

Optimization of the Application of Carbon Dioxide Flooding Enhanced Oil Recovery Technology in High-temperature and High-Pressure Reservoirs

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Abstract: In this paper, in view of the development problems of high-temperature and high-pressure reservoirs, the application optimization strategies of carbon dioxide flooding enhanced oil recovery technology are systematically discussed. Through the analysis of the characteristics of high-temperature and high-pressure reservoirs and the mechanism of carbon dioxide flooding, combined with numerical simulation and field practice cases, the influence of key parameters such as gas injection pressure, injection rate, injection volume, and CO₂ concentration on the oil displacement effect was deeply studied. This paper proposes a comprehensive application scheme that optimizes injection-production well pattern, innovates wellbore insulation technology and combines other stimulation technologies to provide theoretical basis and practical guidance for the efficient development of high-temperature and high-pressure reservoirs.

Keywords: Carbon dioxide flooding; High-temperature and high-pressure reservoirs; Enhanced oil recovery; App optimization; Injection and production process; Displacement mechanism.

1. Introduction

With the continuous growth of global energy demand and the decreasing of conventional oil and gas resources, the effective development of high-temperature and high-pressure reservoirs, as important unconventional oil and gas resources, is of great significance to ensure energy supply. High-temperature and high-pressure reservoirs have the characteristics of high formation temperature (often more than 150°C), high pressure (formation pressure coefficient up to 1.8 - 2.5), high viscosity of crude oil, and complex fluid properties, resulting in poor fluidity of crude oil and low recovery rate by conventional mining methods, generally only 20% - 30%^[1-3].

Carbon dioxide flooding enhanced oil recovery (CO₂ - EOR) technology has achieved remarkable results in the development of many reservoirs at home and abroad due to its advantages of reducing crude oil viscosity, expanding the sweep volume, and extracting light components. However, in the environment of high temperature and high pressure, the physical and chemical properties of CO₂ change, the stability of the gas-liquid interface deteriorates, and the corrosion of wellbore equipment intensifies, which makes the carbon dioxide flooding technology face many challenges. Therefore, it is of great practical significance to study the application optimization strategy of carbon dioxide flooding in high-temperature and high-pressure reservoirs to improve reservoir recovery and realize efficient resource development^[4,5].

2. Characteristics of High-temperature and High-pressure Reservoirs and Carbon Dioxide Flooding Mechanism

2.1. Reservoir characteristics at high temperature and pressure

The significant characteristics of high-temperature and

high-pressure reservoirs are reflected in the aspects of temperature, pressure and fluid properties. The high temperature environment will change the viscosity and density of crude oil, increasing the flow resistance of crude oil. Under high pressure conditions, the compressibility of reservoir rocks and fluids changes, which affects the seepage law. In addition, the high temperature and high pressure environment accelerates the chemical reaction between fluid and rock, leading to scaling, corrosion and other problems, which puts forward higher requirements for wellbore equipment and mining technology^[6,7].

2.2. Carbon dioxide displacement mechanism

2.2.1. Reduces the viscosity of crude oil

When CO₂ is soluble in crude oil, it can dilute the heavy components in crude oil, reduce the viscosity of crude oil, and improve its fluidity. Under high temperature and high pressure conditions, the mutual miscibility between CO₂ and crude oil is enhanced, and the viscosity reduction effect is more significant.

2.2.2. Expanding the volume of crude oil

When CO₂ is injected into the reservoir, it expands the volume of crude oil, increasing the elastic energy of crude oil and providing power for the flow of crude oil.

2.2.3. Extraction and vaporization of light components

CO₂ can extract the light components in crude oil to form miscible or near-miscible displacement, reduce the gas-liquid interfacial tension, and improve the microscopic displacement efficiency.

2.2.4. Improve the oil-water fluidity ratio

CO₂ injection changes the fluid distribution in the reservoir, reduces the aqueous permeability, improves the oil-water fluidity ratio, and thus expands the ripple volume.

3. The Key Influencing Factors of Carbon Dioxide Flooding in High-temperature and High-pressure Reservoir Applications

3.1. Injection pressure

Injection pressure is one of the key factors affecting the effect of CO₂ flooding. In high-temperature and high-pressure reservoirs, the miscible displacement of CO₂ and crude oil can be realized only when the gas injection pressure reaches or exceeds the miscible pressure, and the recovery factor can be greatly improved. However, excessive injection pressure can lead to formation rupture, causing problems such as gas channeling. The results show that in a high-temperature and high-pressure reservoir, when the gas injection pressure is increased from 1.2 times to 1.5 times of the original formation pressure, the oil recovery rate increases by 10%, but if the pressure continues to increase, micro-fractures appear in the formation, the gas channeling phenomenon is aggravated, and the effect of oil recovery enhancement is weakened^[8,9].

3.2. Injection speed

The injection rate has a direct impact on the distribution and displacement efficiency of CO₂ in the reservoir. Low injection rate is beneficial to the full contact and miscibility of CO₂ with crude oil, but it will prolong the development cycle. Excessively high injection rates may result in severe CO₂ fingering and reduced spillover volume. For example, in the simulation, when the injection rate was increased from 0.5 m³/d to 2 m³/d, the initial production increased rapidly, but the later recovery increased slowly and the gas-oil ratio increased significantly.

3.3. Injection volume

There was a positive correlation between injection volume and oil recovery, but there was an economically reasonable range. Increasing CO₂ injection can increase the sweep volume and improve oil recovery, but excessive injection can increase equipment investment and operating costs. According to the economic evaluation model, when the CO₂ injection reaches 30% of the crude oil geological reserves, the best balance between the oil recovery improvement and the cost input is achieved in a high-temperature and high-pressure reservoir.

3.4. CO₂ concentration

CO₂ purity and concentration have a significant impact on the effectiveness of oil displacement. The high purity of CO₂ can better achieve miscible with crude oil and improve the efficiency of oil flooding. In practice, if CO₂ contains impurities (such as N₂, H₂S, etc.), the miscible pressure will be reduced and the displacement effect will be affected. The study found that when CO₂ concentrations increased from 90% to 98%, oil recovery increased by 5% to 8%.

4. Optimization Strategy for The Application of Carbon Dioxide Flooding in High-temperature and High-pressure Reservoirs

4.1. Optimize the injection-production well pattern

According to the geological characteristics of the reservoir and the distribution of fluids, the injection-production well pattern is reasonably designed. For high-temperature and high-pressure reservoirs with strong heterogeneity, irregular well patterns can be used to infill gas injection wells in areas with high permeability to increase the coverage range of CO₂. At the same time, the injection-production well spacing should be optimized to avoid CO₂ inreach due to too large well spacing, or gas channeling caused by too small well spacing. For example, in one reservoir, the oil recovery was increased by 8% by adjusting the well pattern from the regular five-point method to the irregular well pattern^[10,11].

4.2. Innovative wellbore insulation process

In view of the influence of high temperature environment on wellbore equipment, new thermal insulation materials and thermal insulation processes were developed. Double-layer insulated tubing, nano insulating coating and other technologies are used to reduce the CO₂ temperature loss in the wellbore and ensure its oil displacement performance in the reservoir. At the same time, strengthen the anti-corrosion measures of wellbore, select anti-corrosion alloy materials and add corrosion inhibitors to reduce the corrosion of shaft equipment by CO₂ under high temperature and high pressure.

4.3. Combined with other stimulation technologies

Combine CO₂ flooding with other stimulation technologies to create synergies. For example, hydraulic fracturing can be carried out to form artificial fractures, improve the seepage conditions of the reservoir, and then implement CO₂ flooding, which can improve the CO₂ injection capacity and ripple volume. Or combined with chemical flooding technology, surfactants, polymers, etc. can be injected to further reduce the interfacial tension and improve the oil-water fluidity ratio.

4.4. Real-time dynamic monitoring and control

Establish a complete reservoir monitoring system to monitor gas injection pressure, temperature, flow, production dynamics and other parameters in real time. Numerical simulation software is used to simulate and predict the reservoir development process in real time, adjust the gas injection plan in time according to the monitoring data, optimize the gas injection parameters, and ensure the maximum effect of carbon dioxide flooding.

5. Case Studies of Field Applications

Taking a high-temperature and high-pressure reservoir in western China as an example, the average formation temperature of the reservoir is 160°C, the pressure coefficient is 2.0, the crude oil viscosity is high, and the conventional recovery rate is only 25%. Carbon dioxide flooding technology was used for development, but due to improper control of gas injection pressure and injection rate, problems such as gas channeling and slow improvement of oil recovery

rate occurred in the early stage.

By applying the optimization strategy proposed in this paper, the injection-production well pattern is adjusted, and the irregular well pattern is used to infill the gas injection well. Replace the new double-layer insulated tubing and add corrosion inhibitors; Combined with hydraulic fracturing technology, the target interval is fractured and then CO₂ is injected. After optimization, the injection pressure was stabilized in a reasonable range, the CO₂ spread volume was significantly expanded, and the recovery rate was increased to 40%, which achieved good economic benefits and development results.

6. Conclusion

Carbon dioxide flooding (EOR) technology has a broad application prospect in the development of high-temperature and high-pressure reservoirs, but the challenges brought by high-temperature and high-pressure environment need to be fully considered. Through in-depth study of key influencing factors such as gas injection pressure, injection speed, injection volume and CO₂ concentration, optimization strategies such as optimizing injection-production well pattern, innovating wellbore insulation technology, combining with other stimulation technologies, and real-time dynamic monitoring and regulation can effectively improve the effect of carbon dioxide flooding and improve the recovery ratio of high temperature and high pressure reservoirs. In the future, we can further explore the integration and application of carbon dioxide flooding and emerging technologies, improve the theory and technical system of carbon dioxide flooding in high-temperature and high-pressure reservoirs, and promote the efficient development of unconventional oil and gas resources.

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