The research aims to evaluate the technical feasibility and effectiveness of CO_2 injection into a high-temperature, high-pressure formation, using dynamic reservoir simulation. Key objectives include assessing injection capacity, breakthrough time, storage efficiency, and pressure behavior under varying operational scenarios. The study integrates geological, petrophysical, and fluid data to build a robust sector model, calibrated with historical production data. Simulation results demonstrate favorable injectivity and containment, with minimal risk of CO_2 leakage. These findings contribute to the growing body of knowledge on field-scale CCUS deployment and support the development of sustainable carbon management strategies in mature oil and gas provinces.

Keywords: carbon capture, carbon use, carbon storage, Tengiz oil field, climate change, greenhouse gases, oil industry.

Introduction

The accelerating accumulation of atmospheric carbon dioxide (CO_2), largely driven by the combustion of fossil fuels, is recognized as a leading contributor to global climate change. Carbon capture, utilization, and storage (CCUS) technologies have emerged as a key component in international efforts to reduce industrial CO_2 emissions, as outlined in major agreements such as the Paris Agreement [4]. These technologies enable the capture of CO_2 from large point sources, its transportation, and its long-term storage in geological formations, particularly depleted oil and gas reservoirs and deep saline aquifers.

The implementation of CCUS offers dual benefits: mitigating greenhouse gas emissions and potentially enhancing hydrocarbon recovery through mechanisms such as CO_2-enhanced gas recovery (EGR). However, the deployment of these technologies on a field scale requires a comprehensive understanding of subsurface conditions, reservoir integrity, and long-term storage performance.

The Tengiz field in western Kazakhstan, one of the world's deepest and most prolific carbonate reservoirs, presents a promising site for CCUS application [8]. Following decades of gas and condensate production, significant pore space remains available for CO_2 injection. The unique geological and operational characteristics of the Tengiz field such as its high reservoir pressure and temperature, complex faulted structure, and availability of historical production data make it an ideal candidate for CO_2 sequestration studies.

This paper explores the technical feasibility of CO_2 injection into a depleted gas zone at the Tengiz field. The study applies dynamic reservoir simulation to evaluate storage capacity, injectivity, and pressure evolution over time. It aims to provide a practical framework for assessing similar opportunities in mature hydrocarbon provinces worldwide.

Materials and Methods

This study integrates laboratory measurements, geological analysis, and dynamic reservoir simulation to assess the feasibility of CO_2 storage in a depleted gas-bearing formation of the Tengiz field. The research methodology is divided into three main stages: data acquisition, model construction, and simulation.

The geological model was developed using Petrel 2017.1 software based on structural maps, well logs, and production history data. The reservoir of interest is located at a depth of approximately 2000 meters, within a carbonate formation characterized by moderate porosity and low permeability. Core analysis and petrophysical interpretation provided average porosity values ranging from 7–10% and permeability in the range of 1–5 mD. Fluids are primarily composed of methane (C_1), with minor fractions of heavier hydrocarbons (C_2–C_6^+) and residual water saturation. Fluid composition was analyzed by chromatograph Viscosity and compressibility data were obtained from standard pressure-volume-temperature (PVT) analysis. Schematic diagram of a gas chromatograph is demonstrated in Figure 1 [1].

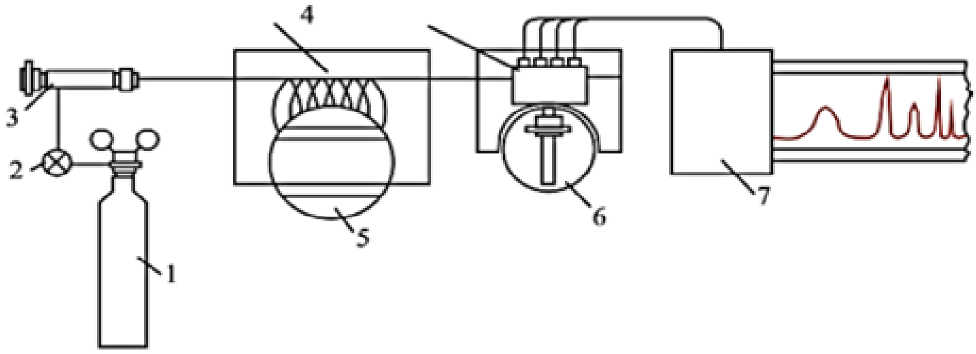

Figure 1 – Schematic diagram of a gas chromatograph: 1 – cylinder with carrier gas; 2 – flow regulator; 3 – sample entry point (metering valve, evaporator); 4 – thermostats; 5 – column; 6 – detector; 7 – recorder

A gas chromatograph is an analytical device for chromatographic separation of a mixture of substances, analysis of its components and properties of complex mixtures. For more accurate laboratory studies to improve the equation, this chromatography is an effective method for assessing the uniformity of a substance and allows us to separate and identify substances with similar properties. The gas chromatograph has high accuracy, fast analysis, sensitivity, and the ability to combine with other research methods.

Table 1 – Standard test method for boiling range distribution of petrolium fractions by gas chromatography

Chemical formula	Common name	Release time, min
C5H12	Pentane	0,528
C6H14	Hexane	1,11
C7H16	Heptane	2,55
C8H18	Octane	4,774
C9H20	Nonane	6,379
C10H22	Decane	7,459
C11H24	Undecane	8,258
C12H26	Dodecane	8,935

Continuation of table 1

C14H30	Tetradecane	10,079
C15H32	Pentadecane	10,59
C16H34	Hexadecane	11,082
C17H36	Heptadecane	11,523
C18H38	Octadecane	11,967
C20H42	Eicosane	12,752
C24H50	Tetracosane	14,153
C26H54	Hexacosane	14,768
C30H62	Triacontane	15,888
C36H74	Hexatriacontane	17,973
C40H82	Tetracontane	18,744
C44H90	Tetratetracontane	21,097

Table 2 – Oil composition for field Tengiz

Compound	MW, g/mol	Area	Concentration
C6H14	86,17	887670,925	0,068
C7H16	100,2	971729,246	0,074
C8H18	114,22	803974,842	0,061
C9H20	128,25	1044493,479	0,08
C10H22	142,28	565721,045	0,043
C11H24	156,3	495299,112	0,038
C12H26	170,33	608490,038	0,046
C13H28	184,35	512765,933	0,039
C14H30	198,38	489367,044	0,037
C15H32	212,41	918882,889	0,07
C16H34	226,43	447721,375	0,034
C17H36	240,46	501876,376	0,038
C18H38	254,48	466490,794	0,036
C19H40	268,51	470921,672	0,036
C20H42	282,54	340213,694	0,026
C21H44	296,56	337946,298	0,026
C22H46	310,59	297049,693	0,023
C23H48	324,61	438519,578	0,033
C24H50	338,64	304577,664	0,023
C25H52	352,67	447460,244	0,034
C26H54	366,69	456810,907	0,035
C27H56	380,72	234213,225	0,018

Continuation of table 2

C28H58	394,74	73976,485	0,006
C29H60	408,77	497671,403	0,038
C30H62	422,8	232821,369	0,012
C31H64	436,82	153609,123	0,004
C32H66	450,85	55859,537	0,002
C33H68	464,87	32516,446	0,009

In this case, the sum of all areas is 13115103.7. Knowing the area of each compound, we can find the concentration of each compound. For example:

Table 3 – How the composition of oil affects the injection of CO_2

The solubility of CO2 in oil	CO2 is well soluble in light hydrocarbons (C5-C10) – in my case, there are many of them: C5-C10 totaling ≈ 33% of the composition. The dissolution of CO2 in oil causes: reduction of oil viscosity; oil swelling; a change in phase equilibria – oil may begin to release gas when pressure drops.
Residual oil and CO2 capture	Heavy components (C20+) make up about 40% of my products – they do not dissolve CO2 well, but they create traps (residual oil trapping). CO2 can: partially dissolve in the light fraction; stuck in the pores, surrounded by heavy residual oil.

CO_2 injection modeling was performed using the ECLIPSE 300 simulator, which is capable of handling compositional flow and tracking multi-component phase behavior. Five vertical injection wells were defined at a depth of 1750 meters. Simulation parameters included a time frame of 25 years, injection rate of 100,000 sm^3/day per well, and temperature of 90°C.

The reservoir grid was constructed with 60×60×10 cells, refined around wells to improve numerical accuracy. Sectoral geological model of depleted reservoir is demonstrated in Figure 2.

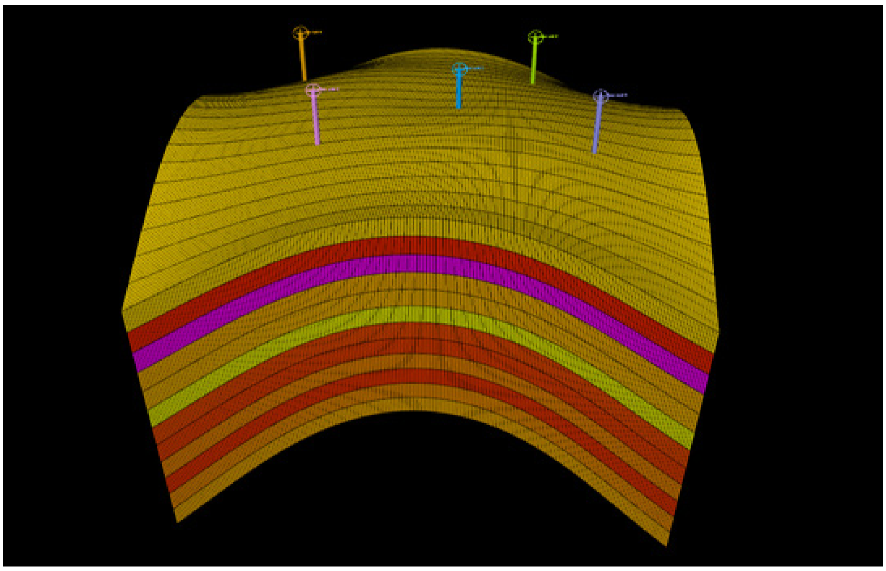

Figure 2 – Sectoral geological model of depleted reservoir

Dynamic modeling accounted for CO_2 rock interactions, pressure build-up, and gas migration pathways. Relative permeability and capillary pressure functions were adjusted based on literature data and laboratory measurements. Sensitivity analysis was conducted to evaluate the effect of injection rate, well placement, and seal integrity on storage efficiency and containment security [6].

Results and Discussion

The results of the numerical simulation demonstrate that the selected reservoir zone is capable of safely accommodating significant volumes of CO_2 over a multi-decade timescale. The dynamic model indicates stable pressure buildup within acceptable limits, suggesting minimal risk of caprock fracturing or fault reactivation. Injection performance remained consistent throughout the 25-year period, with no breakthrough at observation wells, confirming effective confinement.

The injected gas preferentially migrated through high-permeability streaks, forming a stable plume beneath the caprock. Vertical movement was limited due to the presence of interbedded low-permeability layers. The plume evolution over time was characterized by lateral spreading, which maximized contact with residual hydrocarbons and improved storage efficiency.

The CO_2 storage capacity for the simulated scenario reached approximately 12.6 million tonnes, which corresponds to about 72% of the available pore volume in the targeted grid blocks. Storage efficiency was further enhanced by residual gas trapping and dissolution into formation water. While mineral trapping was not modeled in this study, it is expected to contribute to long-term immobilization over geological timescales.

The simulation also evaluated potential enhanced gas recovery. Although the original gas reserves were largely depleted, CO_2 injection mobilized additional hydrocarbons from lower-permeability zones. This incremental recovery was estimated at 4.3% of the original gas in place, highlighting the potential for combined storage and recovery operations.

The modeled scenario aligns with field-scale observations from comparable projects in North America and the Middle East [9]. Parameters such as depth, formation type, and fluid composition are consistent with other successful CCUS initiatives, reinforcing the relevance of Tengiz as a candidate site. Overall, the model results provide technical justification for pilot-scale implementation under strict monitoring protocols.

Conclusion

This study evaluates the feasibility of implementing carbon capture, utilization, and storage (CCUS) in the mature Tengiz gas field. The simulation results confirm that the depleted reservoir possesses favorable geological and petrophysical characteristics for safe and efficient CO_2 storage. Key outcomes include stable plume migration, minimal leakage risk, and measurable enhanced gas recovery. These findings reinforce the technical and environmental viability of CO_2 injection in this context.

Among the evaluated storage techniques, amine-based absorption methods emerged as the most applicable for this field [10], given the gas composition and surface infrastructure. Alternatives such as physical adsorption or cryogenic separation are less economically viable under current operating conditions. The integrated approach combining surface capture technologies with subsurface geological storage provides a holistic strategy for emissions mitigation.

Moreover, the simulation model can serve as a foundation for optimizing well placement, injection rates, and monitoring protocols in future field trials. Quantitative outputs, such as the 12.6 Mt CO_2 storage potential and 4.3% incremental recovery, offer valuable benchmarks for stakeholders assessing the economic and environmental return on investment. These metrics also support regulatory reporting and alignment with national decarbonization targets [15].

However, further studies are needed to refine long-term risk assessments, including geochemical modeling of CO_2 brine-rock interactions and fault reactivation scenarios. Comprehensive site characterization and real-time monitoring will be essential for full-scale deployment. Collaborative efforts with academic institutions and regulatory bodies will also enhance transparency and knowledge sharing [7].

In conclusion, the Tengiz reservoir exhibits strong potential for integrated CCUS deployment. The findings of this study contribute to the growing body of knowledge supporting CCUS in high-capacity gas fields. Future work should focus on expanding pilot-scale operations, validating models with field data, and exploring the scalability of this approach within Kazakhstan's broader climate strategy.

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УЛАВЛИВАНИЕ, ИСПОЛЬЗОВАНИЕ И ХРАНЕНИЕ УГЛЕРОДА НА ТЕНГИЗСКОМ НЕФТЯНОМ МЕСТОРОЖДЕНИИ

Аннотация
Технологии улавливания, использования и хранения углерода (CCU) стали важнейшими инструментами снижения антропогенных выбросов парниковых газов и достижения глобальных климатических целей. В данном исследовании изучается потенциал связывания CO_2 в истощенных газовых залежах месторождения Тенгиз, уникального участка, характеризующегося глубокими пластовыми условиями и историей интенсивной добычи углеводородов. Целью исследования является оценка технической осуществимости и эффективности закачки CO_2 в высокотемпературный пласт с высоким давлением с использованием динамического моделирования коллектора. Ключевые задачи включают оценку мощности закачки, времени

прорыва, эффективности хранения и изменения давления при различных сценариях эксплуатации. Исследование объединяет геологические, петрофизические данные и данные о флюидах для построения надежной модели сектора, скорректированной с учетом исторических данных о добыче. Результаты моделирования демонстрируют благоприятную приемистость и герметичность при минимальном риске утечки CO_2. Эти результаты дополняют растущий объем знаний о внедрении CCU в полевых условиях и поддерживают разработку стратегий устойчивого управления выбросами углерода в зрелых нефтегазоносных провинциях.

Ключевые слова: улавливание углерода, использование углерода, хранение углерода, Тенгизское нефтяное месторождение, изменение климата, парниковые газы, нефтяная отрасль.

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ТЕҢІЗ МҰНАЙ КЕНІШІНДЕ КӨМІРТЕКТІ АЛУ, ПАЙДАЛАНУ ЖӘНЕ САҚТАУ

Аңдатпа

Көміртекті алу, кәдеге жарату және сақтау технологиялары (CCU) антропогендік парниктік газдар шығарындыларын азайтудың және жаһандық климаттық мақсаттарға жетудің маңызды құралына айналды. Бұл зерттеу Теңіз кен орнының таусылған газ қоймаларында, терең резервуар жағдайларымен және көмірсутектерді кең көлемде өндіру тарихымен сипатталатын бірегей учаскеде CO_2 секвестрінің әлеуетін зерттейді. Зерттеу резервуардың динамикалық модельдеуін пайдалана отырып, жоғары температуралы, жоғары қысымды қабатқа CO_2 енгізудің техникалық орындылығы мен тиімділігін бағалауға бағытталған. Негізгі мақсаттарға әртүрлі операциялық сценарийлерде айдау қуатын, серпіліс уақытын, сақтау тиімділігін және қысым тәртібін бағалау кіреді. Зерттеу тарихи өндіріс деректерімен калибрленген сенімді салалық модельді құру үшін геологиялық, петрофизикалық және сұйықтық деректерін біріктіреді. Модельдеу нәтижелері CO_2 ағып кету қаупі аз болған кезде қолайлы инъекцияны және оқшаулауды көрсетеді. Бұл нәтижелер CCU-ны далалық ауқымда енгізу бойынша өсіп келе жатқан білімге ықпал етеді және жетілген мұнай-газ провинцияларында көміртекті тұрақты басқару стратегияларын әзірлеуге қолдау көрсетеді.

Тірек сөздер: көміртекті алу, көміртекті пайдалану, көміртекті сақтау, Теңіз кен орны, климаттың өзгеруі, парниктік газдар, мұнай өнеркәсібі.

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