Applied Energy Symposium 2022: Clean Energy towards Carbon Neutrality (CEN2022)
April 23-25, 2022, Ningbo, China
Paper ID: 101

Exploration Experiment of Development Method After Depletion of Tight Oil

Hao Chen[1,2*], Haizeng Yu[1,2], Chenghao Xu[1,2], Yiqi Zhang[1,2], Mingsheng Zuo[1,2], Yi Wu[1,2]

1 State Key Laboratory of Petroleum Resources and Engineering, 102249

2 College of Safety and Ocean Engineering, China University of Petroleum, 102249 (*Corresponding Author)

ABSTRACT

With the development of Carbon Capture, Utilization and Storage (CCUS) technology, CO_2 injection to improve tight oil recovery has become a new hot spot in the field of tight oil development. At present, horizontal well fracturing, CO_2 huff and puff and other technical methods to develop tight oil are not ideal, so it is particularly important to explore new methods to improve tight oil development. In this paper, reservoir cores were selected from a tight oil reservoir in Xinjiang, and the self-developed experimental device of simultaneous well and asynchronous well huff and puff was used to simulate the development process of tight oil, CO_2 injection and asynchronous huff and puff and development process under different recovery pressures and production pressures, and to evaluate the displacement characteristics and development effects of asynchronous huff and puff and development process under different CO_2 injection. The research shows that the integrated experiment of "same well and different well asynchronous" can better simulate the seepage characteristics and development characteristics of single well and different well stimulation after depletion development. Compared with conventional single well huff and puff method, CO_2-injection asynchronous huff and puff can increase recovery by 20%-40%. The key to achieving better development results is to establish a circulating "displacement-soaking-displacement" synergistic system of different wells through pressure recovery, soaking and production process alternately between different wells. The oil transportation distance becomes smaller, the oil saturation field is constantly redistributed, and the diffusion and sweep range of CO_2 is expanded. With the increase of pressure difference between "recovery and production", the harvest effect was significantly improved. The development process can effectively avoid the CO_2 backflow process, improve the CO_2 utilization rate, and realize the effective storage of CO_2.

Keywords: Carbon Capture, Utilization and Storage; Tight oil; Asynchronous huff and huff

NONMENCLATURE

Abbreviations	
CCUS	Carbon Capture, Utilization and Storage
Symbols	
n	Year

1. INTRODUCTION

Tight reservoirs are characterized by poor physical properties, strong heterogeneity and obvious low permeability, so it is difficult to establish an effective inter-well displacement system, and the recovery rate of depletion development is mostly less than 10%. Horizontal well fracturing and other technical means are not ideal for developing tight oil.

Indoor experiments show that CO_2 huff and puff after depleted development can effectively improve oil recovery (EOR). B. Todd Hoffman[1] evaluates the results from these field tests and discusses the successes and opportunities. However, the field test results are not satisfactory. As production time goes on, the production efficiency decreases rapidly [2-5]. Therefore, there is an urgent need to explore feasible enhanced oil recovery technologies. The CO_2 flooding is a proven enhanced oil recovery technique to obtain high oil recovery from complicated formations and can be applied to various

Selection and peer-review under the responsibility of the scientific committee of the CEN2022.
Copyright © CEN2022

types of oil reservoirs. Aziz Arshad et al.[6] investigate the performance of CO_2 miscible flooding in tight oil reservoirs, and addresses the results of CO_2 miscible flooding applied to a known reservoir. However, relevant research on the combination of huff and puff and CO_2 flooding has not been carried out.

Well or interwell injection and production technology can effectively establish interwell and interfracture displacement system. Such as Shiqing Cheng[7] for dense oil reservoir is put forward, such as the horizontal sync injection-production technology, reservoir physical property were studied using numerical simulation method and fracturing technology to the influence of the seam between the asynchronous injection-production well. Research shows that horizontal well with injection-production technology can significantly improve the waterflood swept area, to realize uniform water drive, control the moistur content of oil wells, improve the oil well production, at the same time reduce the number of injection wells. Haiyang Yu[8] conducted a feasibility study on asynchronous injection-production from different wells through numerical simulation and optimized parameters. The results showed that water injection and stimulation enhanced recovery with short cycle, small amplitude and insignificant, and asynchronous injection-production from different wells had a longer stable production period and higher recovery degree, which could significantly improve the development effect of horizontal Wells. However, water injection development not only affects well performance due to connectivity between two fractures, but also risks cement leakage or effective short circuit from highly conductive secondary fractures. CO_2 injection can effectively reduce the risk and realize effective CO_2 storage, but relevant research has not been carried out.

Aiming at how to improve oil recovery and CO_2 utilization rate after tight reservoir depletion, this paper proposes a new method of CO_2 injection and asynchronous huff and puff development experiment for tight reservoir development. The development process of CO_2 injection huff and puff after depletion was compared with that of CO_2 injection asynchronous huff and puff, and the extraction and production mechanism of asynchronous huff and puff development in different Wells was revealed.

2. EXPERIMENT DESIGN

2.1 Experimental Materials

Experimental cores: The core samples were taken from the real cores taken from the target interval of oil wells in the domestic M oilfield, and the cores with less damage were selected for the experiment (as shown in Figure 1, and the parameters are shown in Table 1).

Fig. 1 Experimental core

Table 1 Test results of basic physical properties of cores used in experiments

Core number	Diameter, cm	Length, cm	permeability, md	Porosity, %	Pore volume, cm^3
A	3.86	5.12	1.22	9.86	5.91
B	3.81	5.26	1.58	11.02	6.61

Experimental gas: CO_2 gas, purity 99.9%.

Simulated formation oil: Referring to the PVT data of formation crude oil in M oilfield, use degassed crude oil and natural gas to configure crude oil with simulated formation conditions. Under formation conditions, the dissolved gas-oil ratio is 140 m^3/m^3, the bubble point pressure is 25.61 MPa, and the miscible pressure is 26.4 Mpa.

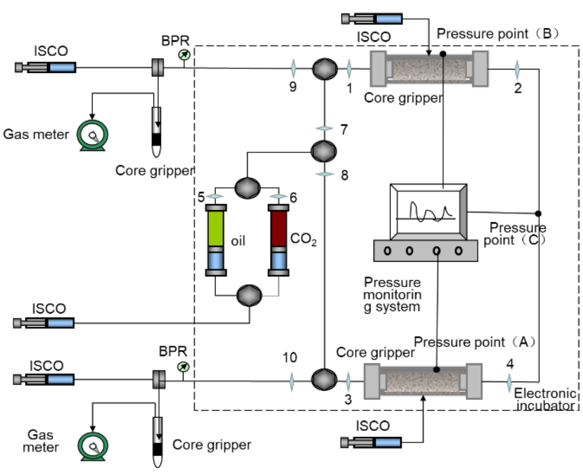

Fig. 2 Schematic diagram of asynchronous huff and puff experimental device in different wells

2.2 Experimental device

The experimental device is the integrated experimental device of "same-well, different-well asynchronous" huff and puff developed by our laboratory, which consists of thermostat, high-

Copyright © CEN2022

precision, high-temperature and high-pressure displacement pump, high-temperature and high-pressure core gripper, pressure sensor and accurate metering system, etc. The device can effectively monitor the change of core pressure, and select the same well huff and puff experiment or different well asynchronous huff and puff experiment by switching state, which avoids disassembly and saves a lot of time.

2.3 Experimental steps

2.3.1 huff and puff experiments

Connect the experimental setup according to Figure 2. During the experiment, in order to maintain the independence of the huff and puff experiment between A and B, always keep switches 2 and 4 closed. (1) Connect the equipment as shown in Figure 2, and check the system air tightness (40 MPa, 12h pressure change less than 0.5%); (2) Clean and dry the core and put it into the core gripper to vacuum; (3) Saturate kerosene and boost the pressure (above the bubble point pressure), saturate the experimental live oil, and increase the pressure of the back pressure valve and core gripper's front line to 40MPa; (4) Open switches 1, 3, 9, 10, and close switches 2, 4, 5, 6, 7, 8 to reduce the pressure to 34 MPa for depletion development, and record pressure changes at points A and B and oil production at the outlet end; (5) Open switches 1, 3, 6, 7, 8, and close switches 2, 4, 5, 9, 10. Perform huff and puff experiments on wells A and B at the same time, restore the pressure to 37MPa, and soak for 12h; (6) Open switches 1, 3, 9, 10, and close switches 2, 4, 5, 6, 7, 8. The pressure of well A and B is reduced to 27MPa, and the pressure change at point A and B and the oil production at the outlet end are recorded. (7) Use organic solvent to clean the core.

2.3.2 Asynchronous huff and puff experiments

On the basis of 1.4.1 single well huff experiment, wells A and B were connected to realize asynchronous huff and puff experiment, and the inter-well synergy system was constructed. After depletion development, wells A and B were alternately operated with pressure recovery, well soak and pressure reduction. According to different recovery pressures and production pressures, four groups of asynchronous huff and puff experiments were conducted (experimental schemes 1, 2, 3 and 4 in Table 2).

(1) Same as the single well stimulation test, perform the experimental steps (1) - (3) in 1.4.1; (2) Open switches 1, 2, 3, 4, 9, 10, and close switches 5, 6, 8 for depletion development, step-down to 34MPa, and record pressure changes at points A and B and oil production at the outlet end; (3) To restore the pressure of well A, open switches 1, 2, 4, 6, 7, close switches 3, 5, 8, 9, 10, inject CO_2 gas into well A at A constant pressure of 40MPa, and keep constant pressure for 12h; (4) Well B is depressed-down to 27MPa, switches 2, 3, 4 and 10 are opened, switches 1, 5, 6, 7, 8 and 9 are closed, and pressure changes at points A, B and C and oil production at the outlet end are recorded; (5) To restore the pressure of well B, open switches 2, 3, 4, 6, 8, close switches 1, 5, 7, 9, 10, inject CO_2 gas into well B at a constant 40MPa pressure and maintain constant pressure for 12h; (6) Step-down production of well A, step-down to 27MPa, open switches 1, 2, 4, 9, close switches 3, 5, 6, 7, 8, 10, and record pressure changes at point A, B, C and oil production at the outlet end; (7) Clean the core with organic solvent, repeat steps (1)~(7) according to the experimental plan, and carry out the other three groups of experiments respectively.

2.4 Experimental scheme

Experimental conditions: the experimental temperature was 79.61 °C, and the simulated reservoir pressure was 40 MPa.

Experimental scheme: According to the experimental requirements, 5 groups of huff and puff experiments in the same well and asynchronous huff and puff in different wells were carried out according to different recovery pressures and production pressures.

Table 2 Design table of asynchronous huff and puff experiment scheme in different Wells

program	cores	Depletion pressure, MPa	recovered pressure, MPa	Production pressure, MPa
1	A	34	37	27
	B	34	37	27
2	A	34	40	27
	B	34	40	27
3	A	34	37	23
	B	34	37	23
4	A	34	40	23
	B	34	40	23
5	A	34	37	27
	B	34	37	27

3 RESULTS AND DISCUSSION

3.1 Analysis of experimental results

3.1.1 Analysis of recovery results

Figure 3 shows the recovery factor of different experimental schemes. The total recovery factor of conventional CO_2 huff and puff experiment is 26.01%,

Copyright © CEN2022

and the recovery factor of CO_2 asynchronous huff and puff is about 20%-40% higher than that of conventional CO_2 huff and puff. The asynchronous huff and puff experimental method has higher utilization efficiency of CO_2, more full interaction with the remaining oil after exhaustion, wider diffusion area, increased oil displacement efficiency and higher recovery degree.

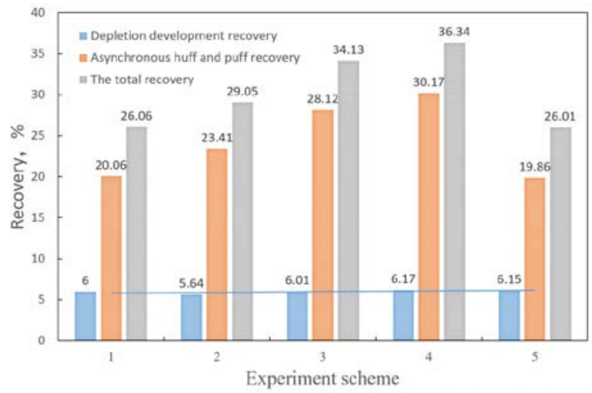

Fig. 3 Recovery efficiency of different experimental schemes

In the process of depletion development, the recovery factor mainly depends on reservoir physical properties and exploitation pressure, and the pressure gradually decreases from 40MPa to 34MPa. By comparing the recovery factor of five different development schemes in total area A and B (fig. 3), it can be seen that the recovery factor of well A and well B fluctuates around 6% in the depletion development stage, and the recovery factor is almost the same. As the permeability of well B is larger than that of well A, the recovery factor of well B is slightly higher.

Recovery factor in asynchronous huff and puff stage is the key to total recovery factor of different experimental schemes. By comparing different asynchronous huff and puff experimental schemes, recovery pressure is appropriately increased and production pressure is reduced, thus recovery factor is increased.

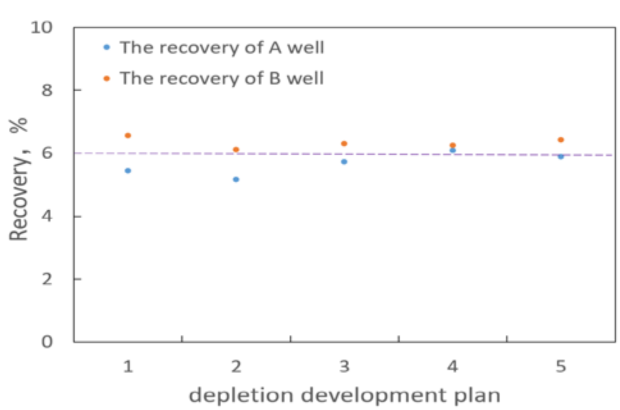

Fig. 4 Depletion development recovery of A and B

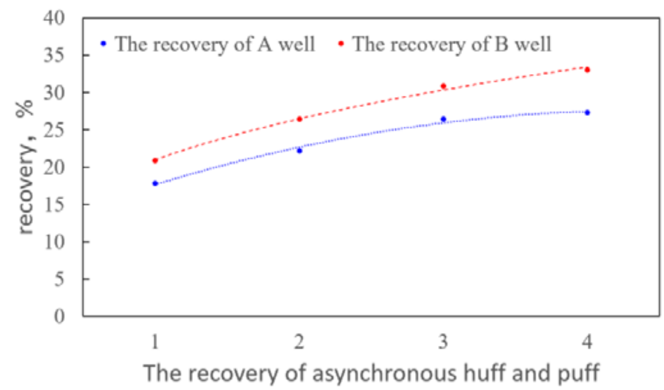

Fig. 5 The recovery of asynchronous huff and puff

3.1.2 Asynchronous huff and puff development features

As the exploitation progresses, the pressure gradually decreases, and the CO_2 dissolved in the oil phase spills out of the tight pores and carries the residual oil. Compared with the change regular of the conventional pressure reduction production process [8], it can be divided into three stages (fig 6, 7, 8, 9): (1) high-speed oil production stage. This stage is mainly dominated by dissolved gas flooding. During the soaking process, CO_2 and crude oil contact miscibility, and promote the miscibility front of CO_2 and crude oil to continuously move to the production well, and part of the crude oil is gathered near the production well. In the early production stage, with the decrease of pressure, this part of the crude oil is first produced, and the gas-oil ratio is small, and the oil production rate is high. (2) Gas generation and oil carrying stage. As the miscible zone of CO_2 and crude oil continues to advance, finally CO_2 gas breaks through, and the expanded crude oil in the matrix is produced by CO_2 displacement and transport. This stage is similar to the CO_2 huff-and-puff experiment in a single well, showing the phenomenon of "large section of gas, small section of oil". (3) Oil production slowdown stage. After gas breakthrough, CO_2 produced rapidly and carried a little crude oil. The pressure difference between wells A and B decreased rapidly, CO_2 carrying capacity decreased, and oil production rate decreased significantly, and finally decreased to 0.

It is important to note that when production pressure drops below miscible pressure, CO_2 from the oil phase, and the rapid emergence oil production rate increased, but the shorter duration, oil production rate decline dramatically.

fig. 5 shows the comparison of recovery efficiency of well A and well B under different development schemes. The recovery efficiency of well B is significantly higher than that of well A, because in

Copyright © CEN2022

addition to the permeability of well B is slightly higher than that of well A, during the experiment, pressure recovery operation of well A is carried out first. CO_2 is injected from well A in the soaking stage, and with CO_2 injection, the pressure near well A increases. The pressure of Wells A and B is almost the same, and the pressure fluctuation is small but still exists. At this time, the dissolution and diffusion between CO_2 gas and crude oil is dominant, and the flow of crude oil caused by pressure difference is weak. After 12h, the pressure reaches stability and the well soaking is finished. After the production of well B, the pressure recovery and soaking process are carried out, which is the reverse process of the previous process. The recovery pressure remains unchanged, the amount of CO_2 injected increases significantly, the diffusion range of CO_2 increases, and the small pores that were not affected in the previous stage are entered, and the miscibility state is rapidly reached, and the final output is from well A.

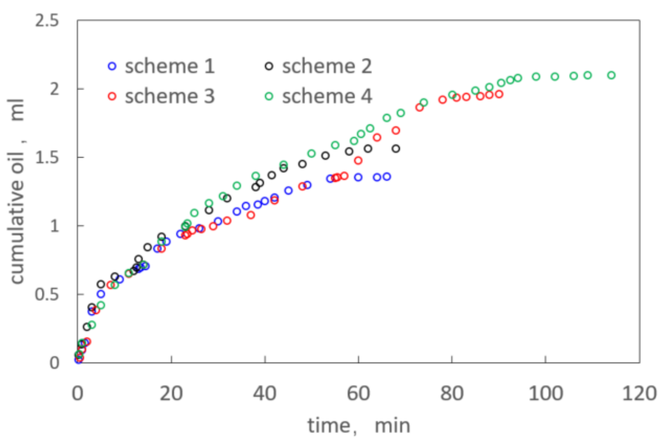

Fig. 6 The cumulative oil of well A

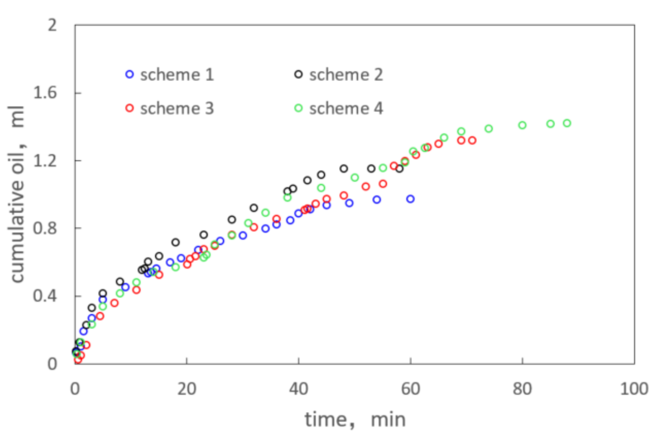

Fig. 7 The cumulative oil of well B

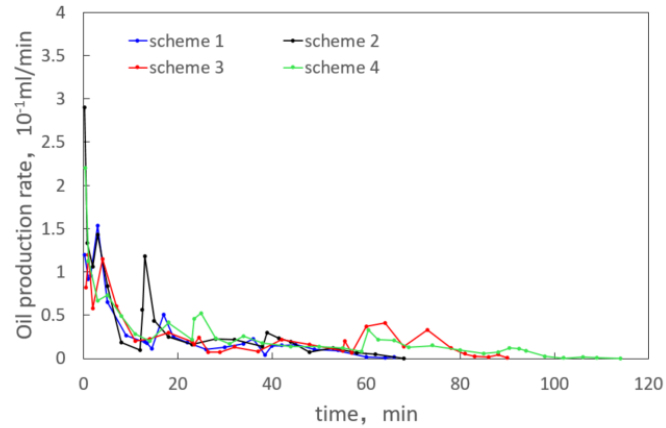

Fig. 8 Oil production rate of A

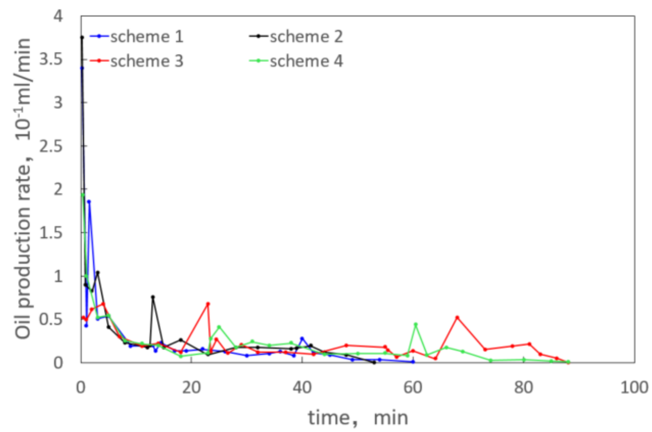

Fig. 9 Oil production rate of B

Compared with different experimental schemes, the lower the production pressure is, the higher the recovery pressure is, the more obvious the pressure fluctuation is, the more intense the dissolution and diffusion behavior of crude oil flow and CO_2 in the oil phase is, and the more obvious the difference between the recovery efficiency of well A and well B is, resulting in the increase of the recovery efficiency of well B is much larger than that of well A.

3.1.3 EOR mechanism

Compared with conventional single well CO_2 huff and puff experiment[9,10,11], because of the lack of CO_2 flowback stage, the production process is more similar to the CO_2 injection flooding process. Compared with CO_2 injection flooding, the CO_2 diffusion degree is higher in the soaking stage of asynchronous injection and production in different Wells, which promotes the miscibility degree between CO_2 and crude oil. Effectively suppresses the "fingering phenomenon" in the process of CO_2 flooding, and delayed the CO_2 breakthrough time, effectively improve the oil recovery, also increase the efficiency of CO_2, at the same time, solved the

Copyright © CEN2022

conventional single well stimulation rounds each need to inject a large number of CO_2 and dense reservoir into difficult problems, work for CO_2 storage provides a new thought and method.

The asynchronous huff and puff method establishes an effective alternate well displacement-soak-displacement system through the synergistic effect of two wells, effectively avoiding the reduction of CO_2 transport capacity caused by the increase of the number of huff and puff rounds and the longer oil transport distance in the production process of conventional huff and puff. As wells A and B alternate pressure recovery, soaking, and production, the saturation field inside the core is redistributed multiple times, providing more opportunities for CO_2 to enter microscopic pores that are not affected by conventional single well stimulation, resulting in significantly increased oil production and recovery.

4. CONCLUSIONS

The integrated experimental device of "same-well and differ-well asynchronous huff and puff" can efficiently and accurately simulate the seepage process of same-well and differ-well asynchronous huff and puff and define the reaction process mechanism.

The asynchronous huff and puff of different wells has better effect than the same well huff and puff, and the recovery rate is higher, which can reach 20%-40%. Because of the lack of a CO_2 flowback stage, effective CO_2 sequestration is achieved.

The key to enhanced oil recovery is the establishment of an interwell circulation "displacing, soaking and displacing" system, in which the oil saturation field is redistributed several times during the development process, so that CO_2 can enter the tiny pores that could not be entered before, and the reduction of oil migration capacity due to the long transportation displacement during the same well stimulation is reduced.

Soaking time and pressure difference between wells are the key factors affecting the recovery effect. It is necessary to test reasonable soaking time, recovery pressure and production pressure and formulate reasonable production policy before the actual oilfield development.

ACKNOWLEDGEMENT

This study was supported by China Natural Science Foundation (Grant 51704303), Beijing Natural Science Foundation (Grant 3173044), and Open Foundation of State Key Laboratory of Offshore Oil Exploitation (2015-YXKJ-001). Duncan's participation in this project was funded in part by a U.S. Department of Energy contract under DOE Award Number FE0024375 (PI: Duncan).

REFERENCE

[1] Hoffman, B. Todd. "Huff-N-Puff Gas Injection Pilot Projects in the Eagle Ford." Paper presented at the SPE Canada Unconventional Resources Conference, Calgary, Alberta, Canada, March 2018.

[2] Wang Z, Sun B, Wang J, et al. Experimental Study on the Friction Coefficient of Supercritical Carbon Dioxide in Pipes [J]. International Journal of Greenhouse Gas Control, 2014, 25: 151-161.

[3] Zhang K, Gu Y. Two Different Technical Criteria for Determining the Minimum Miscibility Pressures (MMPs) From The Slim-Tube and Coreflood Tests [J]. Fuel, 2015, 161: 146-156.

[4] Song-Shui P. Gas Channeling Rules of CO_2 Flooding in Extra-Low Permeability Reservoirs in Zhenglizhuang Oilfield [J]. Journal of Oil and Gas Technology, 2013, 3: 147-149.

[5] Li L, Su Y, Sheng J. J, et al. Experimental and Numerical Study On CO_2 Sweep V olume During CO_2 Huff-n-Puff Enhanced Oil Recovery Process in Shale Oil Reservoirs [J]. Energy & Fuels, 2019, 33(5): 4017-4032.

[6] Arshad, Aziz, Al-Majed, Abdulaziz A., Menouar, Habib, Muhammadain, Abdulrahim M., and Bechir Mtawaa. " Carbon Dioxide (CO2) Miscible Flooding in Tight Oil Reservoirs: A Case Study." Paper presented at the Kuwait International Petroleum Conference and Exhibition, Kuwait City, Kuwait, December 2009.

[7] Shiqing Cheng, Lian Duan, Haiyang Yu, Zhenzhen Zhao, Zhongguo Sun. Petroleum geology & oilfield development in daqing,2019,38(04):51-60.

[8] Haiyang Yu, Zhonglin Yang, Tian MA, Zhengdong Lei, Shiqing Cheng, Hao Chen. Petroleum science bulletin, 2018, 3(01): 32-44.

[9] Xiang Tang, Yiqiang LI, Xue Han, Yongbing Zhou, Jianfei Zhan, Miaomiao Xu, Rui Zhou, Kai Cui, Xiaolong Chen, Lei Wang. Dynamic characteristics and influencing factors of carbon dioxide huff and puff in tight oil [J]. Petroleum Exploration and Development, 201, 48(04): 817-824.

[10] Shenglai Yang, Liang Wang, Jianjun He, Rongguang Di. Mechanism of CO_2 huff and puff and oil increase and field application effect [J]. Journal of Xi 'an Shiyou University (Natural Science Edition), 2004(06): 23-26+89.

[11] Identification the distinctions of immiscible CO_2 huff and puff performance in Chang-7 tight sandstone oil reservoir applying NMR, microscope and reservoir simulation

 Copyright © CEN2022