Energy Proceedings
Vol 35, 2023
ISSN 2004-2965

The Research and Application of Supercritical CO2 Fracturing in Tight Reservoirs

Zhang Lijun[1], Yang Renfeng[1], Tian Xiaofeng[1], Jiao Yujia[1], Yang Erlong[2], Bai Mingxing[2], Zhang Zhichao[2*]
1 CNOOC Research Institute, Beijing, 100028
2 Key Laboratory of Ministry of Education to Improve Oil and Gas Recovery , Northeast Petroleum University, Heilongjiang Daqing, 163318 (*Zhang Zhichao: 1209712605@qq.com)

ABSTRACT

Hydraulic fracturing is an important means to develop tight reservoirs. However, many drawbacks have been exposed in the hydraulic fracturing process for a tight reservoir. For example, the clay minerals in the fractures are soaked and hydrated by fracturing fluid, which results in high pollution and poor transformation effect of the near-well area and seriously affects the flow capacity of reminding oil and the fracturing effect of tight reservoirs. This paper proposes a fracturing method that uses CO2 as the fracturing fluid to transform the seepage capacity and quickly supply energy for a tight reservoir. The EOR mechanism of CO2 fracturing has also been discussed by analyzing the physical properties change of CO2 in reservoir conditions. Three kinds of advantages can be shown in the fracturing process with CO2 fracturing fluid. Firstly, the fractures of CO2 fracturing are more complex than those caused by hydraulic fracturing, which greatly enhances the seepage capacity of a tight reservoir after CO2 fracturing. Secondly, a quick reservoir energy supply can be found in the process of CO2 injection, because of the high diffusion ability and good solubility of CO2 in oil of tight reservoir pores. Thirdly, as an inert gas, CO2 can reduce the influence of water sensitivity on reservoir rock, which can effectively resist the clay swelling pollution to oil production. The numerical simulation method of CO2 fracturing is used to optimize the supercritical CO2 fracturing parameters. According to the simulation results of CO2 fracturing, the optimized fracture half-length in the tight reservoir is 130 m, the fluid conductivity ability of a sand-filled fracture is 30 μm2・cm, the injection rate of CO2 fracturing fluid is 5.5 m^3/min, and the energy storage time of a CO2 injection well is 7 days in the tight reservoir with permeability 0.35 mD. Compared with before fracturing, the actual CO2 fracturing wells in the study block also have an obvious oil increase effect, with a daily oil increase of 3.2 tons and a cumulative annual oil increase of 1650 tons.

Keywords: tight reservoir, CO2 fracturing, numerical simulation, parameter optimization

1. INTRODUCTION

With the decreased oil production of conventional sandstone reservoirs and the increased demand for oil resources every year, unconventional oil reservoirs, such as ultra-low permeability and tight reservoirs, have emerged as strategies for increasing oil and gas reserves and productivity [1]. Tight reservoirs are those with permeability below 1 mD, this low permeability increases the difficulty of tight oil reservoir development. In China, abundant tight oil and gas resources have been discovered in the Cretaceous region of the Songliao Basin, oil and gas reserves are estimated at 1.9 – 2.31 billion tons [2]. However, the ultra-low permeability and porosity of tight reservoirs means that conventional water flooding development technologies, such as water flooding, polymer flooding, and alkali-surfactant-polymer(ASP) flooding technology, are not appropriate for tight reservoir development because of the water injection difficulty. At present, the most frequently used technique for tight reservoir development is hydraulic fracturing to enhance the seepage capacity and establish an effective flooding system [3-4].

This paper reports further research on CO2 as a fracturing fluid to fracture and supply energy for tight reservoirs. In the proposed method, numerical simulation of CO2 fracturing and energy storage is used to optimize the parameters of CO2 injection rate, fracture half-length, fluid conductivity ability of fracture, and energy storage time. Optimized CO2 fracturing and energy parameters were applied in the simulation to the X tight reservoir reconstruction project, and good development results were achieved.

2. THE MECHANISM OF SUPERCRITICAL CO2 FRACTURING

2.1 The properties of supercritical CO2

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

The physical properties of supercritical CO_2 can be viewed as Fig. 1 and Table 1. Supercritical CO_2 has low viscosity, density and greater compressibility than water. Therefore, the CO_2 injected into the tight reservoir has low friction resistance and high gas diffusion ability. Thus, a tight reservoir can be quickly supplied with energy by CO_2 injection. Furthermore, CO_2 injected in an tight reservoir has highly solubility with crude oil, and thereby increases the oil flow capacity and reduces the viscosity of the crude oil. Moreover, the oil – water interface tension also declines after CO_2 is dissolved into the formation water, and the acid water can also acidify the reservoir rock matrix to improve reservoir characteristics. According to the research by Kizaki et al.[5] on the fracture morphology of formation rock with supercritical CO_2 fracturing and hydraulic fracturing, with the same injection rate of 50 ml/min in 15 cm3 of Inada granite and Ogino tuff rock specimens, the average breakdown pressure of the two rock specimens by supercritical CO_2 fracturing fluid was found to be 9.8 MPa, whereas the average breakdown pressure was 11.2 MPa with water-based fracturing fluid fracturing. The fracture pattern formed by water and CO_2 fracturing can be compared with Fig. 2(a) and Fig. 2 (b). From the fracture pattern comparison of rock specimens caused by supercritical CO_2 fracturing and hydraulic fracturing, the artificial fractures caused by the water-based fracturing fluid are relatively simple, whereas those caused by supercritical CO_2 are more complicated because of the lower capillary pressure and high dissolution ability of CO_2 [6].

Table 1. Physical properties of CO2

Critical pressure (MPa)	Critical temperature(K)	Compression factor	Density (kg/m^3)	Viscosity (mPa·s)	PH
7.38	304.35	0.315	467	3.3	5.6

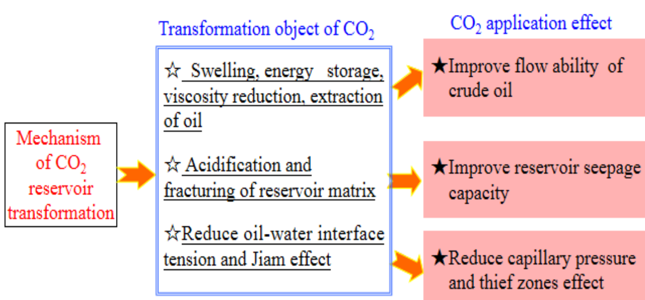

Fig.1 The EOR mechanism of CO2 fracturing

2.2 The CO2 phase conversion analysis in fracturing process

The mechanism of supercritical CO_2 fracturing can be analyzed from the CO_2 P – T phase diagram shown in Fig. 2. Under continuous injection of CO_2 into a tight reservoir formation, the reservoir pressure in the near-well area gradually increases above the miscible pressure, Pm, of oil and CO_2. The reservoir rock in the near-well area is fractured, and complex fractures are formed after the CO_2 injection pressure Pi exceeds the broken stress of the reservoir rock. Subsequently, enough proppant is injected into the fracture to prevent the fracture from closing. After CO_2 fracturing construction is completed, a certain amount of CO_2 is continuously injected into the reservoir formation at a low injection rate to supply the formation energy. After the operation of CO_2 injection, the CO_2 injection well is shut to ensure a thorough mixing of CO_2 and crude oil. When enough CO_2 is dissolved into the crude oil and the oil viscosity decreases sufficiently, the oil well is opened to produce oil, and the well bottom pressure change at this time, as the blue line of P – T phase diagram. According to the field application for this method of CO_2 fracturing in X oil field, the reservoir can maintain longer effective oil development life.

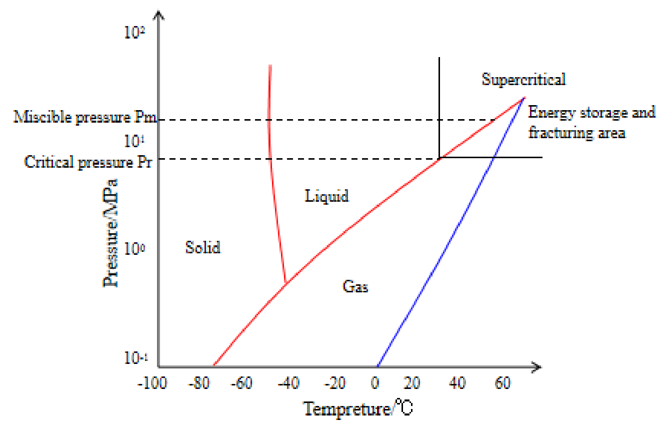

Fig. 2 Phase changes of the CO2 energy storage and fracturing process

2.3 Field application of CO2 energy and fracturing

2.3.1 Reservoir property and construction processes

The permeability of oilfield X is 0.35 mD and porosity is 8.6 %. The oil production rate is low with 0.5 ton/d oil rate at the end of water flooding. The construction process of CO_2 energy storage and fracturing is shown in Fig. 3. Liquid CO_2 stored in a tank is transported to fracture trains and a sand mixer truck by a booster pump. In the CO_2 fracturing process, the fracturing trains pump CO_2 at 5 m3/min into the reservoir to fracture the reservoir rock near the well-bore with 280 m3 liquid CO2 consumption. After the reservoir rock is fractured, the quartz sand is transported into the fractures by the sand mixer truck with viscosity-increased CO2 fluid. After sufficient quartz sand is added into the reservoir fracture, the sand ratio in the fracture has reached 6% and satisfied the supporting effect of the fracture. After the CO2 fracturing process, 377 m3 CO2 is injected continuously to supply the reservoir energy. With 8 day of well shut time for CO2 energy storage, the CO2 huff-n-puff well P1 is opened for oil production.

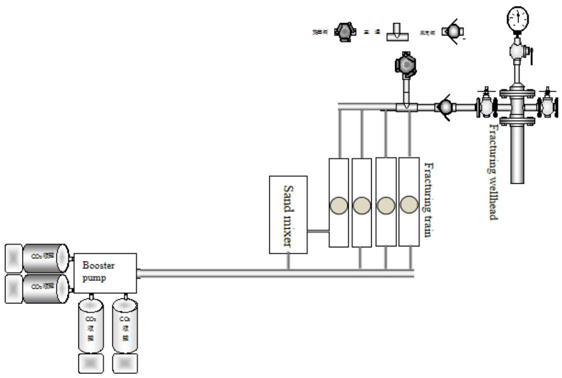

Fig. 3. CO2 energy storage and fracturing process

2.3.2 Oil enhanced effect of production well

The cumulative injection volume of CO2 into the reservoir was 657 m3, and after 8 dads of well shut time for reservoir energy storage, the miscible zone radius reached its maximum range. The oil production rate effect of well P1 after fracturing is shown in Fig.4. The average oil production rate is 4.1 ton/d, which is 2.5 times the oil production rate before fracturing. The average formation pressure within the CO2 energy storage radius also increased significantly, providing enough energy for oil flowing into the production well. For the tight oil reservoir application of CO2 energy storage and fracturing, the proposed technique is considered suitable in ultra-low permeability oil reservoir reconstruction.

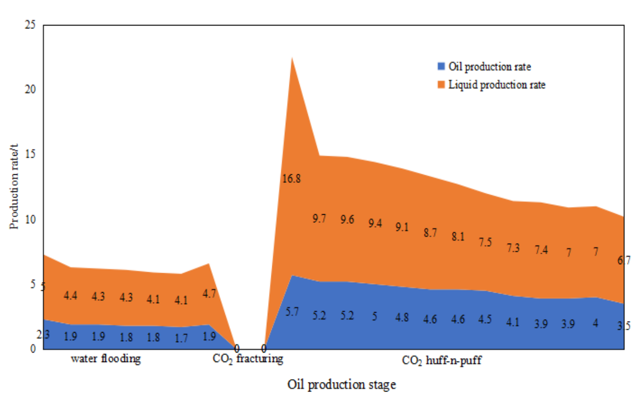

Fig. 4. Oil production rate changes of well P1 after CO2 energy storage and fracturing

3. *DISCUSSION*

(1)The fractures for reservoir rock with CO2 fracturing are more complex than those of hydraulic fracturing. The main cause is when the cold CO2 is injected into a reservoir, the reservoir rock is simultaneously affected by CO2-rock thermal stress and CO2 compressive stress, resulting in a lower fracture open pressure in reservoir rock. In addition, the high diffusion ability of CO2 makes it can enter into smaller rock pore to cause many more rock fractures compared to water-based fracturing fluids.

(2) The miscible area of CO2 with crude oil in a reservoir is mainly controlled by the difference between reservoir pressure and miscible pressure. When reservoir pressure is higher than miscible pressure, the diffusion boundary of CO2 gas in the reservoir is also the boundary of the CO2 miscible zone. But when the reservoir pressure is lower than the miscible pressure, the miscible area of CO2 and oil is mainly occurred in the stage of CO2 injection process, where the local reservoir pressure is higher than the CO2 miscible pressure. In the process of CO2 injection, energy storage and well open for oil production, the closer reservoir area distance from the well bore has the better fracturing effect and higher the fluid conductivity. Therefore, the closer reservoir area from the well bore, the reservoir pressure changes is more obvious.

(3) From the CO2 fracturing and energy storage results analysis, with the length of fractured fracture, the injection rate, the fracture conductivity, and the energy storage time increases, the oil production rate of fractured oil well increases, but the parameters has an upper limit. The main reason is, with the fracture growing, the CO2 migration distance increases, resulting in the CO2 flowing resistance increases and reservoir reformation effect deteriorates in far well area. Moreover, when the fluid conductivity ability of fracture is over small or the CO2 injection rate is over high, the injected CO2 is more likely to accumulate near the bottom of the well, and the radius of the energy supply zone is insignificant. Conversely, large fracture conductivity and CO2 injection rate gives CO2 a strong ability to flow into the more far distant reservoir formation along the fracture, and a large energy supply radius is formed in the reservoir zone. However, when the fracture conductivity and CO2 injection rate increases to a definite value, the injected CO2 diffuses too fast in the high conductivity reservoir formation, resulting in poor formation energy supply. Furthermore,

when the energy storage time(well-shut time) is relatively short, the CO_2 in the formation mixes with crude oil insufficiently and the miscible area is small. However, when the energy storage time increases, the radius of the CO_2 miscible zone is increased, and the oil well has a beneficial oil enhanced effect. Nevertheless, when the energy storage time continues to increase, the gas diffusion leads to excessive gas energy loss, which ultimately reduces the cumulative oil production of the well.

4. CONCLUSIONS

(1) The oil production rate increase mechanism of CO_2 energy storage and fracturing is that CO_2 injected into a tight reservoir can increase the energy of the reservoir, decrease the viscosity of the crude oil and the water – oil interfacial tension, and can also prevent clay mineral swelling. CO_2 fracturing also causes the tight reservoir to form more complex fractures, so the transformation effect of an ultra-low permeability reservoir is better.

(2) The reservoir pressure change near the CO_2 injection well first undergoes a pressure increase during the CO_2 injection process, then suffers from a pressure decline during the well shut time and liquid drainage process. A shorter distance from the CO_2 injection well bore has a sharper formation pressure rise and decline.

(3) When applying CO_2 energy storage and fracturing in tight reservoir X with a permeability of 0.35 mD, the optimized fracture half-length was 130 m, the fluid conductivity ability of fracture was 30 $\mu m^2 \cdot cm$, and the injection rate of CO_2 fracturing fluid was 5.5 m3/ d; the energy storage time was 7 d.

ACKNOWLEDGEMENT

This work was financially supported by the National Natural Science Foundation of China (grant no.: 51774095) and Heilongjiang Postdoctoral Fund (grant no.: LBH-Q20010). Furthermore the authors would like to thank all members of the research team.

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] Zou C N, Zhang G S, Yang Z, et al. Geological concepts, characteristics, resource potential and key techniques of unconventional hydrocarbon: On unconventional petroleum geology[J]. Petroleum Exploration and Development , 2013, 40(4): 385-399.

[2] Wang H Z, Shen Z H, Li G S. Supercritical CO2 development shale gas technology [J]. Petroleum Drilling Technology, 2011, 39 (3): 30-35.

[3] Wu J Q, Gao Z L, Sun X, et al. Research status and prospect of liquid CO2 fracturing technology [J]. Journal of Yangtze University (Natural Science Edition), 2014, 11 (10): 104-107.

[4] Liu H, Wang F, Zhang J, et al. Fracturing with carbon dioxide: Application status and development trend[J]. Petroleum Exploration and Development, 2014,(41):513-519.

[5] Kizaki A, Tanaka H, Ohashi K, et al． Hydraulic fracturing in Inadagranite and Ogino tuff with supercritical CO2[C]. ISRM regional symposium-7th Asian rock mechanics symposium. International Society for Rock Mechanics, 2012.

[6] Li M L., Zhang F S, Zhuang L, Zhang X, et al. Micromechanical analysis of hydraulic fracturing in the toughness-dominated regime: implications to supercritical carbon dioxide fracturing. Computational Geosciences[J]. 2019, 1-17.