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Original Paper

CO2 Research in Dense Sandstone Storage Sets

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Abstract

The dense sandstone storage set in my country's oil and gas collection is an important pillar of Chinese crude oil storage. It is a hot spot for oil exploration and development in recent years. In order to study the relevant factors of CO2 in the density sandstone storage set, based on the research of relevant literature at home and abroad, the study of CO2 in the density sandstone storage collection was systematically explained. Definition and reservoir characteristics, the two phases of gas and water injection into the analysis of the collection of harvesting. With the increase of production pressure differences, the harvesting of CO2 oil -driven oil increases, so it can be preferred before production, which can be preferred to control the pressure. The more conducive to the adoption of CO2 and the development of the storage, the sooner the air and water are alternately. As the water injection cycle increases, the degree of adoption will increase first and then decrease. It remains unchanged after a large, and at the same time increase the injection volume to help improve the degree of adoption, but the conclusion that actually needs to consider the injection ability of the injection well.

Keywords

CO2 driving oil, causing dense sandstone, increasing harvesting, production pressure differences, gas channeling

1. Introduction

Tight sandstone reservoir occupies a large proportion in China's oil reserves, which is a hot topic in petroleum exploration and development in recent years, and has become an important pillar to increase crude oil storage and production in China (Yang, Zhang, Yang, & Chen, 2019; Jia, Zheng, & Zhang, 2012). Such reservoirs have low porosity, low permeability, strong heterogeneity and complex microscopic pore structure, which lead to differences in reservoir quality and oil and gas recovery, seriously affecting exploration benefits.

With the continuous development of oil and gas exploration and development, tight sandstone reservoirs and other unconventional oil and gas have shown great potential under the current economic and technical conditions. China's tight sandstone reservoirs are mainly continental sedimentary, with small distribution area and poor physical properties. The geological characteristics of tight sandstone reservoirs in different basins vary greatly, but the characteristics of low porosity, low permeability and low pressure are prominent. The development of tight sandstone reservoir faces many challenges, and some new technical directions need to be explored. Depletion and water injection are generally adopted in the development of tight sandstone reservoirs, and water injection leads to higher water content of producing Wells, and depletion development leads to larger formation energy deficit and lower overall recovery efficiency of blocks (Li, 2022).

Carbon dioxide enhanced oil recovery (EOR) is one of the methods in tertiary oil recovery and is one of the commonly used measures in the development of oil and gas reservoirs. Carbon dioxide flooding has the advantages of wide application, good economic effect, little pollution and outstanding extraction effect. Therefore, CO2 flooding in tight sandstone reservoirs is another important way of tight reservoir production. CO2 capture, utilization and storage technology (CCUS) is one of the ways to achieve the goal of "double carbon" in China. CO2 displacement technology is a kind of gas injection displacement technology, and it is also an important technical branch of CO2 storage and utilization in CCUS technology, which has broad application prospects and professionalism (Yao, 2023).

2. Definition and Reservoir Characteristics of Tight Oil Reservoirs

In the world, there is no unified standard and definition for geological evaluation of tight gas-bearing sandstone. Different countries and companies usually set their evaluation criteria according to their natural gas resource status and technical and economic conditions in different periods. Even in the same country or region, with the deepening of the understanding of such geological bodies, the concept of tight gas-bearing sandstone is constantly evolving and improving. At present, it is generally adopted in the world that the sandstone gas reservoir below 1×10-3 μm² is regarded as a tight sandstone gas reservoir. In China, the geological evaluation of tight sandstone gas reservoirs has a long history, and gradually tends to reach a consensus. In 2010, I had the honor to participate in a project led by the Research Institute of Petroleum Exploration and Development - "Tight sandstone Gas Geological Evaluation Method", which proposed a new set of evaluation indicators: The porosity is less than 10%, the in-situ permeability is less than 0.1×10-3 μm² or the air permeability is less than 1×10-3 μm², the pore throat radius is less than 1 micron, and the gas saturation is less than 60%. This evaluation method was promulgated and implemented by the National Energy Administration in 2011 and became the first industry standard on tight sandstone gas in China (SY/T6832-2011) (Li, Guo, Zheng, & Yang, 2012).

The tight sandstone reservoir has the typical characteristics of tight lithology, low porosity and low permeability, low pressure coefficient of gas reservoir, low trap amplitude and low natural productivity. According to our standards. Effective permeability of tight reservoir ≤0.1×103μm2(absolute permeability ≤1X103μm2), porosity ≤10%.

Tight oil refers to the oil concentrated in the source rock in adsorbed or free state, or in the tight sandstone, tight carbonate and other reservoirs interbedded with the source rock, without large-scale long distance migration. Generally, there are four obvious signs of tight oil: (1) large-area tight reservoirs (porosity Φ<12%, matrix overburden permeability K<0.1mD, pore throat diameter drt<1.0μm); (2) Widely distributed mature and high-quality source beds (type I or type II kerogen, average TOC greater than 1.0%, R0 0.6%-1.3%); (3) The continuous distribution of tight reservoir and source rock close contact symbiosis relationship, no obvious trap boundary, no concept of oil "reservoir"; (4) The density of crude oil in tight reservoirs is greater than 40℃API or less than 0.825g/cm3, and the oil quality is relatively light (Jia, Zou, Li, Li, & Zheng, 2012).

3. CO2 Enhanced Oil Recovery

Low porosity, low permeability, small pore throat and low mobile fluid saturation are the main reasons for difficult development and low recovery efficiency of permeable and tight oil and gas reservoirs. Therefore, conventional stimulation measures and enhanced oil recovery techniques often fail to achieve the expected results, and water flooding also faces problems such as no injection, no production and high pressure underinjection.

3.1 Research Status of CO2 Flooding at Home and Abroad

Domestic CO2 flooding oil recovery technology development is relatively late, started in the 1970s, after years of research and practice, technology gradually mature. At present, more and more oil fields have applied CO2 flooding technology to enhance oil recovery (Xiang, 2017). Compared with China, the concept formation of carbon dioxide flooding technology in foreign countries is more advanced. Methods of enhanced oil recovery have been explored abroad since the 1930s, and laboratory experiments were carried out in the 1950s. By the 1960s, field experiments were gradually carried out, and the 1970s was the stage of rapid development of carbon dioxide flooding theory. Subsequently, with the continuous maturity of theory and technology, oil field production has made remarkable progress. The United States is one of the fastest developing countries in carbon dioxide flooding technology. Since the 1980s, carbon dioxide flooding technology in the United States has become the second largest enhanced oil recovery technology after steam flooding. Currently, there are 64 CO2-mixed flooding projects underway in the United States. In most of these field displacement schemes, CO2 injection is used, which accounts for about 30% of the hydrocarbon pore volume, resulting in an enhanced recovery rate of 7-12%. It is worth noting that the United States began to use methane for high-pressure gas injection in the 1940s, and turned to liquefied petroleum gas as the main injection gas in the 1950s, and then the injected gas continued to develop, changing to the injection of hydrocarbon gases such as propane for miscible mining; In the late 1960s, the injection of hydrocarbon gas into the reservoir reached a climax, and it was concluded that miscible flooding between CO2, dry gas and rich gas could be achieved. In the 1970s, the rapid development of CO2 injection began (Royal, 1982). From 1980s to 2000, CO2 flooding was vigorously promoted and applied. After 2000, it entered the stage of CO2 storage. Only in 2004, the output of CO2 injection flooding in the United States has reached 31% of the total output, and most of the carbon dioxide flooding projects in the United States are mainly medium and low permeability (Merechant, 2010).

In terms of China's oil resources, the newly increased crude oil reserves are difficult to meet the needs of national economic development. Therefore, to further improve the recovery rate of used geological reserves and develop difficult-to-deploy reserves has become the top priority to solve this problem. Most of the existing oil fields in China are continental sedimentary reservoirs with significant heterogeneity and high viscosity of crude oil, which leads to rapid rise in water content and low water drive recovery rate. The average recovery rate is 32.0%, which indicates that 68% of the geological reserves remain underground after water flooding in developed oil fields in China, and a new type of enhanced oil recovery technology is urgently needed to be born and applied. CO2 flooding enhanced oil recovery technology has a broad application prospect, which has been confirmed by numerous research results and field tests at home and abroad. The injection of CO2 into the reservoir as a displacement agent can greatly improve oil recovery (see Figure 1) (Shen & Jiang, 2009). The main oil producing areas in the east of China have less carbon dioxide sources, so it is still necessary to strengthen the research and practical application of relevant technologies. The application of carbon dioxide injection technology in oilfield is gradually spreading. For example, Daqing Oilfield uses chemical by-products to carry out carbon dioxide flooding test, although the test is affected by the heterogeneity of the reservoir, the swept effect is not very obvious. For the super heavy oil reservoir of Shengli Oilfield, the oil production Institute and Shengli Petroleum Development Center jointly carried out the CO2-assisted steam huff and puff test, and made some progress. However, in the process of using CO2 to enhance oil recovery, there is a need to continue to explore and improve the relevant technologies and strategies in order to better achieve the objective of enhanced oil recovery.

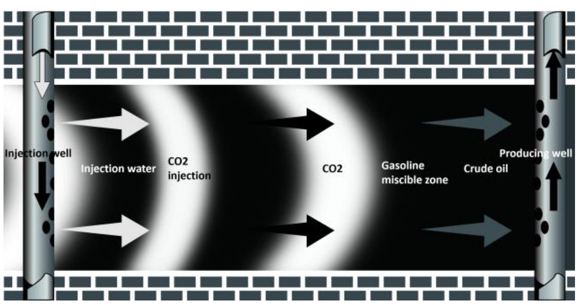

Figure 1. The Mechanism of CO2EOR

In the tight sandstone reservoirs developed in China, the permeability of the reservoirs has been as low as $0.1\times10^{3}\mu m^{2}$, which belongs to the range of ultra-low permeability oil fields. Wang Guangxia (2013) described the role of well test data in the development of carbon dioxide flooding in ultra-low permeability reservoirs. Based on the two-zone composite model, Zhu Jianwei, Shao Changjin et al.

(2011) added the change of pressure drop caused by the change of fluid properties during CO2 injection, and obtained the pressure and pressure derivative curves under the change of different components and viscosity. The whole pressure response at the bottom of the well is given by derivation. By using the numerical inversion method, the pressure and pressure derivatives under different mobility ratios are calculated (Zhou, 2015).

3.2 Definition and Process Principle of CO2 Flooding

The reason why carbon dioxide can be used as an effective displacement agent to improve oil recovery is that as carbon dioxide is injected into the formation, it can dissolve in the formation crude oil, and the properties of the crude oil and the reservoir change. The important reason for the effective displacement agent is that carbon dioxide is easy to reach a supercritical state in the injected reservoir because the critical point temperature is 31.1℃ and the pressure is 7.38Mpa. Supercritical CO2 has good injection performance and solubility. Compared with the water medium, it not only replenishes the energy of the formation, but also improves the water absorption capacity of the injection well (Li, 2022). Carbon dioxide resource utilization technology mainly focuses on carbon dioxide oil recovery technology. The research of carbon dioxide flooding technology includes carbon dioxide foam mobility control, carbon dioxide gas flooding, carbon dioxide flooding with a small amount of impurities, gas water alternate flooding and so on (Long, Qi, & Feng, 2018).

CO2 improves oil recovery in pore rocks through the following mechanisms: (1) high miscibility displacement, CO2 dissolved in crude oil can be enriched by acetylene, and the miscible pressure of CO2 is lower than that of other gaseous acetylene; (2) immiscible flooding through crude oil expansion and reduction of crude oil viscosity; (3) Production of crude oil from miscible pore rocks. (4) Due to the high relative molecular weight of the heavy oil, the miscible pressure is usually higher than the reservoir pressure. The immiscible mechanism of enhancing oil recovery through CO2 injection is dissolving gas drive and reducing interfacial tension (KayhanIssever, Mo, Xiong, & Hu, 2000).

According to the study of Guo Maolei et al. (2018), it is found that after CO2 injection, the bubble point pressure increases less, and the solubility of the gas in crude oil is better. When dissolved to a certain extent, the dissolution ability decreases, and the bubble point pressure rises faster. When CO2 is injected under constant pressure, the reservoir fluid volume expands after dissolution, and the fluid density decreases with the increase of CO2 concentration. The injection of CO2 has little effect on the viscosity of crude oil, and the gas-liquid is close to the miscible state with the increase of concentration, and the viscosity does not change with the change of pressure. At the same time, the volume expansion coefficient of formation fluid can reach 1.81 under 30MPa pressure, which is conducive to CO2 recovery.

3.3 Dissolution and Diffusivity of CO2 in Oil and Oil Water

The equilibrium solubility and mass transfer diffusion coefficient of CO2 in crude oil both increase linearly with the increase of pressure difference, and the slope (Figure 2) is obviously greater than the dissolution and diffusion of CO2 in water. Under reservoir conditions, the equilibrium solubility and mass transfer diffusion coefficient of CO2 in crude oil are about 2 times larger than that in water (Yang, Zhang, Yang, & Chen, 2019).

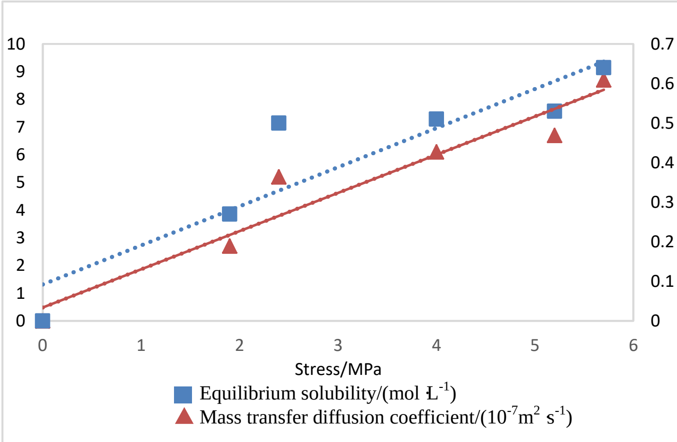

Figure 2. Mass Transfer Diffusion Coefficient and Equilibrium Solubility of CO2 in Crude Oil at Different Pressures (105°C)

The diffusion coefficient of CO2 mass transfer under the coexistence of two phases of oil and water represents the dissolution rate, which belongs to the dynamic property, while the solubility represents the total dissolution amount after a certain dissolution time, which belongs to the static property. Based on the research on the dissolution and diffusion performance of CO2 in oil and water, it is necessary to further study the change rule of the properties of crude oil after CO2 injection (Yang, Zhang, Yang, & Chen, 2019).

3.4 CO2 Flooding is Suitable for Geological Conditions

CO2 miscibility: (1) Viscosity <12mpa.s (2) Density >0.88g/cm^3 (3) percentage of remaining oil (before enhanced oil recovery)>25% (4) oil accumulation abundance =4.0x10-3 (5) porosity/saturation >0.04 (6) Depth >900m (7) Temperature is a non-critical factor (8) Initial reservoir pressure >10.3mpa(9) Effective thickness of the reservoir is non-critical coefficient (10) Permeability is non-critical coefficient (11) Penetration is non-critical coefficient (12) The general parameters of the reservoir are preferably thin oil producing and highly inclined. Preferably a homogeneous layer. Low vertical permeability in horizontal reservoirs without natural water drive (13), preferably natural CO2

CO2 immiscible: (1) The viscosity under reservoir conditions is 100 Mpa.s ~1000 mpa s(2) The density is $1^{-0.9}$ g/cm3(3) the percentage of remaining oil (before enhanced oil recovery) in the displaced area is >50%(4) the accumulation abundance of oil is $7.8x10^{-3}$(5) the porosity/saturation is >0.08(6) the depth is >690 m(7) temperature is a non-critical factor (8) initial reservoir pressure >6.9 mpa(9) effective reservoir thickness is a non-critical factor (10) Permeability is a non-critical factor; (11) Penetration capacity is a non-critical factor.

3.5 Advantages of CO2 Flooding

Carbon dioxide flooding has the advantages of wide application range, good economic effect, no pollution and outstanding extraction effect. The heterogeneity of tight reservoirs leads to the existence of starting pressure gradient during waterflood flooding, which makes it difficult to develop waterflood flooding (Ghanizadeha, Clarksona, Aquinos, et al., 2015; Saboorian-Jooybari & Pourafshary, 2015)., Chen Ting (n.d.) showed that in the permeability range of 0.2×10^3 ~ 1.4×10^3 μm^2 in tight sandstone, the higher the permeability, the better the CO2 flooding effect.

CO2 flooding is superior to traditional mining methods in exploiting high-viscosity crude oil, high-water cut tight sandstone reservoirs, and ultra-low permeability reservoirs with poor water flooding effect. In addition, it can extend the production life of the well for 15 to 20 years, improve the oil recovery rate by 7% to 15%, and can store CO2 under the formation to achieve carbon storage and carbon neutrality.

4. The Problem of CO2 Displacement in Tight Sandstone Reservoirs

4.1. Disadvantages of CO2 Flooding

Due to the heterogeneity of the reservoir, the effect of CO2 flooding is not obvious. The viscosity of CO2 is lower than that of crude oil, and the unfavorable mobility ratio will lead to the viscosity pointing, which will eventually lead to the early breakthrough of gas to produce a high gas-oil ratio. The low viscosity of CO2 makes it easier to enter the highly permeable formation, and the different density differences lead to the gravitational separation. Ultimately, it cannot cover most areas of the reservoir. CO2 injected will cause different degrees of chemical corrosion to downhole equipment. Long-term CO2 injection will further aggravate the corrosion of oil casing, reduce the working life and structural stability of downhole tools, increase maintenance costs and reduce effective working hours, and seriously affect the safe injection and storage of CO2. At the same time, after CO2 breaks through the shallow underground water, due to the decrease of ambient temperature and pressure, CO2 diffuses and migrates in the form of gas. After CO2 enters the soil layer, it is rapidly replaced with the native gas in the soil, which eventually leads to the increase of CO2 concentration (Liu, Wang, Yang, Liang, Shen, Wang, Wang, Zheng, & Kang, 2019).

4.2 Asking Questions

Compared with conventional reservoirs, the micro-pore structure of low-permeability tight reservoirs is more complex, and the reservoirs have poor physical properties and strong heterogeneity. Due to the heterogeneity of the reservoir, the oil displacement effect is not obvious, the viscosity of CO2 is lower than that of crude oil, and the unfavorable mobility ratio will lead to the viscosity pointing, and eventually lead to the early breakthrough of gas to produce a high gas-oil ratio. The low viscosity of CO2 makes it easier to enter the highly permeable formation, and the gravity separation caused by different density differences can not cover most areas of the reservoir. To solve the problem of low permeability of tight sandstone, the secondary oil recovery can be divided into water injection and gas injection, and gas injection can be divided into miscible flooding and immiscible flooding. The following questions are asked:

First, CO2 in the process of displacement shows that greater production pressure difference can improve the recovery rate of displacement, but it is not the key factor;

Second, for tight reservoirs, their porosity is small, and after CO2 injection, it is impossible to simulate the underground situation well and understand the influence law of CO2 flooding.

Third, in view of the corrosion of CO2 dissolved in water on the pipeline, how to reduce the corrosion of CO2 on the pipeline.

5. Solution Design of C02 Oil Displacement Problem

The increase of production pressure difference in tight reservoirs has a non-negligible impact on the recovery efficiency of CO2 flooding. Gao Mingming (2020) found that the recovery efficiency of CO2 flooding increases with the increase of production pressure difference, so the production pressure difference can be optimized to achieve the purpose of controlling gas channeling and improve the recovery efficiency of CO2 flooding. Yang Daqing et al. (2014) indicated that injection pressure should be optimized during production to ensure gas drive recovery efficiency and prolong gas discovery time to delay gas breakthrough. Jia Kaifeng (2019) studied the gas injection horizon, indicating that high injection and low production on the plane have more development advantages. Wang Yuxia's (2019) research shows that pressure is the biggest factor affecting EOR of CO2, followed by injection speed.

Tight sandstone has the characteristics of low permeability and is dominated by micro - and nano-sized pores. In order to further study the seepage law of CO2 in reservoir, a suitable nonlinear flow model is selected to build a numerical simulation model of oil reservoir, and the seepage law and application of CO2 flooding on crude oil are clarified. The use of CO2 flooding can not only improve oil recovery but also have high economic benefits. Wang Yong (2021) established mathematical and numerical models of CO2 flooding for such low-permeability reservoirs.

Protective measures for acid gas corrosion are generally divided into two categories: one is to use corrosion-resistant alloys to control corrosion, and the other is to control corrosion through anti-corrosion processes (Xie, Wei, Chen, Liang, & Yang, 2010). In the case of CO2 gas flooding, wellbore anticorrosion work can usually be carried out from the aspects of selecting corrosion-resistant alloy materials, adding protective agents, selecting coating materials, and applying cathodic protection (Liu, 2018).

6. Summary

Based on the definition of tight reservoir and reservoir characteristics, the comparison of injection reservoirs with different media, and the mechanism of CO2 displacement, this paper expounds the influence of different factors in the process of CO2 displacement. CO2 injection has little influence on the viscosity of crude oil, and the gas-liquid state approaches miscible state with the increase of concentration, and the viscosity does not change with the change of pressure. When the pressure reaches 30MPa, the volume expansion coefficient of formation fluid can reach 1.81, which is conducive to CO2 recovery.

In CO2 flooding production, the pressure during development is the biggest factor affecting the CO2 recovery efficiency, so it is necessary to master its pressure and understand its influence law in the development process. The use of mathematical and numerical models plays a very important role in identifying the distribution of remaining oil in the reservoir, taking reasonable injection and production measures, and improving the recovery efficiency. Meanwhile, according to the study of He Minxia (2021), the gas-water alternation process includes five independent variables, namely, the time of gas-water alternation, gas injection cycle, gas injection rate, water injection cycle and water injection rate. Meanwhile, the earlier the reservoir development starts, the more favorable the gas-water alternation will be. With the increase of water injection cycle, the recovery degree will first increase and then decrease. The degree of recovery increases at first and then stays the same, while increasing the injection volume helps to improve the degree of recovery, but the actual injection capacity of the injection well needs to be considered.

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