Influence Study of CO2 Flooding on Formation Oil Parameters in Ultra-Low Permeability Oilfield

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Abstract. In ultra-low permeability reservoir, the fluid permeability is poor, the productivity is low, and the recovery factor is low in conventional way. As an oil displacement agent, CO2 has obvious effect of increasing oil and reducing water in oil and gas development. It can not only improve oil recovery, but also store CO2 and reduce carbon emissions, which has double benefits for environmental protection and oilfield production. CO2 flooding pilot test was carried out in ultra-low permeability Y oilfield in 2007, which has been developed for 14 years. Through the research and practice of CO2 flooding in ultra-low permeability oilfield, this paper systematically summarizes the influence of CO2 injection on formation oil. The results show that: with the increase of CO2 injection, the rise range of saturation pressure becomes smaller; the dissolved gas oil ratio and expansion coefficient increase, the range becomes larger; the density and viscosity decrease, the range becomes smaller; the minimum miscible pressure of produced fluid in multiple contact decreases gradually. CO2 can extract light components. With the decrease of light components, the proportion of components above C18 begins to increase, and the main peak carbon is between C13 and C23. At present, the block is in the initial stage of gas breakthrough, and the effect of oil increase is obvious, which provides a reference for the technology and practice of gas injection to enhance oil recovery in other types of reservoirs.

1. Introduction
With the deepening of oil and gas field exploration, the proportion of difficult to exploit low permeability reserves in newly proved reserves in China is increasing [1]. By the end of 2013, the III reservoirs geological reserves of ultra-low permeability in Y oilfield was 65.1% of the total reserves. Focusing on the establishment of effective displacement, since y oilfield was put into development, well fracturing, active water injection, horizontal well water injection and infill technology have been tested, and no obvious effect has been achieved. CO2 flooding can improve oil recovery by dissolving, expanding, reducing viscosity, changing wettability, reducing start-up pressure and enhancing percolation capacity. Compared with other gases, CO2 flooding has low cost, easy recovery and great application prospect [2] [3]. Since 2007, CO2 flooding has been applied in two blocks of Y oilfield and good results have been achieved. This paper summarizes the research and practice of CO2 flooding effect in relevant blocks, further clarifies the change rule of CO2 influence on formation fluid with time, and provides guidance for further development.

2. Regional overview
Block X is a gentle monoclinic fault block with high in the East and low in the west, with a dip angle
of 2° to 4° and a structural amplitude difference of 60m. The surrounding faults are relatively developed, and they are normal faults with nearly north-south strike. The fault extension length is generally 2-4km, the fault distance is generally 30-50m, and the dip angle is generally 30-50 degrees. They are block boundary faults. Natural fractures are not developed. The overall sedimentary environment is delta distributary plain sedimentary environment. There are 5 main oil layers, and the average effective thickness of the whole well is 10.2m. The average porosity is 10.65% and the average air permeability is 1.06mD. It is an ultra-low permeability reservoir. It is necessary to use the resources in batches to alleviate the contradiction between the layers. The reservoir temperature varies from 94°C to 106.1°C with an average of 98.5 °C, the pressure coefficient is 1.04, which belongs to normal pressure system, and the original formation pressure is 22.1MPa. The original gas oil ratio is 22.8m³/t. Matching the direction of the designed well row with the direction of the maximum horizontal principal stress can realize the linear gas injection mode of oil displacement to both sides of the artificial fracture, which is conducive to improving the sweep efficiency and slowing down the gas channeling. Three kinds of well patterns, rectangular five point pattern, square nine point pattern and diamond seven point pattern, are designed. Considering that the five point pattern has a high degree of gas drive control, is conducive to maintaining a higher formation pressure, and the injection production well spacing is more uniform than the reverse nine point pattern, the rectangular five point pattern is preferred.

3. Effect on formation oil of CO₂ injection

By dissolving, expanding, reducing viscosity, changing wettability, CO₂ can reduce start-up pressure and enhance percolation capacity, so as to improve crude oil recovery [4]. CO₂ injection has a great influence on the properties of formation oil, and a series of changes have taken place in fluid density, viscosity, saturation and volume coefficient.

3.1. Changes in physical properties of crude oil

The bubble point pressure of formation crude oil is 4.7mpa. Since the pilot test of CO₂ flooding was carried out in shu101 in 2007, underground oil samples were obtained in well m in 2008 (one year of gas injection, PV 0.02), 2011 (four years of gas injection, PV 0.096) and 2017 (ten years of gas injection, PV 0.248). From the comparison of three high-pressure physical property samples, the gas oil ratio and bubble point pressure of the produced oil increase, while the viscosity gradually decreases.

Compared with the test results in 2008 and 2017, the local formation pressure is higher than the bubble point pressure. With the increase of CO₂ injection, the dissolved oil-gas ratio and saturation pressure of formation oil increase, the expansion coefficient increases, and the viscosity and density decrease. After gas injection, the physical properties of crude oil become better, which is conducive to the decrease of residual oil saturation, making the crude oil easier to be produced, thus improving the recovery of formation crude oil. In 2017, it has been ten years of gas injection development, and it has been lightened due to the effect of CO₂ solubilisation. The gas oil ratio has reached 183.6m³/t, and the viscosity has decreased. Therefore, the impact of CO₂ injection on the test is smaller than that of the oil sample test in 2008. For example, in 2008, the viscosity of formation oil was 3.6MPa•s, when the CO₂ concentration reached 58.6%, the viscosity decreased to 1.02MPa•s, a decrease of 71.7%; while in 2017, the viscosity of formation oil was 1.56MPa•s, when the CO₂ concentration reached 50.0%, the viscosity decreased to 0.8MPa•s, a decrease of 48.7%.

3.2. Component changes

Continuous sampling of miscible and immiscible displacement crude oil in slim tube experiment was carried out to analyze the variation of crude oil components under different displacement conditions by gas chromatography analyser [5]. Through the sampling of crude oil produced by oil wells in different displacement stages in the test area, the variation law of crude oil composition in the test area was studied.
Taking C18 as the dividing line, the left figure shows that with the increase of displacement PV number, the relative content of product components is higher than that of crude oil components, and with the increase of displacement multiple, the peak value of carbon components shifts to the right, indicating that CO₂ displacement first extracts light components [6], and then extracts heavier components, but the extracted carbon components are less than C18. When the displacement is about to end, the relative content of C8 is higher than that of crude oil. It should be low. The graph on the right shows that with the increase of displacement PV number, the relative content of each component of the product is lower than that of the crude oil, which indicates that the heavy component of the product decreases, and that the heavy component above C18 cannot be extracted by CO₂ in immiscible flooding.

Tracing the results of crude oil analysis in the same well over the years, it can be found that the change is most obvious in the initial stage of gas injection, the content of components below C18 in the initial production oil increases greatly, the content of components above C18 decreases, and the main peak carbon changes from C23 to C13; with the decrease of light components, the proportion of components above C18 in the production oil begins to increase, and the main peak carbon is between C13 and C23. The single well test data in the test area show that CO₂ flooding mainly extracts components below C18, which further proves that immiscible flooding is dominant in this area. More and more heavy components remain in the injection end due to the extraction, and the injection well is easy to be blocked. The results show that the asphaltene and gum contents are 12.35% and 21.75% respectively, which are 11.7% and 13.57% higher than those of oil samples, and the saturated hydrocarbon content is 64% lower.

Figure 1. Product composition change curve of X Block between 2009 and 2020.

Among the three times of single oil removal in Well M, the content of c11⁺ decreased from 70.86% to 54.3%.

3.3. Multiple contact mixed phase pressure of oil produced
The fine tube experiment is a standard method to determine whether the injected gas is mixed with crude oil. The minimum mixed phase pressure of multiple contact measured by three oil samples of Well M is 32.2MPa, 28.6MPa and 21.1MPa respectively, which decreases gradually. The main reason is that CO₂ can be extracted from crude oil to displace light components to the end of the well. The longer the development time is, the higher the content of light components in the oil samples at the end of the well, the lower the miscibility pressure is. On the contrary, more heavy components remain in the stratum, and the pressure of the mixed phase is higher and higher.

3.4. Interfacial tension
The interfacial tension between CO₂ and formation crude oil decreases with the increase of system
pressure. The lower the interfacial tension is, the higher the oil displacement efficiency is. When the system pressure is high enough, the oil-gas interface disappears and the interfacial tension is zero. At this time, miscibility is achieved and the oil displacement efficiency is the highest. By testing the interfacial tension between CO\(_2\) and formation crude oil under different pressures at formation temperature, the variation of oil-gas interfacial tension with injection pressure can be studied, and the minimum miscibility pressure when CO\(_2\) and formation crude oil reach the first contact miscibility can be determined by testing the vanishing point of oil-gas interface. The pressure of one contact miscible phase is generally higher than that of multiple contact miscible phase, and the miscible phase in actual reservoir is multiple contact miscible phase. The results show that the interfacial tension decreases gradually under the same pressure. The minimum miscible pressure of one contact measured by the interfacial tension method is 34.1MPa, 30.5MPa and 26.5MPa, respectively. The variation law is consistent with that of multiple contact miscible pressure, and decreases gradually, and each time is higher than that of multiple contact miscible pressure.

4. Conclusion

(1) With the increase of CO\(_2\) injection, the dissolved oil-gas ratio and saturation pressure of formation oil increase, the expansion coefficient increases, and the viscosity and density decrease.

(2) CO\(_2\) can extract light components. With the decrease of light components, the proportion of components above C18 begins to increase, and the main peak carbon is between C13 and C23.

(3) With the increase of CO\(_2\) injection, the minimum miscible pressure of produced fluid in multiple contact decreases gradually.

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