Energy Proceedings
Vol 33, 2023

ISSN 2004-2965

Using the precipitation process of potassium carbonate with Ethanol + KOH solution to enhance the efficiency of CO_2 mineralization storage in low permeability reservoirs

Chengwei Wang[1,2], Yuliang Su [1,2*], Wendong Wang[1,2], Lei Li[1,2], Yongmao Hao[1,2], Xincheng Guo[1,2]

1 Key Laboratory of Unconventional Oil & Gas Development (China University of Petroleum (East China)), Ministry of Education, Qingdao 266580, P. R. China

2 School of Petroleum Engineering, China University of Petroleum (East China), Qingdao, 266580, P. R. China

(*Corresponding Author: suyuliang@upc.edu.cn)

ABSTRACT

Carbon dioxide displacement and storage is the most feasible technology to realize carbon neutralization, and also the key technology to improve the recovery of tight reservoirs. CO_2 capture and carbonization can be achieved by precipitation of potassium carbonate by using the “Ethanol + KOH” solution system. The reaction process in the solution system is affected by the ethanol concentration, resulting in different CO_2 carbonization amounts with the change of ethanol concentration. At the same time, the potassium-based acid salt generated by precipitation can react with water to complete the regeneration of ethanol. In this paper, experimental means are used to study the CO_2 capture efficiency of the "Ethanol + KOH" system, monitor the ethanol content in the solution in real time, and screen out the best ethanol concentration suitable for the formation temperature. Add KOH to the solution, use the ethanol regenerated in the solution after carbonization reaction to carbonize again, and determine the maximum CO_2 capture of "ethanol + KOH". Based on the high temperature and high pressure core displacement device, the CO2 burial experiment after the injection of "Ethanol + KOH" solution was carried out to clarify the change rule of CO_2 burial under the action of "Ethanol + KOH" system in low permeability cores. The research results show that "96% ethanol+3g KOH" can effectively capture CO_2, and each capture will produce 4.56g precipitation on average. At the same time, after the core is saturated with "96% ethanol+3gKOH" solution, CO_2 is injected to generate sediment, and the core permeability decreases by about 15%. The research results of this paper prove that, compared with direct injection of CO_2 into the formation, injection of this system into the formation in advance can accelerate the CO_2 carbonization process, thus effectively improving the CO_2 burial efficiency.

Keywords: Carbon dioxide, Ethanol+KOH+CO_2, potassium-based, CO_2 Storage

1. INTRODUCTION

Climate change is a global issue that has garnered significant international attention from governments and individuals worldwide[1-3]. How to deal with excessive greenhouse gases and mitigate the greenhouse effect is a major challenge that human development needs to face[4-6]. Carbon Dioxide Capture and Storage (CCS) technology is widely recognized as the most cost-effective and feasible approach for reducing CO_2 emissions and addressing the global warming challenges resulting from the combustion of fossil fuels[7-9].

This is a paper for International CCUS Conference 2023 (ICCUSC2023), April 14-15, 2023, Beijing, China.

It can not only rely on a large amount of storage space in the formation to store greenhouse gases, but also use its own properties to change the properties of crude oil and improve its recovery rate[10-12]. This process includes three steps: capture, transportation, and burial.

Carbon dioxide geological burial refers to storing carbon dioxide in adsorbed, water-soluble, and mineralized forms within buried geological structures[13-16]. Currently, the main geological burial options include depleted oil and gas reservoirs, deep salt water reservoirs, unexplainable coal seams, and deep-sea burial[17, 18]. According to different rock types and reservoir types, carbon dioxide injected into the ground can be stored underground through various burial mechanisms[19-21]. The burial mechanism can be roughly divided into physical burial, geochemical burial, hydrodynamic burial and adsorption burial. Geochemical burial can be categorized as dissolution burial and mineralization burial.

Compared to China, foreign countries have significantly more mature CO_2 displacement and geological storage technologies[22-24]. A large number of CO_2 displacement and geological burial pilot tests and field applications have been conducted in developed countries such as the United States and Canada[25-27]. Currently, global CO_2 storage projects still maintain a rapid growth momentum. R. Kovscek have used numerical simulation methods to clarify the impact of CO_2 injection into water layers and oil layers on the geological storage of CO_2 and crude oil recovery rate. According to the study findings, the injection of CO_2 into both water and oil layers yields the most substantial crude oil recovery rate[28]. Serdar Bender studied the impact of injected gas types on CO_2 geological storage and crude oil recovery. The research results indicate that since flue gas does not require purification and separation, injecting flue gas produces greater economic benefits than pure CO_2[29]. Yao Zhenjie have established a CO_2 potential evaluation model for the Yanchang Oilfield in the Jingbian CO_2 experimental area. The research results indicate that the CO_2 storage capacity in the Jingbian CO_2 experimental area reaches 209.879 × 10^4 t[30]. Liu Bin evaluated the impact of reservoir heterogeneity on CO_2 flooding effectiveness. The research results indicate a positive correlation between crude oil recovery rate and reservoir heterogeneity. The stronger the reservoir heterogeneity, the worse the CO_2 flooding effect[31]. Pufu Xiao conducted displacement experiments on four different injection schemes for Daqing ultra-low permeability oil reservoirs. The four schemes included CO_2/water alternating injection, CO2 immiscible flooding, miscible flooding, and CO_2 huff and puff. The research results indicate that the remaining oil is mainly distributed in pores with pore sizes less than 10 ms, while CO_2 miscible and non miscible flooding mainly extract crude oil from large pores[32]. Tang Yong conducted long core CO_2 displacement experiments to investigate the effects of high temperature and pressure on CO_2 enhanced oil recovery, specifically focusing on the changes in permeability and injection rate. The research results indicate that under the action of dissolution and gravity, the breakthrough of carbon dioxide lags behind, resulting in an increase in recovery rate[33]. Jiang have established a multi-component numerical simulation considering multiple transport mechanisms (Kundsen diffusion, adsorption) to study the burial effect of CO_2 in shale gas reservoirs. The results show that the fracture properties have great influence on shale gas productivity. CO_2 injection into shale gas reservoir is a technically feasible method for CO_2 capture and enhanced recovery of shale gas. At the same time, N_2 can also be selected to assist CO_2 burial in shale gas reservoir[34]. Zhao Renbao established a calculation model for CO_2 diffusion coefficient in bulk and porous media based on Fick's law. The research results indicate that as the viscosity of crude oil increases, the CO_2 diffusion coefficient decreases and the time for the system to reach equilibrium extends[35]. Mu et al. used numerical simulation to study the effects of different impurities (N_2, SO_2) on the dissolution and burial mechanisms. The simulation results indicate that an increase in N_2 or O_2 concentration reduces the rate of CO_2 dissolution, weakens the ability to dissolve and store, and further leads to CO_2 leakage more easily through cracks and faults. On the contrary, SO_2 can advance the start time of density driven fingering, thereby promoting the dissolution and burial of CO_2[36]. The research results of Zhang et al. show that during the CO_2 injection period, the burial of tectonics plays a major role, and the contribution of solution burial gradually increases with the amount of dissolved CO_2 in formation water. After CO_2 injection is stopped, tectonics traps and residual gas traps gradually decrease, solution traps increase, and mineralization burial contribution increases with time[37].

The current research focuses on assessing the potential of CO_2 storage under different geological conditions, as well as the contribution of various burial mechanisms to CO_2 storage. However, it has neglected the slow process of CO_2 mineralization and storage, which requires a long time. Therefore, this study independently built a CO_2 storage experimental device under formation temperature and pressure conditions, and conducted multi medium assisted CO_2 storage experimental research.

2. THEORY

Potassium hydroxide reacts with CO2 to generate potassium carbonate (2-1). With the increase of CO2 H2O, potassium carbonate gradually generates potassium bicarbonate (2-2). Although potassium bicarbonate is soluble in water, it is insoluble in ethanol. The reaction is as follow (2-3).

$$2KOH_{(aq)} + CO_{2(aq)} \rightarrow K_2CO_{3(aq)} + H_2O_{(l)} \qquad (2\text{-}1)$$

$$K_2CO_{3(aq)} + CO_{2(aq)} + H_2O_{(l)} \rightarrow 2KHCO_{3(aq)} \qquad (2\text{-}2)$$

$$2KHCO_{3(aq)} + C_2H_5OH_{(l)} \rightarrow 2KHCO_{3(s)} + C_2H_5OH_{(l)} \qquad (2\text{-}3)$$

When the concentration of ethanol in the solution is high, the (2-1) (2-2) (2-3) reaction is inhibited. KOH reacts with ethanol to generate potassium ethoxide, and finally KOH reacts with ethanol to generate potassium ethoxide, which is then converted into PEC and water, as shown in Formula (2-4) and (2-5).

At the same time, some PEC react with water in solution to complete ethanol regeneration and KHCO3 generation.

$$KOH_{(aq)} + C_2H_5OH_{(l)} + CO_{2(aq)} \rightarrow C_2H_5OCOOK_{(s)} + H_2O_{(l)} \qquad (2\text{-}4)$$

$$C_2H_5OCOOK_{(s)} + H_2O_{(l)} \rightarrow 2KHCO_{3(s)} + C_2H_5OH_{(l)} \qquad (2\text{-}5)$$

To sum up, the mixed system of ethanol and KOH can produce $KHCO_3$ and PEC precipitation. The CO_2 injected is fixed through mineralization reaction. The type of sediment depends on the ethanol concentration in the solution[38, 39].

3. EXPERIMENT SECTION

3.1 Experiment of carbon dioxide mineralization in ethanol + potassium hydroxide solution

Eight kinds of CO_2 mineralized solutions were prepared by dissolving 3 g KOH in 500ml ethanol aqueous solution with different concentrations (70%, 80%, 90%, 92%, 94%, 96%, 98%). Put the solution into a CO_2 reactor that can control the temperature. The flow chart of CO_2 mineralization reaction experiment is shown in Figure 1.

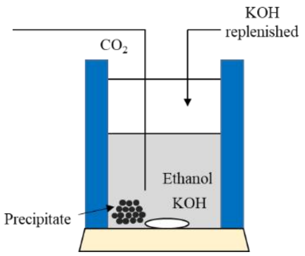

Fig. 1. Flow Chart of CO_2 Mineralization in Ethanol + Potassium Hydroxide Solution

(1) Inject CO_2 into the reactor and stir the solution at a speed of 380 rpm to mineralize CO_2.

(2) During the reaction process, use the pH meter in the reactor to measure the PH change every 1 minute.

(3) After the reaction, filter the carbonization solution to obtain the precipitate, and dry it at 50 degrees Celsius.

(4) Change the ethanol concentration and reaction temperature in mineralized solution, and repeat (1) - (4).

3.2 Experiment of carbon dioxide burial in cores after the action of ethanol+ potassium hydroxide solution.

The best proportion of CO_2 mineralization reaction is selected according to part 3.1 experiments. This article uses a self-developed CO_2 storage device to conduct CO_2 storage experiments and study the pore permeability changes of different permeability cores after saturation with a mixed solution.

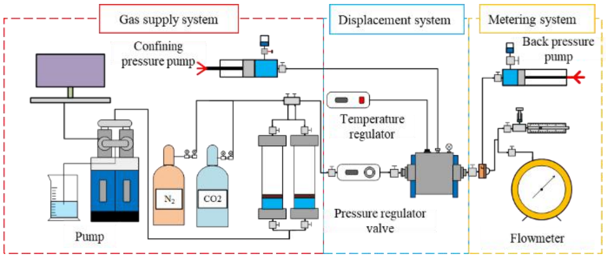

Fig. 2. Flow chart of core scale CO2 storage experiment

(1) The core pore distribution under original conditions was determined using a nuclear magnetic resonance experimental device.

(2) Place the saturated CO_2 mineralized solution of the core in the core support to maintain the temperature of the core support at the formation temperature.

(3) The inlet end of the core holder injects CO_2 at a constant rate. Measuring core gas permeability and porosity.

(4) Saturated the core with water again, and use a nuclear magnetic resonance experimental device to determine the pore distribution after the CO_2 mineralization reaction.

4. RESULTS AND DISCUSSION

4.1 Experimental Research Results of CO2 Capture

Experimental study on CO_2 capture was carried out under atmospheric pressure and 80 degrees Celsius. The CO_2 capture characteristics of dissolved 3g potassium hydroxide were determined at different ethanol concentrations (75%, 80%, 85%, 90%, 92%, 94%, 96%, 98%). In accordance with the reaction process described in section 3.1, CO_2 was injected into the KOH + ethanol solution system to carry out the experiment on mineralization capture. The characteristics of the precipitation quality changing with ethanol concentration are shown in Figure 3, and the pH change characteristics of the reaction solution are shown in Figure 4.

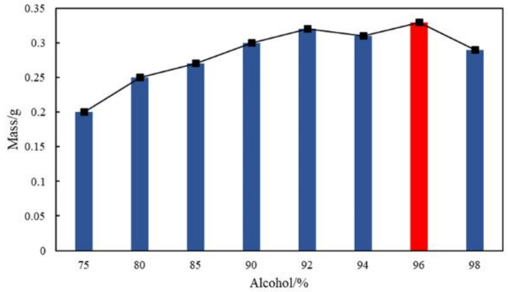

Fig. 3. Flow Chart of CO_2 Mineralization in Ethanol + Potassium Hydroxide Solution

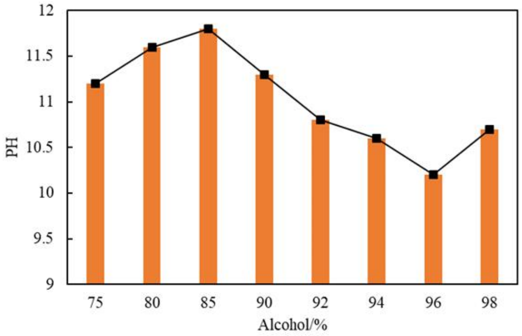

Fig. 4. Variation characteristics of PH value

The results show that the ethanol potassium hydroxide system can effectively carry out CO_2 mineralization and capture, thereby accelerating the CO_2 mineralization and capture process Comparing the CO_2 precipitation results with different ethanol concentrations, it can be seen that the "96% ethanol+3 gram potassium hydroxide " 500 milliliter solution has the highest quality of CO_2 capture, so it is the best ratio of CO_2 mineralization capture solution.

4.2 Experimental Research Results of CO2 Mineralization and Storage

The purity of CO_2 and N_2 used in the experiment is 99% and 99% respectively. The experimental liquid was compounded by 95% KOH and ethanol. The selected core porosity and permeability are shown in Table 1.

Table 4-1 Physical Property Data of Core Foundation

Core	Porosity /%	Permeability /mD	Porosity change rate/%	Permeability change rate/%
#1	13.2	6.18	7.57	12.13
#2	12.6	6.05	3.96	15.20
#3	11.2	5.83	3.57	10.63
#4	15.1	7.38	3.31	11.38
#5	13.6	6.32	3.67	10.60
#6	13.2	7.01	3.03	11.41
#7	12.2	6.35	4.91	12.12
#8	13.2	7.13	2.27	12.90
#9	12.8	6.11	6.25	12.43
#10	11.8	5.99	4.23	13.02
#11	10.82	5.01	4.73	13.7

Table 4-1 Physical Property Data of Core Foundatio (continued)

Core	Porosity /%	Permeability /mD	Porosity change rate/%	Permeability change rate/%
#12	10.82	5.01	5.23	13.98
#13	10.76	4.95	5.73	14.04
#14	10.67	4.86	6.23	14.15
#15	10.16	4.35	6.73	14.21
#16	9.39	3.58	7.23	14.29
#17	8.83	3.02	7.73	14.46
#18	8.76	2.95	8.23	14.63
#19	7.83	2.02	8.73	14.81
#20	6.81	1	9.23	15.05
#21	6.31	0.5	9.73	16.12
#22	6.24	0.43	10.23	18.21
#23	6.04	0.23	10.73	20.16
#24	5.96	0.15	11.23	24.26
#25	5.91	0.1	11.73	26.45
#26	5.86	0.05	12.23	30.02
#27	5.84	0.03	12.37	34.26

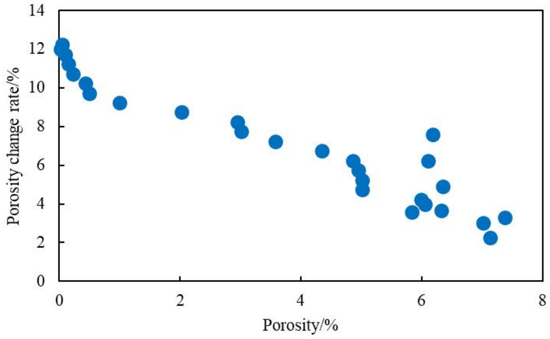

Fig. 5 Porosity change after CO_2 storage

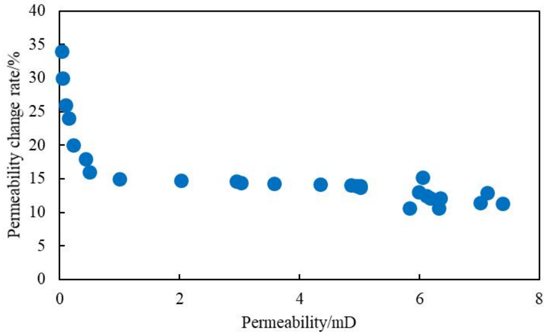

Fig. 6 Permeability change after CO_2 storage

Based on the experimental steps in section 3.2, CO_2 mineralization and burial experiments were conducted using sandstone cores. The results of CO_2 mineralization and burial experiments on low-permeability cores are shown in Figures 5 and 6. After CO_2 mineralization and burial, the core porosity decreases by an average of about 7%, and the permeability decreases by an average of about 16%. The porosity and permeability change rate has a negative correlation with the porosity and permeability data. When the permeability is less than 1 millidarcy, the porosity and permeability change greatly.

4.3 *Experiment Results of Nuclear Magnetic Resonance*

Porosity and permeability are not sufficient to characterize the efficiency and conductivity of inter-reservoir pores in tight formations. Therefore, Nuclear Magnetic Resonance (NMR) experiments are frequently used to assess fluid mobility in various types of pores[40,41]. The foundation of nuclear magnetic resonance is the interaction between the magnetism of atomic nuclei and the external magnetic field. The return of nuclei from a polarized state to the equilibrium state is referred to as the relaxation process, with the duration required being referred to as the relaxation time. The relaxation time can be divided into two types: longitudinal relaxation time T_1 and transverse relaxation time T_2. T_2 is commonly used in the laboratory to characterize the depletion process of the sample. During the relaxation process, pore size plays an important role, and the relaxation rate is related to the rate at which protons collide with the surface. In large pores, collisions occur less frequently and the relative relaxation time is longer. It can be concluded that the size of pores is positively correlated with the relaxation time of hydrogen nuclei. For nuclear magnetic resonance experiments, the lateral relaxation time of rock samples measured in a uniform magnetic field can be expressed as:

$$\frac{1}{T_2}=\frac{1}{T_{2B}}+\frac{1}{T_{2D}}+\rho_2\frac{S}{V}$$

T_2 is the lateral relaxation time of the rock, ms; T_{2B} is the lateral relaxation time of the fluid volume, ms; T_{2D} is the diffusion lateral relaxation time of the fluid, ms; ρ is the T_2 surface relaxation strength; S/V is the specific surface area of pores, 1/μm.

This experiment clarified the characteristics of fluid changes in dense rock cores saturated with different solutions through nuclear magnetic resonance experiments. The research results are shown in Figures 7 and 8.

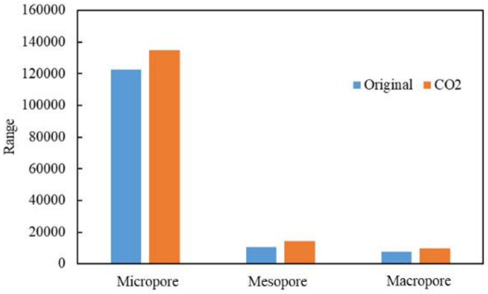

Fig. 7 Variation characteristics of different pores

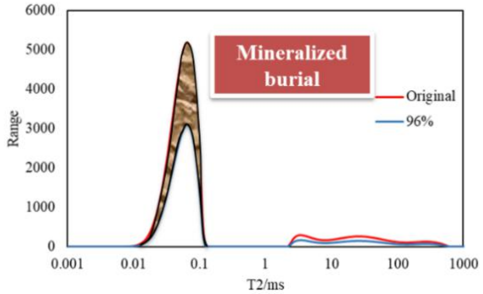

Fig. 8 Carbon dioxide burial NMR experiment(96% ethanol)

The experimental results show that after CO_2 treatment, the average pore size of the reservoir increases by about 12.8%, with medium and large pores increasing by 30% and micropores increasing by 12%. Injecting CO_2 into the reservoir will enhance pore connectivity and reduce the degree of CO_2 storage. From the analysis of Figures 8, it can be seen that conducting CO_2 burial experiments after saturating the core with an "ethanol+ potassium hydroxide " solution can effectively bury CO_2 in the formation in the form of sediment.

Due to the large number of small pores in the core, the contact area between CO2 and solution is relatively large, there are more precipitates in the micropores (decreases by about 20%). It will be seen from this that the reservoir treated with " 96% Ethanol+3 gram " solution can significantly accelerate the efficiency of CO_2 mineralization and burial, shorten the time of CO_2 mineralization and burial, and increase the total amount of CO_2 burial.

5. CONCLUSIONS

(1) The research results show that the ethanol potassium hydroxide system can effectively carry out CO_2 mineralization and capture, thereby accelerating the CO_2 mineralization and capture process. It can be seen that the "96% Ethanol+3 gram potassium hydroxide " 500ml solution has the highest quality of CO_2 capture, so it is the best ratio of CO_2 mineralization capture solution.

(2) After CO_2 mineralization and burial, the core porosity decreases by an average of about 7%, and the permeability decreases by an average of about 16%.

The porosity and permeability change rate has a negative correlation with the porosity and permeability data. When the permeability is less than 1mD, the porosity and permeability change greatly. 96% Ethanol+3 gram potassium hydroxide can accelerate the CO_2 precipitation process in the reservoir and shorten the mineralization and burial time of CO_2 in the reservoir.

(3) The results of nuclear magnetic resonance experiments indicate that after the action of " 96% Ethanol+3 gram " solution, CO_2 can be effectively captured in the form of precipitates in the reservoir, with the largest degree of capture in the medium to large pores. From this, it can be seen that the reservoir treated with " 96% Ethanol+3 gram " solution can significantly accelerate the efficiency of CO_2 mineralization and burial, shorten the time of CO_2 mineralization and burial, and increase the total amount of CO_2 burial.

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.

REFERENCE

[1] Bachu S, Bonijoly D, Bradshaw J, et al. CO2 storage capacity estimation: Methodology and gaps[J]. International journal of greenhouse gas control, 2007, 1(4): 430-443.

[2] Kelemen P, Benson S M, Pilorgé H, et al. An overview of the status and challenges of CO2 storage in minerals and geological formations[J]. Frontiers in Climate, 2019, 1: 9.

[3] Cao C, Liu H, Hou Z, et al. A review of CO2 storage in view of safety and cost-effectiveness[J]. Energies, 2020, 13(3): 600.

[4] Godec M L, Kuuskraa V A, Dipietro P. Opportunities for using anthropogenic CO2 for enhanced oil recovery and CO2 storage[J]. Energy & Fuels, 2013, 27(8): 4183-4189.

[5] Rani S, Padmanabhan E, Prusty B K. Review of gas adsorption in shales for enhanced methane recovery and CO2 storage[J]. Journal of Petroleum Science and Engineering, 2019, 175: 634-643.

[6] Kelemen P, Benson S M, Pilorgé H, et al. An overview of the status and challenges of CO2 storage in minerals and geological formations[J]. Frontiers in Climate, 2019, 1: 9.

[7] Li X, Peng B, Liu Q, et al. Micro and nanobubbles technologies as a new horizon for CO2-EOR and CO2 geological storage techniques: A review[J]. Fuel, 2023, 341: 127661.

[8] Jia B, Tsau J S, Barati R. A review of the current progress of CO2 injection EOR and carbon storage in shale oil reservoirs[J]. Fuel, 2019, 236: 404-427.

[9] Klewiah I, Berawala D S, Walker H C A, et al. Review of experimental sorption studies of CO2 and CH4 in shales[J]. Journal of Natural Gas Science and Engineering, 2020, 73: 103045.

[10] Massarweh O, Abushaikha A S. A review of recent developments in CO2 mobility control in enhanced oil recovery[J]. Petroleum, 2022, 8(3): 291-317.

[11] Jiang S, Li Y, Wang F, et al. A state-of-the-art review of CO2 enhanced oil recovery as a promising technology to achieve carbon neutrality in China[J]. Environmental Research, 2022, 210: 112986.

[12] Burrows L C, Haeri F, Cvetic P, et al. A literature review of CO2, natural gas, and water-based fluids for enhanced oil recovery in unconventional reservoirs[J]. Energy & Fuels, 2020, 34(5): 5331-5380.

[13] Farajzadeh R, Eftekhari A A, Dafnomilis G, et al. On the sustainability of CO2 storage through CO2–Enhanced oil recovery[J]. Applied Energy, 2020, 261: 114467.

[14] Li H, Peng S, Xu M, et al. CO2 Storage Mechanism in Deep Saline Aquifers[J]. Science & Technology Review, 2013, 31(02): 72-79.

[15] Yuan S, Ma D, Li J, et al. Progress and prospects of carbon dioxide capture, EOR-utilization and storage industrialization[J]. Petroleum Exploration and Development, 2022,49(04):828-834.

[16] Jiang H, Shen P, Zhong T, et al. The relationship between carbon dioxide storage and enhanced oil recovery[J]. Petroleum Geology and Recovery Efficiency, 2008(06):52-55+114.

[17] Janna F, Le-Hussain F. Effectiveness of modified CO2 injection at improving oil recovery and CO2 storage—Review and simulations[J]. Energy Reports, 2020, 6: 1922-1941.

[18] Vo Thanh H, Sugai Y, Sasaki K. Application of artificial neural network for predicting the performance of CO2 enhanced oil recovery and storage in residual oil zones[J]. Scientific reports, 2020, 10(1): 18204.

[19] Ajoma E, Sungkachart T, Ge J, et al. Water-saturated CO2 injection to improve oil recovery and CO2 storage[J]. Applied energy, 2020, 266: 114853.

[20] Hamza A, Hussein I A, Al-Marri M J, et al. CO2 enhanced gas recovery and sequestration in depleted

gas reservoirs: A review[J]. Journal of Petroleum Science and Engineering, 2021, 196: 107685.

[21] Tang Y, Hu S, He Y, et al. Experiment on CO2-brine-rock interaction during CO2 injection and storage in gas reservoirs with aquifer[J]. Chemical Engineering Journal, 2021, 413: 127567.

[22] Mu L, Liao X, Zhao X, et al. Numerical Analyses of the Effect of the Impurity in the Gas on the Solubility Trapping in the CO2 Sequestration[C]//Carbon Management Technology Conference. OnePetro, 2017.

[23] Zhang W, Li Y, Xu T, et al. Long-term variations of CO2 trapped in different mechanisms in deep saline formations: A case study of the Songliao Basin, China[J]. International journal of greenhouse gas control, 2009, 3(2): 161-180.

[24] Sun L, Dou H, Li Z, et al. Assessment of CO2 storage potential and carbon capture, utilization and storage prospect in China[J]. Journal of the energy institute, 2018, 91(6): 970-977.

[25] Lemieux A, Shkarupin A, Sharp K. Geologic feasibility of underground hydrogen storage in Canada[J]. International Journal of Hydrogen Energy, 2020, 45(56): 32243-32259.

[26] Power I M, Dipple G M, Bradshaw P M D, et al. Prospects for CO2 mineralization and enhanced weathering of ultramafic mine tailings from the Baptiste nickel deposit in British Columbia, Canada[J]. International Journal of Greenhouse Gas Control, 2020, 94: 102895.

[27] Zhu B, Wilson S A, Zeyen N, et al. Unlocking the potential of hydraulic fracturing flowback and produced water for CO2 removal via mineral carbonation[J]. Applied Geochemistry, 2022, 142: 105345.

[28] Kovscek A R, Cakici M D. Geologic storage of carbon dioxide and enhanced oil recovery. II. Cooptimization of storage and recovery[J]. Energy conversion and Management, 2005, 46(11-12): 1941-1956.

[29] Bender S, Akin S. Flue gas injection for EOR and sequestration: Case study[J]. Journal of Petroleum Science and Engineering, 2017, 157: 1033-1045.

[30] Yao Z, Huang, C, Duan J, et al. CO2 Displacement Geological Storage Potential Evaluation of Yanchang Oilfield[J]. Journal of Liaoning Shihua University, 2016,36(03):43-45.

[31] Liu B, Liu Y. Evaluation of carbon dioxide flooding effect based on reservoir heterogeneity[J]. Chemical Engineer, 2017,31(05):40-42+33.DOI:10.16247/j.cnki.23-1171/tq.20170540.

[32] Xiao Pufu, Yang Zhengming, Wang Xuewu, et al. Experimental investigation on CO2, injection in the Daqing extra/ultra-low permeability reservoir[J]. Journal of Petroleum Science & Engineering, 2016, 149: 765-771

[33] Tang Y, Yang R, Bian X. A review of sequestration projects and application in China[J]. The Scientific World Journal, 2014, 2014.

[34] Jiang J, Shao Y, Younis R M. Development of a multi-continuum multi-component model for enhanced gas recovery and CO2 storage in fractured shale gas reservoirs[C]//SPE improved oil recovery symposium. OnePetro, 2014.

[35] Zhao R, Ao W, Xiao A, et al. Diffusion law and measurement of variable diffusion coefficient of CO2 in oil[J]. Journal of China University of Petroleum, 2016,40(03):136-142.

[36] Mu L, Liao X, Zhao X, et al. Numerical Analyses of the Effect of the Impurity in the Gas on the Solubility Trapping in the CO2 Sequestration[C]//Carbon Management Technology Conference. OnePetro, 2017.

[37] Zhang W, Li Y, Xu T, et al. Long-term variations of CO2 trapped in different mechanisms in deep saline formations: A case study of the Songliao Basin, China[J]. International journal of greenhouse gas control, 2009, 3(2): 161-180.

[38] Yoo M R, Han S J, Shin J Y, et al. A study on carbon dioxide capture performance of KOH aqueous solution via chemical absorption[J]. Journal of Korean Society of Environmental Engineers, 2012, 34(1): 55-62.

[39] Pak J, Han S J, Wee J H. Precipitation of potassium-based carbonates for carbon dioxide fixation via the carbonation and re-carbonation of KOH dissolved aqueous ethanol solutions[J]. Chemical Engineering Journal, 2022, 427: 131669.

[40] Song Y, Song Z, Zeng H, et al. N2 and CO2 Huff-n-Puff for Enhanced Tight Oil Recovery: An Experimental Study Using Nuclear Magnetic Resonance[J]. Energy & Fuels, 2022, 36(3): 1515-1521.

[41] Wei B, Zhang X, Wu R, et al. Pore-scale monitoring of CO2 and N2 flooding processes in a tight formation under reservoir conditions using nuclear magnetic resonance (NMR): A case study[J]. Fuel, 2019, 246: 34-41.