CO_2 Flooding and Geological Storage Potential Evaluation Method for Low Permeability Reservoirs in Dagang Oilfield

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Abstract. Permanently sequestering carbon dioxide during carbon dioxide flooding is the most realistic way to meet carbon dioxide emission reduction obligations in developing countries. In order to effectively evaluate the potential of carbon dioxide flooding and geological storage of low permeability reservoirs in Dagang Oilfield, it is necessary to establish a reliable CO_2 flooding and geological storage potential evaluation method. Based on the characteristics of low permeability reservoirs in Dagang Oilfield, this paper establishes a CO_2 enhanced oil recovery (EOR) and geological storage potential evaluation method based on fractional flow theory. Through theoretical analysis and numerical simulation method, the carbon dioxide storage coefficient, carbon dioxide storage and CO_2 flooding efficiency of low permeability reservoirs in Dagang Oilfield under carbon dioxide miscible and immiscible flooding conditions were determined, and these values were analyzed and evaluated. The results show that the CO_2 flooding efficiency and storage coefficient of miscible flooding are significantly higher than that of immiscible flooding. In addition, as the amount of carbon dioxide injected increases, the carbon dioxide flooding oil increase and the amount of storage increase. Through the evaluation of 272 oil layers in the low-permeability oil area of Dagang Oilfield, the enhanced oil recovery and geological storage potential of CO_2 in this area were analyzed. It can be seen from the analysis and evaluation results that CO_2 miscible flooding is an effective displacement and storage method. The conclusions drawn can

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provide technical reference for the implementation of CO_2 flooding and storage in low permeability reservoirs in Dagang Oilfield.

Keywords: CO_2 flooding · CO_2 geological storage · Potential evaluation method · Low permeability reservoir

1 Introduction

With the increasing global warming and climate deterioration, greenhouse gas emissions, especially CO_2 emissions, have attracted more and more attention of countries. Achieving the geological storage of CO_2 in reservoirs can not only greatly reduce the emission of CO_2 in the atmosphere, but also greatly improve the oil recovery. Research on CO_2 flooding and its storage has been carried out earlier, and a more complete theory of displacement and storage has been formed [1–12]. In 1997, Taber et al. summarized the screening criteria for CO_2 flooding reservoirs based on the successful case of CO_2 enhanced oil recovery [2]. In 2002, Shaw et al. screened the reservoir parameters suitable for CO_2-EOR on the basis of summarizing the previous research results, and graded the target reservoir by setting the optimal value and parameter weight [5, 6]. The potential of CO_2 flooding enhanced recovery was evaluated in the Alberta reservoir [8]. CO_2 sequestration is widely evaluated using CO_2 utilization coefficient in American and European countries, which is defined as total sequestration amount divided by cumulative oil production [9–12]. Shen Pingping et al. also proposed a similar approach in 2009 [13]. At present, China has a relatively late start in this field, especially for the potential of carbon dioxide storage in China's major oil areas, it is necessary to further establish a reasonable evaluation system. There are a large number of low permeability reservoirs in Dagang oilfield. After decades of exploitation, the effect of water injection development has been worse year by year. Comparatively speaking, CO_2 flooding has the advantages of low injection pressure and fast formation energy replenishment, and can obtain lower solvent/crude oil mobility ratio when miscible flooding is realized, which improves sweep efficiency and realizes geological storage of CO_2 while increasing production and tapping potential. Based on the establishment of CO_2 enhanced oil recovery and geological storage potential evaluation method, 272 oil layers in the low-permeability oil area of Dagang Oilfield are used as the evaluation objects, and the CO_2 enhanced oil recovery and geological storage potential in this area are analyzed.

2 Method

2.1 Numerical Simulation Calculation Models

The current CO_2 flooding enhanced recovery and geological storage numerical simulation calculation models mainly include four types: component model, black oil model, streamline model and split model. The advantage of the split model is that the three-dimensional problem is transformed into a one-dimensional flow problem, that the data volume needs to be reduced, and the operation speed is faster. The leakage characteristics of the split model are simplified. Considering that Dagang Oilfield CO_2 flooding enhanced oil recovery and geological storage potential evaluation workload is large, detailed data is difficult to obtain, we adopted the split model.

According to the principle of conservation of mass, the following conservation equations are established:

$$\frac{\partial C_{ij}}{\partial t_D} + \frac{\partial F_{ij}}{\partial X_D} = 0 \quad (1)$$

$$C_{ij} = C_{i0}S_0 + C_{i1}S_1 + C_{i2}S_2 \quad (2)$$

$$F_{ij} = C_{i0}f_0 + C_{i1}f_1 + C_{i2}f_2 \quad (3)$$

Here, C_{ij} is concentration of component i in j phase; S_j is j phase saturation; i is component of fluid; $i = 0$ is water component; $i = 1$ is crude oil component; $i = 2$ is injection gas component; t is time; X is length distance; f is split flow; D represents dimensionless.

Based on the traditional model, the calculation model considers the following main influencing factors in combination with the characteristics of Dagang oilfield reservoir: (1) viscous fingering and heterogeneity; (2) gas injection gravity differentiation; (3) introducing the minimum miscibility pressure calculation method to define the state of CO_2 flooding phase; (4) the difference of area sweep coefficient between miscible flooding and immiscible flooding; (5) the influence of interfacial tension effect on relative permeability change.

From this model, the CO_2 flooding enhanced oil recovery range can be determined, and the amount of CO_2 storage in the reservoir can be calculated from the following formula.

$$\begin{aligned} M_{CO_2t} = \rho_{CO_2r} \times [R_f \times A \times h \times \varphi \times (1 - S_{wi}) \\ - V_{iw} + V_{pw}] \end{aligned} \quad (4)$$

Here, M_{CO_2t} is CO_2 storage potential, t; ρ_{CO_2r} is CO_2 density in the formation, t/m^3; R_f is oil recovery; A is reservoir area, m^2; h is reservoir thickness, m; φ is reservoir porosity; S_{wi} is reservoir irreducible water saturation; V_{iw} is injected water volume, m^3; V_{pw} is producted water volume, m^3.

2.2 Model Reliability Analysis

Based on the CO_2 flooding enhanced recovery calculation model, a numerical simulation calculation program was developed. The program runs fast and the calculation results show that the reservoir engineering theory can be effectively reflected. Taking the typical reservoir of Dagang Oilfield as the research object, as shown in Fig. 1, the calculation results of the calculation software using this study are close to the calculation results of the commercial software Eclipse, and the difference between the two is within 10%, and the precision is high.

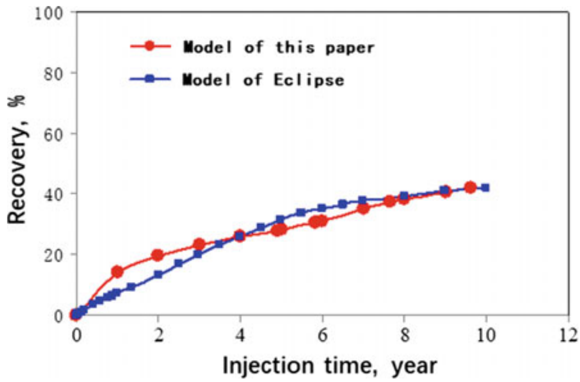

Fig. 1 The calculation results of this study and the commercial software Eclipse

2.3 Analysis of Influencing Factors

2.3.1 Influence of Reservoir Thickness

As shown in Fig. 2, as the thickness of the reservoir increases, the recovery of crude oil decreases. Mainly because the greater the thickness, the gravity differentiation causes the sweep volume coefficient to decrease.

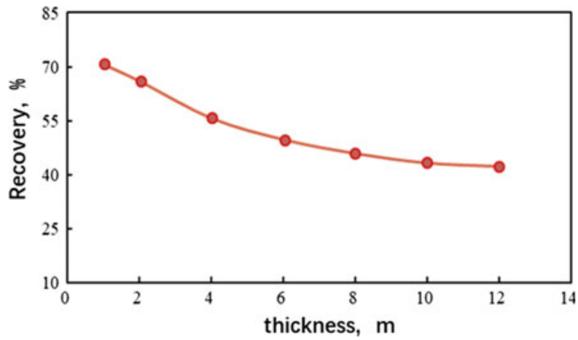

Fig. 2 Relationship between recovery factor and thickness

2.3.2 Influence of Reservoir Heterogeneity

As shown in Fig. 3, as the heterogeneous coefficient increases, the gas injection process leads to the intrusion of gas, and the volume coefficient of the sweep decreases, which in turn reduces the recovery factor.

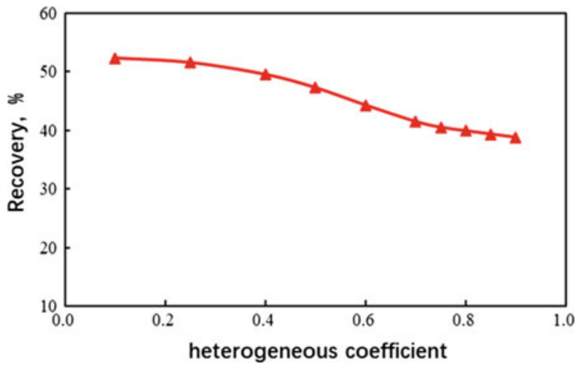

Fig. 3 Relationship between recovery factor and heterogeneous coefficient

2.3.3 Influence of Reservoir Crude Oil Viscosity

As shown in Fig. 4, as the viscosity of the crude oil decreases, the flow performance of the crude oil becomes better, the relative permeability of the oil phase increases, and the recovery factor increases exponentially.

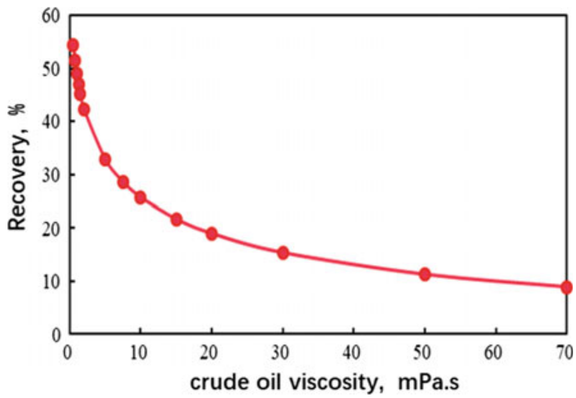

Fig. 4 Relationship between recovery factor and crude oil viscosity

2.3.4 Influence of Reservoir Oil Saturation

As shown in Fig. 5, as the oil saturation increases, the recovery factor has an upward trend with a large increase. It indicates that the better the oil bearing of the reservoir, the better the development of gas flooding.

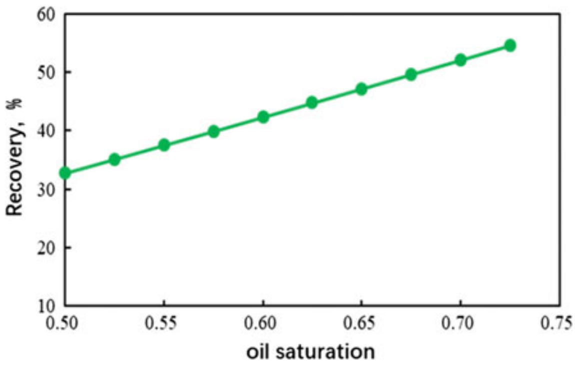

Fig. 5 Relationship between recovery factor and oil saturation

2.3.5 Influence of Reservoir Permeability

As shown in Fig. 6, as the reservoir permeability increases, the recovery rate increases, but when the permeability reaches a certain level, it is prone to gas enthalpy, resulting in a downward trend in oil recovery.

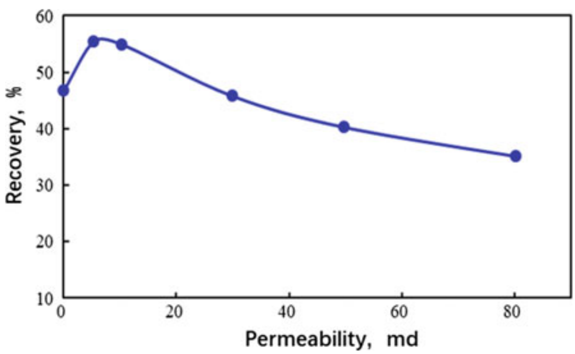

Fig. 6 Relationship between recovery factor and permeability

Based on the above analysis, the sensitivity rankings of factors affecting CO_2 flooding enhanced oil recovery are: crude oil viscosity > permeability > oil saturation > heterogeneity > reservoir thickness.

3 CO_2 EOR and Storage Potential Evaluation

3.1 Evaluation Process

We designed and developed the software, including four basic modules: basic data input, solution design, simulation calculation analysis, and report output. Based on the software, CO_2 flooding and geological storage potential evaluation can be performed through the process shown in Fig. 7.

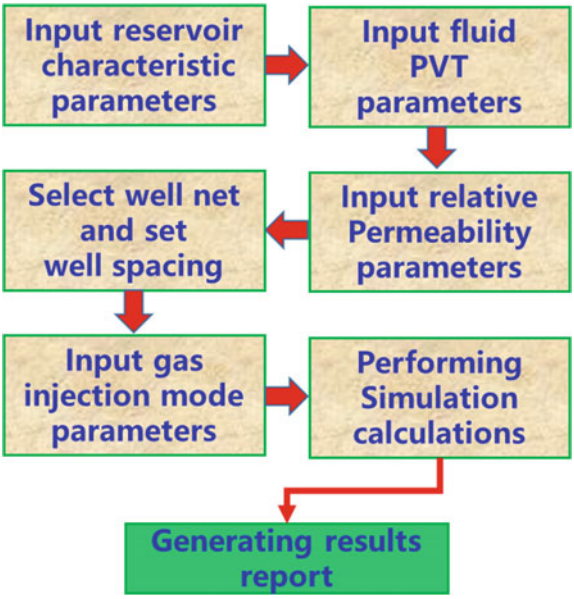

Fig. 7 Potential evaluation process

3.2 CO_2 EOR and Storage Potential Evaluation

3.2.1 CO_2 EOR Potential Evaluation

Through the evaluation of the potential of CO_2 flooding enhanced recovery in the low-permeability reservoirs developed in Dagang Oilfield, the results show that the geological reserves of the miscible flooding are great potential, and the number of miscible flooding blocks is 16. These low-permeability reservoirs can enhance oil recovery by 8.6% by CO_2 flooding, of which the average miscible flooding can be increased by 15.5%, and the average of immiscible flooding can be improved. 5.6%.

The evaluation results of the CO_2 flooding enhanced oil recovery potential of the undeveloped low-permeability reservoirs in Dagang Oilfield indicate that 144 blocks can achieve miscible flooding, accounting for the total amount. 65%. These low-permeability reservoirs can enhance oil recovery by an average of 9.9% by CO_2 flooding, of which the average recovery of miscible flooding is 12.3%, and the average of immiscible flooding increased oil recovery by 5.4%.

3.2.2 CO_2 Storage Potential Evaluation

Figures 8 and 9 show the results of CO_2 geological storage potential of 272 oil layers in the low-permeability oilfield of Dagang Oilfield. Figure 8 shows the CO_2 geological storage potential of the miscible flooding area, and Fig. 9 shows the CO_2 geological storage potential of the immiscible flooding area.

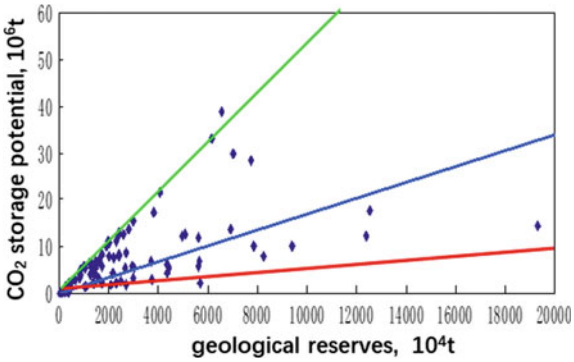

Fig. 8 Storage potential of miscible flooding area

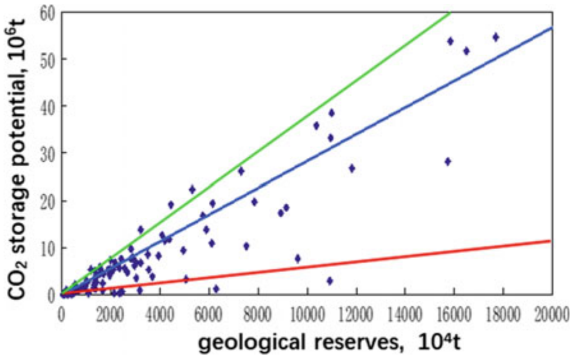

Fig. 9 Storage potential of immiscible flooding area

Shen Pingping et al. [9] predict storage potentials as below:

$$M_{CO_2t} = R_{CO_2} \cdot N \quad (5)$$

In which, M_{CO_2t} is CO_2 storage potentials, t; R_{CO_2} is sequestration storage coefficient, dimensionless; N is geological reserves, t.

According to the formula (5), the sequestration storage coefficients of Figs. 8 and 9 can be obtained. Here, we divide the sequestration storage coefficients into three levels of the highest value, the median value and the lowest value, as shown in Table 1.

Table 1 Sequestration storage coefficients

Values	Miscible area	Immiscible area
The highest value	0.50	0.41
The median value	0.17	0.28
The lowest value	0.06	0.06

4 Conclusion

(1) This paper establishes a method for evaluating the enhanced recovery and storage potential of CO_2 flooding in actual reservoirs of Dagang Oilfield. This method can effectively evaluate CO_2 flooding and geological sequestration potential of low permeability reservoirs in similar oilfields.
(2) By evaluating the CO_2 flooding potential of low-permeability reservoirs in Dagang Oilfield, the results show that Dagang Oilfield has a huge potential for CO_2 flooding to enhance oil recovery.
(3) By evaluating the geological storage potential of CO_2 flooding in low-permeability reservoirs in Dagang Oilfield, the results show that Dagang Oilfield has a considerable amount of CO_2 geological storage, and the highest sequestration storage coefficients can reach 0.5.

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