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Mechanism Study of CO2 Huff-n-Puff for Enhanced Shale Oil Recovery Based on Core Experiments and Numerical Simulation

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ABSTRACT

Shale oil reservoirs suffer from low recovery (<10%) due to ultra-tight formations. CO_2 huff-n-puff (HnP) is a promising enhanced oil recovery (EOR) technique, but its underlying mechanisms remain unclear. This study integrates nuclear magnetic resonance (NMR) experiments and numerical simulations to investigate and quantify the contributions of different EOR mechanisms.CO_2 was injected into shale cores, followed by soaking and production, while NMR tracked oil mobilization distance. Results showed that increasing soak time from 30 minutes to 24 hours extended mobilization distance from 18 mm to 42 mm and boosted recovery from 6% to 20%. A compositional simulation model, history-matched to experiments, revealed that oil swelling and dissolved gas drive dominated the recovery process. With longer soaking (5 minutes to 48 hours), oil swelling increased its contribution from 0% to 50%, while rock expansion remained below 10%. Higher soaking pressures (5–11 MPa) enhanced extraction and gas drive effects.This study provides new insights into CO_2 HnP in shale oil reservoirs and offers a robust framework for evaluating and optimizing EOR performance in ultra-low-permeability systems.

Keywords: CO_2 huff-n-puff; shale oil; numerical simulation; EOR mechanisms

1. INTRODUCTION

Shale oil reservoirs have emerged as significant energy assets. Yet, these formations are characterized by ultra-tight matrix properties (permeabilities in the nano-Darcy range and nanoscale pore throats), so primary production via pressure depletion yields very low recovery factors – on the order of only 5–10%[1-3]. Horizontal drilling and multi-stage hydraulic fracturing have made it feasible to tap shale oil economically, but production rates typically decline sharply after the first few months of output[4, 5]. As a result, the vast majority of oil remains trapped in the matrix, prompting interest in enhanced oil recovery (EOR) methods to improve recovery. Among various EOR techniques, CO_2 injection has gained prominence for shale reservoirs. Continuous CO_2 flooding was initially tested, but in fractured shales the injected gas tends to channel quickly to production wells, resulting in poor sweep efficiency[6, 7]. In contrast, the cyclic huff-n-puff mode – using a single well alternately for CO_2 injection, soak (shut-in), and oil production – avoids immediate breakthrough and has proven effective at recovering additional oil in laboratory experiments and field pilots[5, 8].

Recent studies have investigated CO_2 HnP performance in tight/shale reservoirs through both experiments and simulations[9-12]. Numerous parametric studies have explored factors such as injection pressure, the number of injection cycles, soaking time, pressure depletion rate during production, and injected gas type. These studies consistently show that CO_2 tends to outperform other gases (e.g. N_2) in huff-n-puff EOR performance. For instance, laboratory comparisons have reported that CO_2 HnP can yield cumulative oil recoveries on the order of 33%–85% of the original oil in place, whereas N_2 HnP under similar conditions achieved only about 10%–50%. CO_2 can more readily penetrate shale pores and mix with the oil, leading to greater efficiency in mobilizing hydrocarbons.

Despite these encouraging results, the mechanisms by which CO_2 huff-n-puff enhances oil recovery in shales remain incompletely understood and are a subject of ongoing study[13-21]. CO_2 interacts with the reservoir fluids and rock through multiple mechanisms simultaneously. First, CO_2 dissolves into the crude oil, causing the oil to swell (increase in volume) and reducing its viscosity; Second, CO_2 can extract and vaporize lighter hydrocarbons . from the oil into the gas phase – a vaporization/extraction mechanism evidenced by significant recovery of C_3–C_8 components in produced gas. Third, during the production (blowdown) stage of HnP, the drop in pressure causes the dissolved CO_2 to

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come out of solution (exsolve) inside the oil, generating a foamy oil behavior or internal gas drive that pushes oil towards the production well. Zhou et al[22]. observed in heavy-oil HnP experiments that foamy oil (dissolved gas drive), viscosity reduction, and oil swelling were the most important contributors to CO_2-EOR. In contrast, Pu et al.[23] concluded from tight-core tests that the primary driver of HnP oil production was simply the pressure gradient (injection pressure push) across the matrix. Ma et al[24]. reported that in their nano-pore CO_2 soak tests, oil swelling and the vaporization of oil into CO_2 were the key recovery mechanisms. These varying conclusions highlight that the relative importance of each mechanism can differ greatly depending on oil composition, pressure conditions, and rock properties. Overall, the detailed interplay of mechanisms in shale CO_2 HnP remains not fully resolved, and – critically – current approaches have difficulty quantifying how much each mechanism contributes to the total recovered oil.

To overcome these limitations, researchers have turned to numerical simulation as tools to dissect the combined mechanisms[9, 25-30]. In particular, compositional reservoir simulation has been widely applied to study CO_2 HnP at both core scale and field scale. By history-matching laboratory results, a simulation model can incorporate multi-component mass transfer (diffusion) and phase behavior effects, and thereby infer details of the process that cannot be directly seen in experiments. Tang and Sheng built a core-scale simulation model calibrated to their lab HnP tests, which enabled them to evaluate parameters like the amount of CO_2 dissolved in the oil vs. existing as free gas, the interfacial tension reduction. Li,et al[31]. deduced how CO_2 solubility and miscibility contributed to incremental recovery in a Bakken shale test.

However, numerical simulations come with their own uncertainties. The accuracy of a simulator's predictions depends on the reliability of input parameters (diffusion coefficients, relative permeability in nano-pores, oil swelling factors), which are often not well constrained. Shilov et al[32]. observed that using a default diffusion correlation dramatically over-predicted oil recovery in a shale HnP model, and the diffusion coefficients had to be scaled down to only ~5% of their initial values to match the experimental data. The need for such drastic calibration highlights the importance of tuning simulations to empirical data, and indicates that while simulation is a powerful means to analyze EOR mechanisms, it must be carefully validated against experiments to yield trustworthy quantitative insights.

A critical aspect of CO_2 HnP performance is the spatial sweep of the injected gas, often described in terms of a mobilization distance or penetration depth in the shale matrix. Unlike a conventional flood (which uses separate injectors to drive oil over large areas), the huff-n-puff process only contacts oil in the vicinity of the injection well or fracture during each cycle. CO_2 penetration into the matrix is severely limited by the ultra-low permeability and the finite time for diffusion. In effect, only oil within a certain radius of the fracture/wellbore is mobilized by CO_2, while oil farther away remains unswept in a given cycle. Li et al[33]. reported that in extremely low-permeability cores, CO_2 could not naturally penetrate far into the matrix. Fernø et al.[4] defined a "diffusion length" to quantify the distance CO_2 must travel from a fracture into the matrix, and demonstrated that this distance strongly controls oil extraction efficiency. In their experiments, systems requiring CO_2 to diffuse over a longer distance (on the scale of a few centimeters) showed much slower and lower recovery; for example, when the diffusion length was about 11.8 cm, only ~29% of the oil was recovered even after 1200 hours of CO_2 exposure. These findings illustrate that the spatial reach of CO_2 in HnP is inherently limited. However, to date there have been very few direct measurements of how far into a shale core the CO_2 can mobilize oil during huff-n-puff.

In light of the above knowledge gaps, the present study introduces an integrated experimental–simulation approach to more rigorously quantify the mechanisms of CO_2 huff-n-puff in a shale oil reservoir. First, we design and perform laboratory CO_2 HnP experiments on shale core samples with Nuclear Magnetic Resonance (NMR) measurements during the injection, soaking, and production stages. The NMR 1DHSE relaxation profiles are used to monitor fluid distribution changes along the core, allowing us to directly measure the effective mobilization distance of oil by CO_2 within the core. Second, we develop a detailed core-scale compositional simulation model calibrated against the experimental results Using this calibrated model, we quantitatively evaluate the contributions of individual EOR mechanisms: oil swelling, oil vaporization/extraction, rock expansion, and dissolved gas drive – under the experimental conditions and in various scenarios. By combining these two techniques, our study provides a more comprehensive and quantitative insight into how CO_2 huff-n-puff recovers oil from ultra-tight shale, and elucidates how key parameters (such as soaking time and injection pressure) influence the dominant recovery mechanisms. The findings offer practical guidance for

optimizing CO_2-based EOR in shale reservoirs, and represent a significant step forward in our ability to evaluate EOR mechanism efficacy in such challenging formations.

2. MATERIAL AND METHODS

2.1 Core experiments

This section describes the petrophysical properties of the cores and fluids, the experiment devices, and their assembly. A description of the experiment process and principles is also provided.

2.1.1 Properties of cores and fluids

Table 1:

Core	Length (mm)	Diameter (mm)	Porosity (%)	Permeaability (mD)
1	80.02	25.28	6.2	0.05

The experimental cores were collected from shale outcrops and cut into φ25×80 mm^2 cylindrical samples. The petrophysical properties of cores is shown in Table 1.

The core was first dried in an oven at 120 ◦C for 24 h to remove moisture and was then vacuumed and saturated with oil under 30 MPa for 4 days. A plug was placed at the no-injection end of the saturated core to simulate the resevior condition as shoen in Fig. 1a

The core was saturated with n-dodecane, The density and viscosity of the synthetic oil measured in the lab condition (26 ◦C, 0.1 MPa) are 0.749 g/cm^3 and 1.33 mPa·s. the miscible pressure of CO_2 and n-dodecane is 5.5 MPa, respectively.

2.1.2 NMR monitored CO_2 huff-n-puff experiments

The experimental setup was designed as shown in Fig. 2. The experimental cores were placed in a special non-magnetic core-holder.CO_2 is injected from the left side of the core holder for a period to remove the air in the pipeline. Then, Valve 6 is closed. When the gas pressure rises to a preset value, Valve 5 is closed to simulate the soaking stage of CO_2 huff and puff. After the soaking period ends, Valve 6 is opened to conduct the blowdown cycle under a certain backpressure. Additionally, the confining pressure is set 4 MPa higher

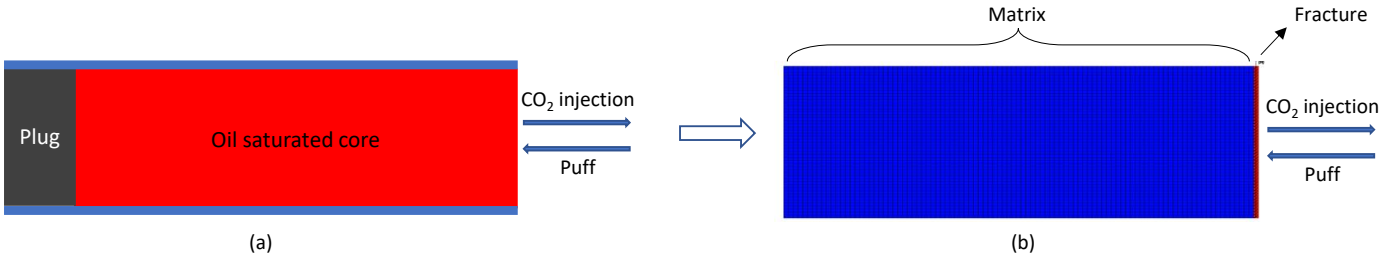


Fig. 1. Schematic of the experimental core in the CO_2 huff-n-puff exoeriments

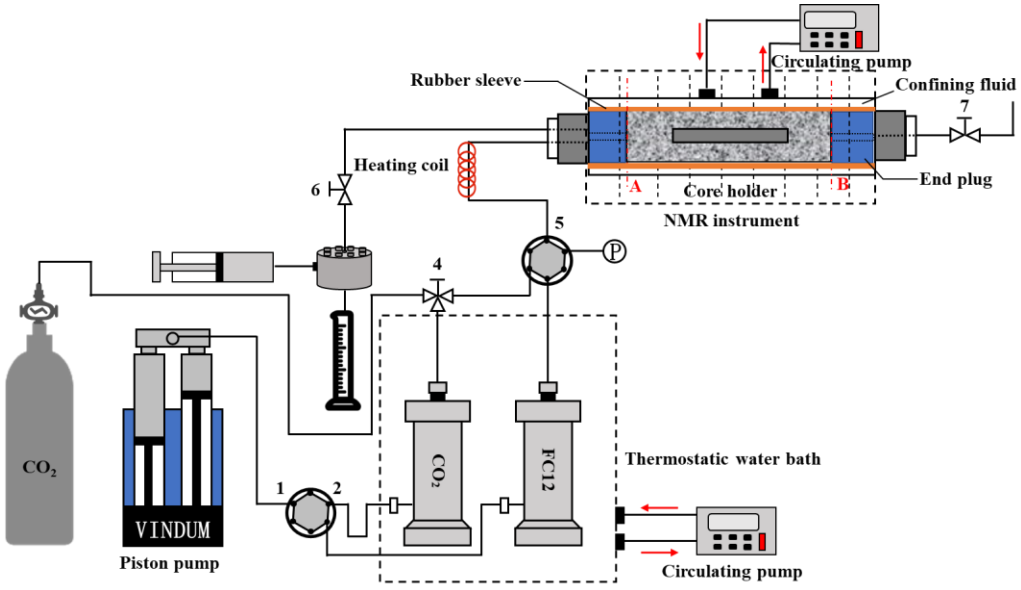


Fig. 2. Core experimental setup

than the pore pressure to eliminate the influence of rock skeleton deformation. The waste CO_2 generated by the experiment is collected by a sodium hydroxide solution.

The low-field NMR instrument is designed and built by Niumag Corporation, China. There are two modules of the NMR instrument: CPMG and GR_HSE, which are applied to monitor the oil migration. Using the CPMG sequence, the oil migration in different pores can be characterized by the alteration of the T2 spectrum. To obtain the NMR signal of the core section using the GR_HSE sequence, a spatial slice is selected by applying a shaped rf pulse in the presence of a gradient. The width of the slice Δx is determined by the frequency bandwidth and the frequency bandwidth Δυ of the pulse and the gradient amplitude g are shown in Eq. (2).

$$\Delta \mathrm{x} = \frac{2\pi\Delta\nu}{\gamma \mathrm{g}}$$

where γ is the nucleus-specific gyromagnetic ratio. These

Table 2: Key parameters of the NMR instruments.

Function	Pulse sequences	Field strength(MHz)	Gradient strength(T/m)	TW(ms)	TE(ms)	Scanning times	Temperature(◦C)
T2	CPMG	12	0	1000	0.1	64	32
1D frequency	GR_HSE	12	0.0487	1000	3.7	64	32

tomographic sections in the instrument have a width of 0.15 mm. The NMR instrument has high accuracy (1 mg) for the experimental oil samples to ensure the reliability of the experiments related to tight rocks. The key parameters of the NMR instrument used in the experiments are listed in Table. 2

Based on the above experimental criteria, we

Table 3:

Group	Number	Pressure/MPa	Soaking time/ h
1	1	3	0.17
	2	5	
	3	7	
	4	9	
2	5	9	0.083
	6		0.17
	7		0.5
	8		1
	9		10
	10		24
	11		48

designed two groups experiments to investagate the effects of injection pressure and soaking time on recovery factor as shown in table 3

2.2 Numerical simulation

A two dimensional model with a cartesian coordinate system and a compositional reservoir simulator(CMG-GEM) were used to simulate the CO_2 cyclic injection experiment.

2.2.1 parametes

In this experiment, the shale core was placed in a core holder, with its right end directly exposed to CO_2, simulating a fracture. During the huff-n-puff process, gas was injected through and produced from this fracture. The simulation model adopted the same dimensions as the physical experiment. During the injection, diffusion, and production phases, only the face in direct contact with CO_2 was kept open. The shale core permeability was set to 0.005 millidarcies. The model comprised 50 layers and 100 grid blocks in the x-direction, with the shale matrix designated as Sector 1 and the fracture zone as Sector 2. The production and injection wells were located in Sector 2 grid blocks (1–50, 100, 1). It is important to note that the actual hydrocarbon volume produced by the well differs from the recovery volume from Sector 1. Once the production well is shut in, no hydrocarbons are recovered from the wellbore. However, because pressure depletion in the shale matrix may lag behind that in the fracture network, hydrocarbons can still be driven out of Sector 1 by the pressure gradient. Therefore, the hydrocarbon recovery from the well and Sector 1 are distinct. In subsequent calculations of recovery efficiency, we used the recovery factor of Sector 1. The injection well was constrained by a maximum injection pressure, while the production well was operated under a bottom-hole flowing pressure of 100 kPa.

2.2.2 Quantify the contributes of the EOR mechanisms

Mobilization due to oil swelling is defined as the ratio of the number of moles of oil phase entering the fracture during the soaking period to the initial number of moles of oil phase in the matrix.

$$R_{Oil-swell} = \frac{y}{t}$$

Mobilization due to extraction is defined as the ratio of the number of moles of oil phase dissolved into the

gas and entering the fracture during the soaking period to the initial number of moles of oil phase in the matrix.

$$R_{Oil-extraction} = \frac{z}{t}$$

Mobilization due to elastic energy is defined as the change in oil quantity during the depressurization stage when the matrix grid pressure is greater than the bubble point pressure.

$$R_{Rock-expansion} = \frac{\sum_{j\in\kappa}(x_{m,j} - x'_{i,j})}{t}(P_{i,j} > P_b)$$

Mobilization due to dissolved gas drive is defined as the change in oil quantity during the depressurization stage when the matrix grid pressure is lower than the bubble point pressure.

$$R_{Dissolve-gas} = \frac{\sum_{j\in\kappa}(x_{m,j} - x'_{i,j})}{t}(P_{i,j} < P_b)$$

3. RESULTS AND DISCUSSION

3.1 CO_2 huff-n-puff Experiments

we established the CO_2 mobilization distance which is defined as the largest distance of the CO2 front from the fracture plane. The first point that extended internally from both ends of the cores more than 98% (the average noise signal is less than 0.8, the average effective signal is greater than 220) was used as the CO2 front. For instance, the CO2 mobilization distance is 26 mm at 6 MPa as shown in Fig. 3

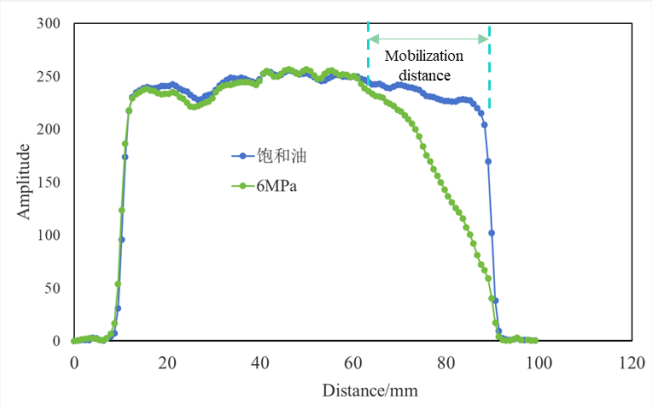


Fig 3 NMR signal of experimental core

3.1.1 injection pressure

The first group experiments were performed to investigate the effect of injection pressure on oil recovery. Fig. 4-5 recorded the NMR signals of

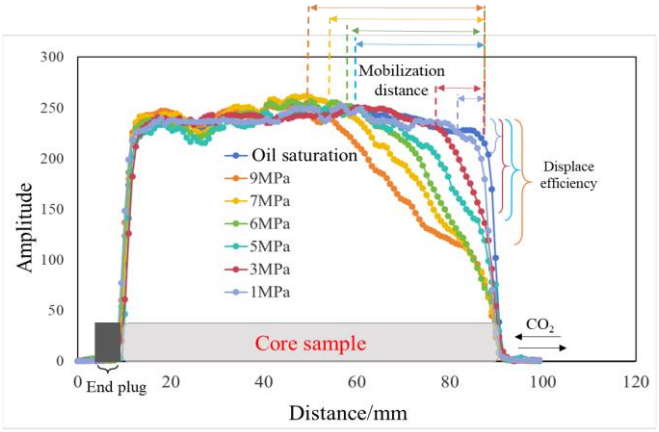


Fig 4 1D HSE of experimental cores under different injection pressures

experimental cores at various stages of the CO_2 huff-n-

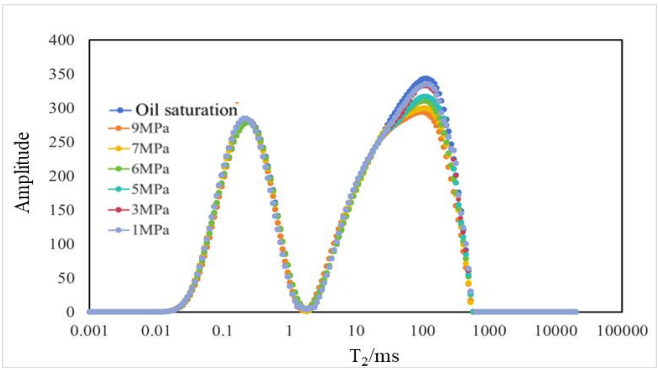


Fig 5 T2 spectra of experimental core under different injection pressures

puff process under different injection pressures.

3.1.2 soak time

The second group experiments were performed to investigate the effect of soak time on oil recovery. Fig. 6-7 recorded the NMR signals of experimental cores at various stages of the CO_2 huff-n-puff process under different soak time.

3.2 Numerical simulation

3.2.1 history-match

To achieve a historical match with experimental data, model input parameters (including shale matrix permeability, relative permeabilities, and diffusivities of oil and gas phases) were adjusted within acceptable ranges.

The comparison between the simulated oil recovery efficiency and the measured results under experimental conditions is presented in Figure 8-9. Under varying soaking times and injection pressures, the root mean square errors (RMSE) between the experimental values and simulated

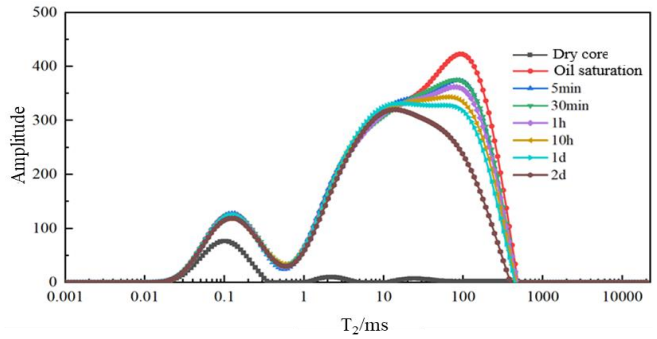


Fig 6 T2 spectra of experimental core under different soak time

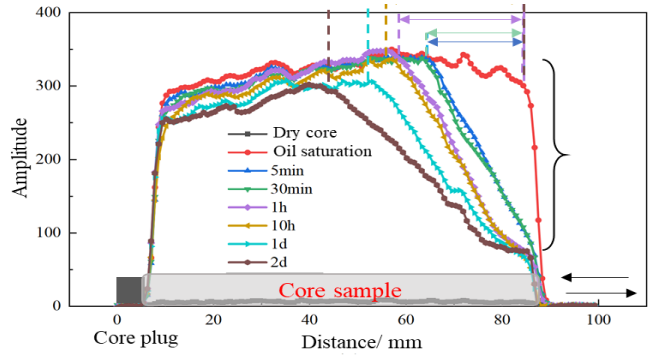


Fig 7 1D HSE of experimental cores under different soak time

values are 0.0258 and 0.00219, respectively, indicating a good fitting between the two.

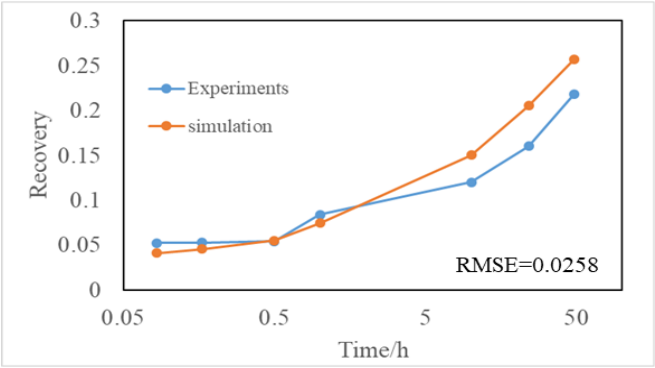


Fig 8 comparision between the results of experiments and simulation(soak time)

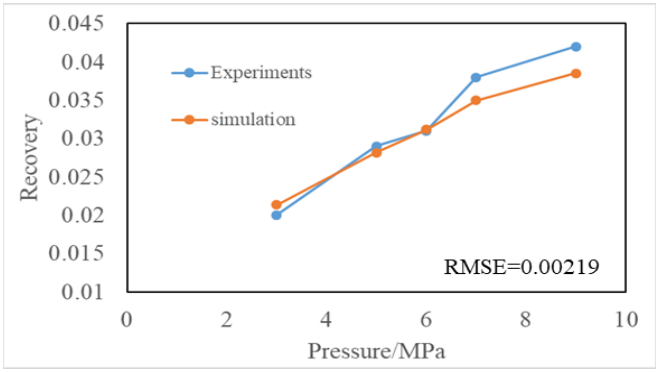
3.2.2 The contributes of different EOR mechanism

As the soaking time increased from 5 minutes to 48 hours, the contribution of oil swelling increased from 0% to 45%. oil swelling and dissolve gas drive were shown to be the dominant EOR mechanisms.

An increase in pressure results in only a marginal enhancement in the overall mobilization of the matrix.At lower pressure, oil swelling and dissolved gas drive are the primary recovery mechanisms.At higher pressures, the mobilization significantly increases due to extraction.

4. CONCLUSIONS

(1) CO_2 huff-n-puff experiments confirmed that soaking pressure and time are key parameters influencing oil mobilization.



(b)

Fig 9 comparision between the results of experiments and simulation (injection pressure)

(2) When the soaking time was increased from 30 minutes to 24 hours, the oil mobilization distance expanded from 18 mm to 42 mm, and the corresponding oil recovery improved from 6% to 20%.

(3) Oil swelling and dissolve gas drive were shown to be the dominant EOR mechanisms across multiple scenarios.

(4) As soaking pressure increased from 5 MPa to 11 MPa, the dominant EOR mechanism shifted toward extraction and dissolve gas drive.

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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] Emami--Meybodi Hamid, Ma Ming, Zhang Fengyuan, et al. Cyclic Gas Injection in Low--Permeability Oil Reservoirs: Progress in Modeling and Experiments[J]. SPE Journal, 2024: 223116.

[2] Burrows Lauren C., Haeri Foad, Cvetic Patricia, 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.

[3] Salama Amgad, Amin Mohamed F. El, Kumar Kundan, et al. Flow and Transport in Tight and Shale Formations: A Review[J]. Geofluids, 2017, 2017: 1-21.
[4] Fernø M. A., Steinsbø M., Eide Ø, et al. Parametric study of oil recovery during CO2 injections in fractured chalk: Influence of fracture permeability, diffusion length and water saturation[J]. Journal of Natural Gas Science and Engineering, 2015, 27: 1063-1073.
[5] Zhou Xiang, Yuan Qingwang, Peng Xiaolong, et al. A critical review of the CO2 huff 'n' puff process for enhanced heavy oil recovery[J]. Fuel, 2018, 215: 813-824.
[6] Harith F, Meng Qingbang, Wakeel H, et al. Predicting minimum miscible pressure in pure CO2 flooding using machine learning: Method comparison and sensitivity analysis[J]. Fuel, 2023, 354(5): 129263.
[7] Mehran S, Ali D, Dabir H, et al. Microscopic Mechanisms of Oil Recovery By Near-Miscible Gas Injection[J]. Transport in Porous Media, 2007, 72(3): 351-367.
[8] Wan Yidi, Jia Chengzao, Lv Weifeng. Recovery mechanisms and formation influencing factors of miscible CO2 huff-n-puff processes in shale oil reservoirs: A systematic review[J]. Advances in Geo-Energy Research, 2024, 11(2): 88-102.
[9] Alahmari Saeed, Raslan Mohammed, Khodaparast Pooya, et al. CO2 Huff-n-Puff: An Experimental and Modeling Approach to Delineate Mass Transfer and Recovery from Shale Cores[D]. Day 2 Mon, February 20, 2023, CO2 Huff-n-Puff: An Experimental and Modeling Approach to Delineate Mass Transfer and Recovery from Shale Cores, 2023.
[10] Huang Xing, Li Xiang, Zhang Yi, et al. Microscopic production characteristics of crude oil in nano-pores of shale oil reservoirs during CO2 huff and puff[J]. Petroleum Exploration and Development, 2022, 49(3): 636-643.
[11] Gringarten Alain C. A COMPARISON BETWEEN DIFFERENT SKIN AND WELLBORE STORAGE TYPE-CURVES FOR EARLY-TIME TRANSIENT ANALYSIS[J]. SPE Journal, 1979: 8205.
[12] Li Lei, Sheng James J. Upscale methodology for gas huff-n-puff process in shale oil reservoirs[J]. Journal of Petroleum Science and Engineering, 2017, 153: 36-46.
[13] Hawthorne Steven B., Miller David J. A comparison of crude oil hydrocarbon mobilization by vaporization gas drive into methane, ethane, and carbon dioxide at 15.6 MPa and 42 °C[J]. Fuel, 2019, 249: 392-399.
[14] Hemmati-Sarapardeh Abdolhossein, Khishvand Mahdi, Naseri Ali, et al. Toward reservoir oil viscosity correlation[J]. Chemical Engineering Science, 2013, 90: 53-68.
[15] Jia Bao, Tsau Jyun-Syung, Barati Reza. Role of molecular diffusion in heterogeneous, naturally fractured shale reservoirs during CO2 huff-n-puff[J]. Journal of Petroleum Science and Engineering, 2018, 164: 31-42.
[16] L. Mohammed-Singh Petrotrin, and A.K. Singhal. Screening Criteria for Carbon Dioxide Huff 'n' Puff Operations[J]. SPE Journal, 2006: 100044.
[17] Lee Ji Ho, Lee Kun Sang. Investigation of asphaltene-derived formation damage and nano-confinement on the performance of CO2 huff-n-puff in shale oil reservoirs[J]. Journal of Petroleum Science and Engineering, 2019, 182.
[18] Liu Junrong, Li Hangyu, Tan Qizhi, et al. Quantitative study of CO2 huff-n-puff enhanced oil recovery in tight formation using online NMR technology[J]. Journal of Petroleum Science and Engineering, 2022, 216.
[19] Stalkup F.I., Oil ARGO. Displacement Behavior of the Condensing/Vaporizing Gas Drive Process[J]. SPE Journal, 1987: 16715.
[20] Zheng Zhixue, Di Yuan, Wu Yu-Shu, et al. Nanopore Confinement Effect on the Phase Behavior of CO2/Hydrocarbons in Tight Oil Reservoirs considering Capillary Pressure, Fluid-Wall Interaction, and Molecule Adsorption[J]. Geofluids, 2021, 2021: 1-18.
[21] Zuo Mingsheng, Chen Hao, Qi Xinyu, et al. Effects of CO2 injection volume and formation of in-situ new phase on oil phase behavior during CO2 injection for enhanced oil recovery (EOR) in tight oil reservoirs[J]. Chemical Engineering Journal, 2023, 452.
[22] Zhou Xiang, Li Xiuluan, Shen Dehuang, et al. CO2 huff-n-puff process to enhance heavy oil recovery and CO2 storage: An integration study[J]. Energy, 2022, 239.
[23] Pu Wanfen, Wei Bing, Jin Fayang, et al. Experimental investigation of CO2 huff-n-puff process for enhancing oil recovery in tight reservoirs[J]. Chemical Engineering Research and Design, 2016, 111: 269-276.
[24] Ma Ming, Emami-Meybodi Hamid. Multicomponent inhomogeneous fluid transport in nanoporous media[J]. Chemical Engineering Journal, 2024, 485.
[25] Alfarge Dheiaa, Wei Mingzhen, Bai Baojun. CO2-EOR mechanisms in huff-n-puff operations in shale oil reservoirs based on history matching results[J]. Fuel, 2018, 226: 112-120.
[26] Alharthy Najeeb, Teklu Tadesse, Kazemi Hossein. Enhanced Oil Recovery in Liquid-Rich Shale Reservoirs: Laboratory to Field[J]. SPE Journal, 2015: 175034.
[27] Connolly Paul R. J., Yan Weichao, Zhang Daniel, et al. Simulation and experimental measurements of internal

magnetic field gradients and NMR transverse relaxation times (T2) in sandstone rocks[J]. Journal of Petroleum Science and Engineering, 2019, 175: 985-997.
[28] Fan Qiao, Luo Mingliang, Bai Yun, et al. Experimental and numerical simulation study on enhanced oil recovery by N2-Assisted water huff-n-puff in a tight oil reservoir[J]. Geoenergy Science and Engineering, 2024, 241.
[29] Janiga Damian, Czarnota Robert, Stopa Jerzy, et al. Huff and puff process optimization in micro scale by coupling laboratory experiment and numerical simulation[J]. Fuel, 2018, 224: 289-301.
[30] Kong Xianhui, Delshad Mojdeh, Wheeler Mary F. History Matching Heterogeneous Coreflood of CO2/Brine by Use of Compositional Reservoir Simulator and Geostatistical Approach[J]. SPE Journal, 2015: 163625.
[31] Li Lei, Zhang Yao, Sheng James J. Effect of the Injection Pressure on Enhancing Oil Recovery in Shale Cores during the CO2 Huff-n-Puff Process When It Is above and below the Minimum Miscibility Pressure[J]. Energy & Fuels, 2017, 31(4): 3856-3867.
[32] Shilov Evgeny, Dorhjie Desmond Batsa, Mukhina Elena, et al. Experimental and numerical studies of rich gas Huff-n-Puff injection in tight formation[J]. Journal of Petroleum Science and Engineering, 2022, 208.
[33] Li Lei, Sheng James J. Gas Selection for Huff-n-Puff EOR in Shale Oil Reservoirs Based upon Experimental and Numerical Study[J]. SPE Journal, 2017: 185066.