Applied Energy Symposium 2020: Low carbon cities and urban energy systems
October 10-17, 2020
Paper ID: xxxx

Implementation Mode and Field Application of Synergistic CO_2 Huff and Puff in Complex Fault-block Reservoir

Wenyue Zhao [1], Lekun Zhao [2], Ganggang Hou [1], Pengxiang Diwu [3], Wanli Kang [1], Tongjing Liu [1*]

1 Unconventional Oil and Gas Institute, China university of petroleum (Beijing), Beijing 102249, China (Corresponding Author)

2 College of Petroleum Engineering, China university of petroleum (Beijing), Beijing 102249, China

3 College of Science, China university of petroleum (Beijing), Beijing 102249, China

ABSTRACT

With the gradual failure of CO_2 huff and puff wells, the overall oil exchange rate shows a downward trend. In order to maintain the good effect of the measure and extend its technical life, CO_2 synergistic huff and puff are proposed. The synergistic mode is proposed based on the peculiarity of small oil-bearing area of the fault block reservoir that geological structure is broken, and there is no completed development well pattern. By using the numerical simulation method, typical simulation models are established to simulate the effects of different geological factors and development factors on the performance of CO_2 synergistic huff and puff. The well selection principle of CO_2 synergistic huff and puff are proposed. The research results of the influencing factors show that the existence of inter-well channel has a negative impact on the stimulation performance, the greater the permeability contrast the worse of oil increasing and water cut decreasing. The injected CO_2 has a certain sweep radius and the limitation of well spacing is 70m. There is negative interference between liquid production rate of high structural position well and the performance of lower position well. For well selection of CO_2 synergistic huff and puff, the reservoir with large formation thickness and large stratum dip should be considered primarily. Then a well located in high structural position and with a well spacing of less than 70 m is the optimal choice. Field application at C2X1 block shows a good performance with a total oil increment of 1280 t and the average water cut reduction of 57.7%.

Keywords: CO_2 synergistic huff and puff, complex fault-block reservoir, implementation mode, well selection principles, field application

1. INTRODUCTION

In recent years, the greenhouse effect has become one of the ten major environmental problems that threaten human survival, and it has become the focus of attention. Although excessive CO_2 content is an essential factor leading to climate change and even serious natural disasters, it is useful in oilfield development [1]. Reasonable use of CO_2 can effectively increase oilfield production and well alleviate the energy shortage [2-4]. The CO_2 flooding and storage technology uses CO_2 to drive oil to improve oil recovery while realizing the geological storage of CO_2. A technology with economic and social benefits is also the most effective way to reduce greenhouse gas emissions under current economic and technical conditions. The types of CO_2 storage are mainly divided into geological storage, marine storage, and vegetation [5]. At present, the main geological bodies recognized internationally as suitable for CO_2 burying include oil reservoirs, natural gas reservoirs, saline aquifers, and coal seams [6]. At present, the ideal place for CO_2 geological storage under economic and technical conditions is oil reservoir [7].

CO_2 can improve the recovery rate and achieve storage, which is the goal pursued by oil companies [8]. CO_2 flooding is the main technology for improving the recovery rate of low-permeability reservoirs and reducing greenhouse gas emissions. However, the implementation of CO_2 flooding requires a complete injection-production well pattern, and there are technical problems such as easy gas channeling and low sweep coefficient [9]. For single oil wells or small oil sand bodies or small fault-block reservoirs with few oil wells, the CO_2 huff and puff technology is proposed [10-12]. For oil wells, liquid CO_2 is injected under the condition of not exceeding the fracture pressure of the formation to carry out reasonable CO_2 huff and puff to supplement the formation energy while promoting the controlled displacement of CO_2 near the well, so as to realize the full spread and effective production of the remaining oil near the well [13-14].

With the gradual failure of the first batch of CO_2 huff and puff wells, multiple rounds of CO_2 huff and puff have been gradually carried out [15]. From the perspective of implementation, the overall oil exchange rate has shown a downward trend, but there are still high measures with high efficiency and input-output ratio. The number of wells of the measure and the proportion of oil increase in the overall measure has been increasing year by year [16]. It is one of the important production stimulation measures for onshore oilfields. In order to continue to maintain the good effect of the measure and extend the technical life of this measure, the onshore oilfield actively develops supporting processes. The study started with the analysis of the causes of inefficient and ineffective wells of CO_2 huff and puff and carried out CO_2 synergistic stimulation measures [17-18]. Multi-well synergistic CO_2 huff and puff adopts multi-well reasonable and orderly, and multiple points are balanced to supplement the formation energy within the well area and promote CO_2 effective sweeping area and efficient utilization ratio under controlled displacement.

Based on the characteristics of fault-block reservoirs with the small oil-bearing area, broken structure, and lack of well-developed well patterns, synergistic huff and puff mode is proposed. Using numerical simulation methods, typical models of CO_2 synergistic huff and puff are established to study the effects of geological factors and development factors on huff and puff. Based on the calculate results of oil increment and water cut, the well selection principles of CO_2 synergistic huff and puff are proposed. Then a field application of CO_2 synergistic huff and puff is carried out and the performance is evaluated.

2. MATHEMATIC SIMULATION MODEL

2.1 Model design

Use component modules of Eclipse to establish typical models of synergistic CO_2 huff and puff. The simulation area is 350m long and 200m wide, and the model uses horizontal well production. The third layer is produced by default. The grid size of the area near the horizontal well is 5m×5m, the grid of other areas is 10m×10m, the total grid number of typical model after encryption is 17600. The model parameters are set according to the reservoir parameters of the C2X1 block. P1 is located in the low part of the structure, and P2 is located in the high part of the structure. The oil saturation distribution is shown in Figure 1.

2.2 Basic parameters

In the research process, in addition to the target parameters of the study, the default parameters of the model are the stratum dip angle of 6°, the oil layer thickness of 6.6m, a large body of water with sufficient energy, positive rhythm, Lorentz coefficient 0.5, horizontal section length of 70m, the crude oil viscosity is 90mPa.s. There is no interlayer, CO_2 huff and puff are carried out after the water cut of production well reaches 98%. The daily gas injection rate of a single well is 100t and a total of 400t is injected, then shut down the gas injection well for 30 days. The high-position well P2 maintains production during the whole program of CO_2 huff and puff of low-position well P1.

2.3 Simulation scheme

Single well synergistic huff and puff means that when two rows of horizontal wells are used in reservoir development, CO_2 huff and puff is implemented in lower position horizontal well while normal production is maintained in higher position horizontal well. Compared with the two wells synergistic huff and puff mode, the research factors including injection volume allocation and the relationship with structural isobaths are uninvolved. Moreover, the influence law of stratum dip and sedimentary rhythm on production performance is universal. Under this mode, it is necessary to study the effect of permeability contrast of inter-well channel, well spacing, and liquid production rate of high structural position well on the performance of synergistic CO_2 huff and puff.

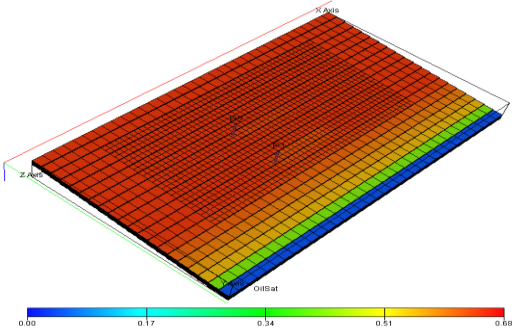

Fig 1 Initial oil saturation distribution

3. SIMULATION RESULTS AND DISCUSSION

3.1 Influence of model parameters on stimulation performance

The main controlling factors in this mode involve permeability contrast, well spacing and daily liquid production rate of higher structural position well. The value of each factors is shown in Table 1.

Tab 1 Factors and parameter levels of single well synergistic mode

Factor classification		Parameter Value
Geological factor	Permeability contrast of inter-well channel	1，20，50，100
Development factors	Well spacing (m)	40，60，70，80，120
	Liquid production rate of high-position well (m3/d)	20,100,200

3.1.1 Permeability contrast of inter-well channel

The dominant flow channels between wells play a leading role in distributing the remaining oil during water flooding development. For gas flooding development, existing studies have shown that the existence of dominant flow channels will cause gas channeling along the flow channel and make the development performance of gas flooding worse. The oil increment of P1, P2, and well group under different channel permeability contrast is shown in Figure 2. The oil increment of well P1 increases with the increase of permeability contrast, and the oil increment of well P2 decrease as the channel permeability level difference increases. When the channel permeability contrast is 1, the oil increment of P1 well is 130t less than 1343t of P2. As the channel permeability contrast increases to 20, the oil increment of P1 decreases to 85t and the oil increment of P2 dropped to 329t. Subsequently, with the further increase of permeability contrast the oil increment of both production wells decreased, but the decrease is small. When there is no main flow channel, the high-position well present a higher oil increment. Figure 3 is the comparison of P1 water cut before and after CO_2 huff and puff. It is can be seen that with the increasing of permeability contrast of inter-well channel, the water cut after CO_2 huff and puff increases. This indicates that the greater the permeability contrast, the worse the water cur reduction ability is.

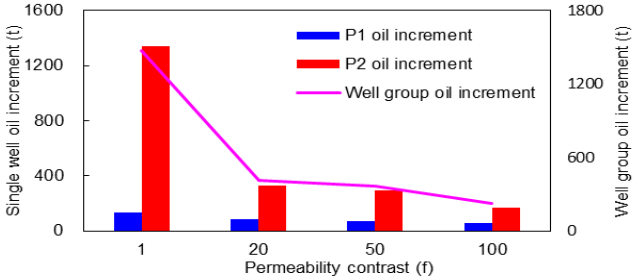

Fig 2 Oil increment with different permeability contrast

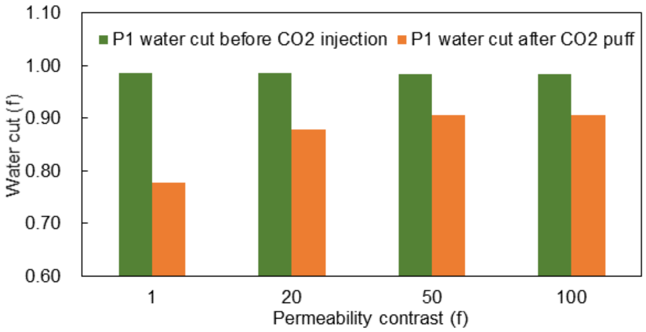

Fig 3 P1 water cut with different permeability contrast

3.1.2 Well *Spacing*

For single well synergistic mode, the influence of well spacing on the oil increase and water cut is shown in Figure 4 and Figure 5. The results show that for the lower structural position well P1, as the well spacing increases, the CO_2 swept volume increases. The lower the water cut after well stuffy, the greater the oil increase. When the well spacing exceeds 70m, the higher structural position well P2 will be less affected by the huff and puff of lower structural position well P1. With the increase of well spacing, the total oil increment continues to increase. When the well spacing exceeds 70m, the total oil increment decreases. This results indicates that CO_2 has a certain sweep radius after injection into the formation.

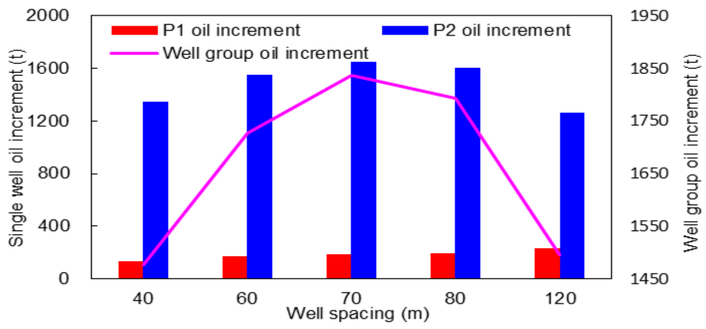

Fig 4 The effect of well spacing on oil increase

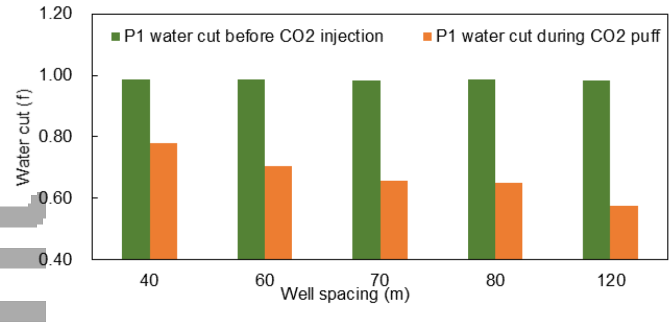

Fig 5 P1 water cut with different well spacing

3.1.3 Liquid Production Rate of High Position Well

The liquid production rate of high-position wells mainly affects the gas migration speed in the formation. Statistics of the oil increase and water cut after well opening at different liquid production rates, the statistical results are shown in Figures 6 and Figure 7. It can be concluded that with the increase of liquid production rate of P2, the oil increment of P1 well decreases but the oil increment of P2 well increases, and the oil increment of the well group first increases and then basically remains unchanged. From Figure 7, it can be found that the production water cut of well P1 after well stuffy decreases.

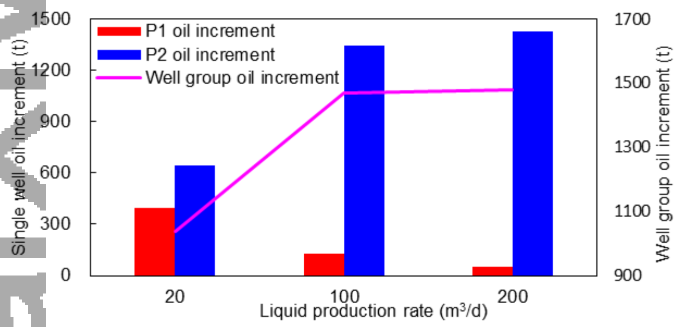

Fig 6 The oil increment with different liquid production rate

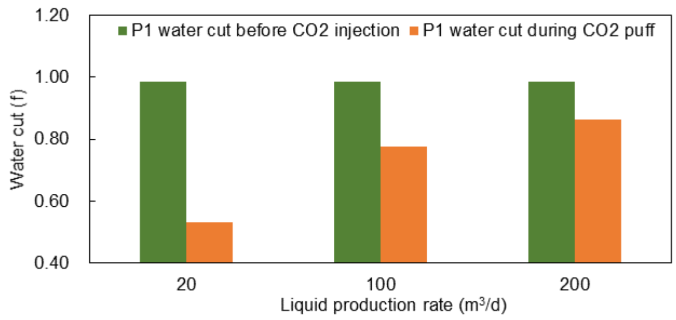

Fig 7 The water cut of P1 before and after CO_2 huff and puff with different fluid production rate

3.2 Principles of synergistic well selection

According to the influence law of the main controlling factors, the principles of CO_2 synergistic huff and puff well selection in complex fault-block reservoirs are proposed.

(1) From the perspective of formation crude oil viscosity, the heavy oil reservoirs with larger crude oil viscosity is priority. Due to the large difference in fluid viscosity and the influence of static heterogeneity, the water cut rises quickly after water flooding development, and the residual oil near and between wells is rich. The residual oil in this distribution mode can be exploited by synergistic CO_2 huff and puff.

(2) For the actual selection of wells with synergistic huff and puff, preferentially select blocks with large stratum dips or well groups obviously controlled by microstructure. Large stratum dip angles are conducive to strengthening gravity differentiation.

(3) For well spacing, it is recommended that the well spacing better to be controlled within 70m. CO_2 owns a limited migration distance after injected into the formation, and too large well spacing is not conducive to balancing the pressure between wells and inhibiting gas channeling. For well groups with obvious gas channeling channels, the well spacing can be appropriately enlarged.

(4) Selecting those wells with better well conditions in order to prevent gas channeling that affects the performance of CO_2 synergistic huff and puff.

Synergistic huff and puff modes can be divided into two categories, one is a mode that is conducive to oil increment and water cut reduction, the other is a mode that the performance is weakened by the existence of gas channeling. This type of mode needs to be reasonably avoided during the selection process.

4. FIELD APPLICATION

4.1 Oilfield Overview

The C2X1 fault block is located in Jidong oilfield with a depth of 1700m and a main layer NG13. The average permeability of is 700 mD, and the average porosity is 26%, the formation pressure is 17MPa, the pressure coefficient is 0.97, and the reservoir temperature is 60℃, the formation crude oil density is 265 mPa.s, and the surface crude oil density is 0.96 g/cm3. It is a typical structurally controlled small fault block ordinary heavy oil reservoir with edge and bottom water. This fault block owns 7 horizontal production wells, but there is no injection well. The location of CO_2 synergistic huff and puff well is shown as Figure 8, and the implementation plan is shown as Table 2.

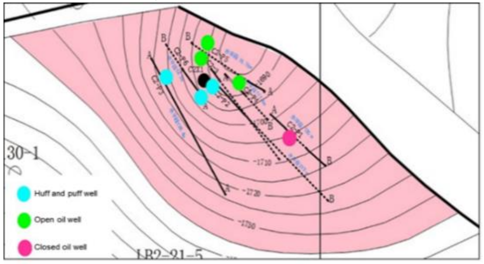

Fig 8 Structural well location map of C2X1

Tab 2 Synergistic throughput implementation plan

Well name	CO_2 injection date	Injection volume (t)	Well stuffy days (d)	Well opening date
C2-P2	2013.1.7-1.12	550	38	2013.2.26
C2-P3	2013.1.7-1.12	550	42	2013.3.7
C2-P6	2013.1.7-1.10	450	37	2013.2.24

4.2 Performance Evaluation

Statistics and calculation of parameters including oil increment, water cut to evaluate the performance of CO_2 synergistic huff and puff. The oil increment of synergistic CO_2 huff and puff is the most intuitive parameter to characterize the oil increase ability. The effect of CO_2 huff and puff is in addition to oil increase and water cut reduction. When the CO_2 injection well is opened for production, the edge and bottom water will form a large amount of foam during the process of displacing CO_2, which increases the additional pressure in the porous medium and reduces the water phase percolation capacity of the severe water flooded layer. The enhance mechanism is reflected in the reduction of water cut in production. Therefore, the water cut reflects the ability of CO2 water cut reduction.

4.3.1 Oil increment

In this CO_2 synergistic huff and puff stimulation program, all three CO_2 injection wells are effective, and C2-3 and C2-P4 wells in adjacent wells are synergistic effective but C2X1 and C2-P5 are not effective. The performance of each well is shown in Figure 9. The oil increment of effective well is higher than synergistic effective well. The total oil increment is 6400.7t and the CO_2 synergistic effective well has increased oil by 995.84t, so the synergistic efficiency is 50%.

Statistics of the oil increment of production wells at different structural positions found that the oil increment of C2-P3 in the lower structural part is significantly less than that of wells in the high structural position, and the oil increment of wells at different structural positions is shown in Figure 10. The oil increment of 1878.54t is significantly lower than the oil increment of the high part wells of 4,521.16t. The reason for this performance is that under the action of gravity differentiation, the injected CO2 migrates upwards, so the amount of CO2 acting on the high part wells is larger. The effectiveness of C2-3 and C2-P4 is mainly caused by the CO2 huff and puff of well C2-P2, so the oil increment of wells in higher structural positions is better than that in low positions.

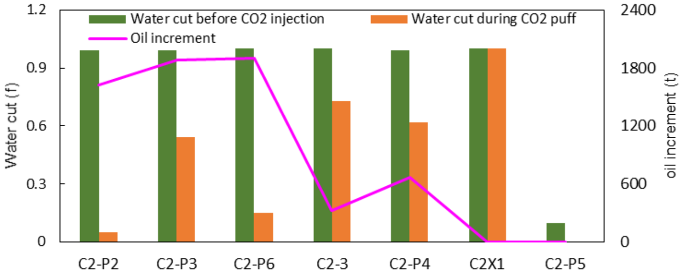

Fig 9 Oil increment at different structural positions

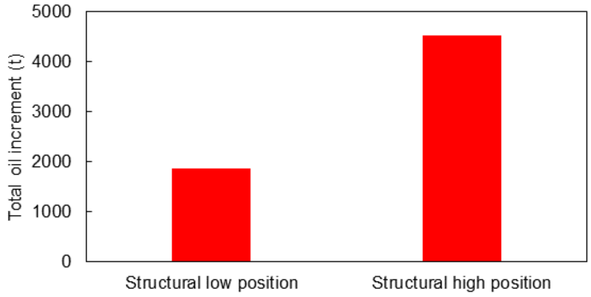

Fig 10 Oil increment at different structural positions

4.3.2 Water cut reduction

Figure 9 is a comparison chart of water cut before and after CO_2 huff and puff. The water cut of the five effective wells before conducting CO_2 huff and puff is closing to 100%. Reopen these productions well after well stuffy, the water cut has dropped significantly, especially C2-P2 and C2-P6, less than 20%. After the wells are opened, the water cut of the synergistic effective wells C2-3 and C2-P4 decrease. This indicates that as the production proceeding CO_2 migrates to the synergistic well, the water control effect is obvious. The changing of water cut shows that CO_2 has a better water control effect. The average water cut reduction of CO_2 synergistic huff and puff is 57.7%.

5. CONCLUSION

Based on the characteristics of fault-block reservoirs with the small oil-bearing area, broken structure, and lack of well-developed well patterns, synergistic stimulation modes are proposed. The sensitivity of each factor is evaluated according to sensitivity degree calculated by oil increment. The well selection principle of CO_2 synergistic huff and puff are also proposed.

(1) Synergistic CO_2 huff and puff is a reasonable and orderly huff and puff with multiple wells, which can maintain good development performance and extend the technical life of CO_2 stimulation.

(2) The evaluation results show that inter-well channel has a negative impact on the stimulation performance, the injected CO_2 has a certain sweep radius and the limitation of well spacing is 70m. There is negative interference between liquid production rate of high structural position well and the performance of lower position well. The larger the rate is; the more serious disturbance is to the lower position well.

(3) The reservoir with a large thickness and high inclination angle should be selected first for CO_2 synergistic huff and puff. The huff and puff well should be located in the high part of the structure, and the synergistic well spacing is less than 70m, also the well condition is better.

ACKNOWLEDGEMENT

This work was supported by National Science and Technology Major Projects (No.2018YFB0605500, 2017ZX05009004).

REFERENCE

[1] Van der Geer J, Hanraads JAJ, Lupton RA. The art of writing a scientific article. J Sci Commun 2010; 163:51–9. (Reference to a journal publication)

[1] S. Li, Y. Tang, and C. Hou. Present situation and development trend of CO_2 injection enhanced oil recovery technology. Reserv. Eval. and Dev 2019; 9:1-8.

[2] L. Peng, H. Yin, and C. Zhong. A search of application and development of carbon dioxide flooding. Guangdong Chem. Ind 2012; 44:143-144.

[3] V. Pranesh. Subsurface CO_2 storage estimation in Bakken tight oil and Eagle Ford shale gas condensate reservoirs by retention mechanism. Fuel 2018; 215:580-591.

[4] R. Deng, W. Tian, Z. Li, L. Zhao, and H. Dai. Microscopic limits of reservoir producing for carbon dioxide flooding. Spec. Oil & Gas Reserv 2019; 26: 133-317.

[5] Y. Hu, M. Hao, G. Chen, R. Sun, and S. Li. Technologies and practice of CO2 flooding and sequestration in China. Petro. Explor. and Dev 2019; 46: 716-727.

[6] S. Sun. Discussion on the feasibility of carbon dioxide oil enrichment technology. Chem. Eng. & Equip 2019; 103-105.

[7] X. Zhou, Q. Yuan, X. Peng, F. Zeng, and L. Zhang. A critical review of the CO_2 huff 'n' puff process for enhanced heavy oil recovery. Fuel 2018; 215:813-824.

[8] S. Li, L. Sun, Z. Chen, J. Li, Y. Tang, and Y. Pan. Further discussion on reservoir engineering concept and development mode of CO_2 flooding-EOR technology. Reserv. Eval. and Dev 2020; 10:11-14.

[9] X. Cao, G. Lv, J. Wang, D. Zhang, and M. Ren. Present situation and further research direction of CO_2 flooding technology in Shengli Oilfield. Reser. Eval. and Dev 2020; 10:51-59.

[10] Z. Wang, F. Zhao, H. Feng, L. Song, Y. Li, and H. Hao. Experimental research on injection volumes optimization of CO_2 huff and puff in horizontal well group in fault block reservoirs with edge water. Petrol. Geol. and Recover. Eff 2020; 27:75-80.

[11] F. Zhao, L. Song, J. Hou, W. Li, P. Wang, and H. Hao. Experiment of nitrogen compound huff and puff for fault-block reservoirs with shallow edge water. Petro. Geo. and Recov. Eff 2019; 26:85-91.

[12] Z. Wang, F. Zhao, J. Hou, and H. Hao. Synergistic effects during CO_2 huff and puff of horizontal well groups in a fault-block reservoir and gas injection optimization under laboratory conditions. Petro. Sci. Bull 2018; 3:183-194.

[13] B. Li, Q. Zhang, S. Li, and Z. Li. Enhanced heavy oil recovery via surfactant-assisted CO_2 huff-n-puff processes. Journal of Petro. Sci. and Eng 2017; 159: 25-34.

[14] X. Liu, Z. Qu, and Y. Du. Experiment research on water control with CO_2 in bottom water reservoir. Fault-Block Oil and Gas Field 2016; 23:350-353.

[15] J. Wang. Discussion on well selection conditions of CO_2 huff and puff in low permeability reservoir. Reser. Eval. and Develop 2019; 9:57-61.

[16] W. Qian, G. Lin, B. Wang, W. Hu, Z. Liang, and J. Zhang. Multi–cycle CO_2 huff and puff matching

technology and parameter evaluation for horizontal wells in heavy oil reservoirs with bottom water drive-by taking HZ block of Subei oilfield as an example. Petro. Geol. and Eng 2020; 34:107-111.

[17] Y. Tian, Y. Qin, J. Qian, F. Liu, and X. Zhu. Evaluation of steam stimulation effect and potential in chenzhuang oilfield. Petrochem. Ind. Tech 2019; 26:109, 144.

[18] L. Ma, C. Ouyang, C. Wang, and F. Lin. Research on CO_2 huffing technology in horizontal wells in low permeability reservoirs. Chem. Eng 2018; 277:38-47.