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Study on Factors Affecting CO_2 Recovery of Fractured Pressure-sensitive Reservoirs

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Abstract

The different deformation degree of fractures caused by the intrinsic strong pressure-sensitive property of the ultra-low permeability reservoirs would change the channeling law of CO_2 in fractures, then affect the oil displacement efficiency. Thus, revealing the seepage characteristics of CO2 in fractured reservoirs is the groundwork to improve the oil displacement efficiency of CO_2. The directional pressure-sensitive property of fractures was simulated by a physical model. The simulation of physical experiment with multi-physics coupling was carried out by theoretical derivation and finite element analysis software COMSOL Multiphysics. The stronger heterogeneity of reservoirs , makes CO_2 much easier to rush. Increasing injection pressure , can increase the proportion of CO_2 in low permeability area. As the pressure-sensitive property between high and low permeability layer is different, increasing the effective stress would induce stronger heterogeneity. Therefore, in order to control the effect of pressure-sensitive property on production， the formation pressure should be controlled reasonably in development process. In this study, the factors, especially the fracture development directions, which show significant influence on the oil recovery of CO_2 flooding in fractured and pressure-sensitive reservoirs, were studied with physical experiments and numerical experiments. The results obtained in the study can provide a more reliable theoretical basis for CO_2 flooding design and profile control technology.

Keywords: CO_2 flooding, pressure-sensitive, fracture direction.

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1. Introduction

There are many indoor methods for testing permeability. As early as the last century 50's, there are many foreign scholars put forward the appropriate test methods and experimental devices. Philippe Renard (2001) through the theoretical calculation and indoor test comparative analysis of the main factors affecting the test error are anisotropic principal value, direction of the permeability, and the sample length to diameter ratio. Green Korn (1964) proposed a similar test method, but still did not solve the calculation problem of anisotropic permeability tensor. Yves Bernabé (1992) obtained the full tensor permeability of the sample by changing the injection conditions which lead to different boundary conditions. After that the corresponding inverse problem had been solved. Bieber (1996) used point tracer water injection and X-ray tomography to directly observe the flow patterns within the sample. If the flow form is spherical, the medium is isotropic. If that is ellipsoid, it is anisotropic. However, most of the fracture permeability tensor tests and theoretical calculations are only applicable to anisotropic media, can't accurately measure and calculate the total tensor of anisotropy permeability. Therefore, it is still a difficult problem to obtain the fracture permeability value when the direction of permeability principal value have angle with the displacement pressure gradient. Due to CO_2 and the oil have large difference in the mobility, it is easy to lead to gas finger or gas cone caused the production decline. When the fracture in different directions and the reservoir has a pressure-sensitive effect, the law of production decline will be more complicated. Therefore, it is of great practical significance to study the influence of fracture direction on the flow pattern of pressure-sensitive reservoir.

2. A Theoretical Model for Calculating Fracture Aperture

The fractures of low permeability reservoirs are more developed, the matrix is used as the reservoir reserve space of oil, and the fractures are the flow channels of oil flow. The properties of fractures play an important role in oil production in low permeability oilfields. Therefore, the correct calculation of the aperture of the fracture is a very important work. As shown in Figs.1 to 4, the fractured core is obtained by applying the Brazilian splitting principle to the horizontal seam, and the fracture surface remains uncontaminated. The permeability of the matrix portion of the fracture core is equal to that of the homogeneous core. The gas permeability in the matrix core is (Equation 1):

$$k_m = \frac{2\mu q_m p_0 L}{A(p_1^2 - p_2^2)} \qquad (1)$$

The gas permeability in the fractured core is (Equation 2):

$$k_{avg} = \frac{2\mu q_{avg} p_0 L}{A(p_1^2 - p_2^2)} \qquad (2)$$

The permeability of a single fracture is (Equation 3):

$$k_f = 8.44\times10^9 w^2 \qquad (3)$$

In a fractured core, the core flow rate is equal to the sum of the flow in a single fracture and the flow of the matrix(Equation 4),

$$q_{avg} = q_f + q_m \qquad (4)$$

To sum up (Equation 5):

$$8.44\times10^9 w^3 l - k_{avg}A + k_m(A - wl) = 0 \qquad (5)$$

The fracture aperture is obtained by the Equation 5, so that the flow rate of the fluid in the matrix and the fracture are (Equation 6):

$$q_m = \frac{6k_m A(p_1^2 - p_2^2)}{10\mu p_0 L}; \quad q_f = 5.064\times10^8 \cdot \frac{w^3 l(p_1^2 - p_2^2)}{\mu p_0 L} \qquad (6)$$

Where k_m = matrix permeability, $10^{-3}\mu m^2$. k_f = fracture permeability, $10^{-3}\mu m^2$.q_m , q_f = flow rate in the matrix and fracture, respectively, cm^3/min. p_1, p_2 = absolute pressure of the core inlet and outlet, respectively, MPa. w = fracture aperture, cm. p0 = atmospheric pressure, MPa. l = fracture length, cm.

Figure 1. Matrix Core Seepage Diagram.

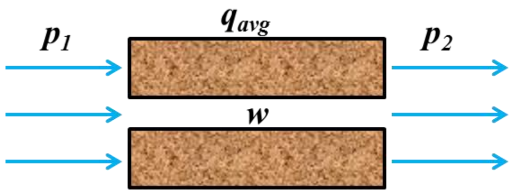

Figure 2. Fracture Core Seepage Diagram.

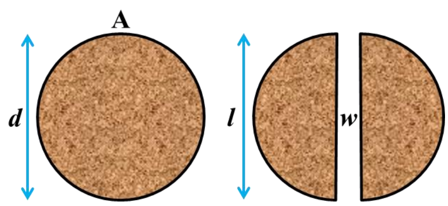

Figure 3. Cross Section of Matrix And Fracture.

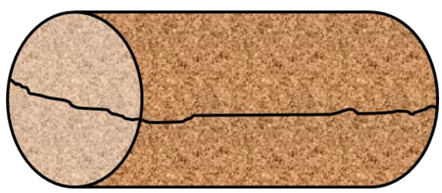

Figure 4. Fractured Core Diagram.

3. Physical Simulation

3.1 Effect of pressure on fracture permeability

All parameters are same as the theoretical model. In order to intuitively observe the dynamic change process of the fracture opening when the fluid pressure changed, the red dye agent is added to the distilled water and the plexiglass tank is used as the experimental model container (Fig.5).

3.2 Effect of pressure on fracture permeability

As shown in Figure.6: When the pressure gradient (pressure difference) is kept constant, as the pressure on the media increases, the overall fracture permeability increases.

Figure.7 is for the relationships between pressure difference and flow rate at the average pressure of 12kPa. As the pressure gradient or injection pressure increases, the flow begins to increase first, and the peak appears in the middle and then begins to decrease. It can be seen that in order to obtain the maximum productivity benefit in the actual oilfield development, it is not the bigger the better on the pressure difference, but existence an optimal value, which is very instructive for the reasonable development of the actual reservoir.

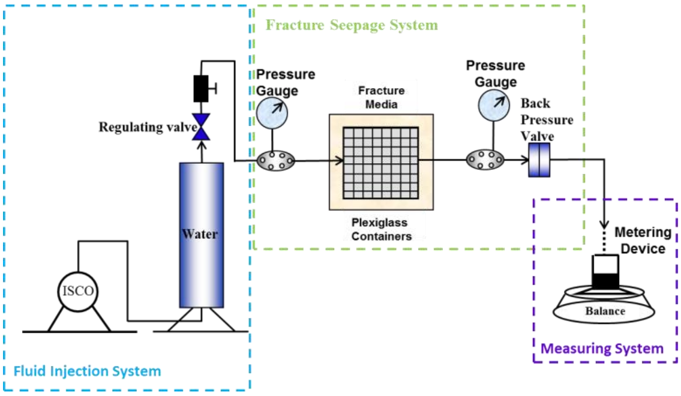

Figure 5. Experimental Device Diagram.

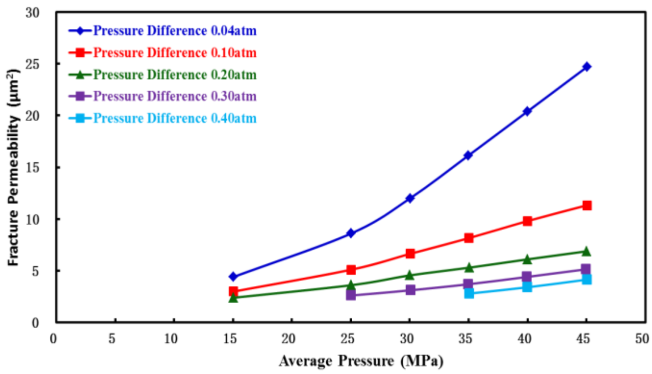

Figure 6. Fracture Permeability With Average Pressure.

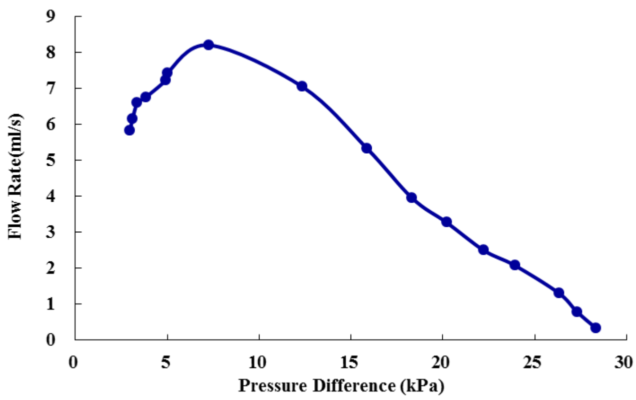

Figure 7. Relationships Between Pressure Difference and Flow Rate at the Average Pressure of 12kPa.

4. Experimental Simulation

The experiment procedure was also simulated by COMSOL Multiphysics. Parameters of the model are the same as the experimental model. Due the development direction of the fractures are different, the reservoir area with preferential pressure spread direction in the development is different (Fig. 8).

As shown in Fig. 9, the pressure is preferentially propagated along the direction of the fracture. As the production process progresses, the pressure gradually affects the matrix around the fracture, and the use degree of matrix is gradually increased. The development direction of the fractures is different, and the reservoir area with preferential pressure spread direction is different. Corresponding to the actual reservoir, different regions with different reserves abundance, the initial production capacity of the production wells will be very different. And ultimately reach a steady state. When the models both have reached a steady state, the total pressure spread area is not same between them. The place where the pressure could not reach, that is difficult to recovery oil and gas even if the reserves are high. Therefore, the angle between the direction of the fracture and the direction of the pressure gradient will affect the final recovery of the reservoir.

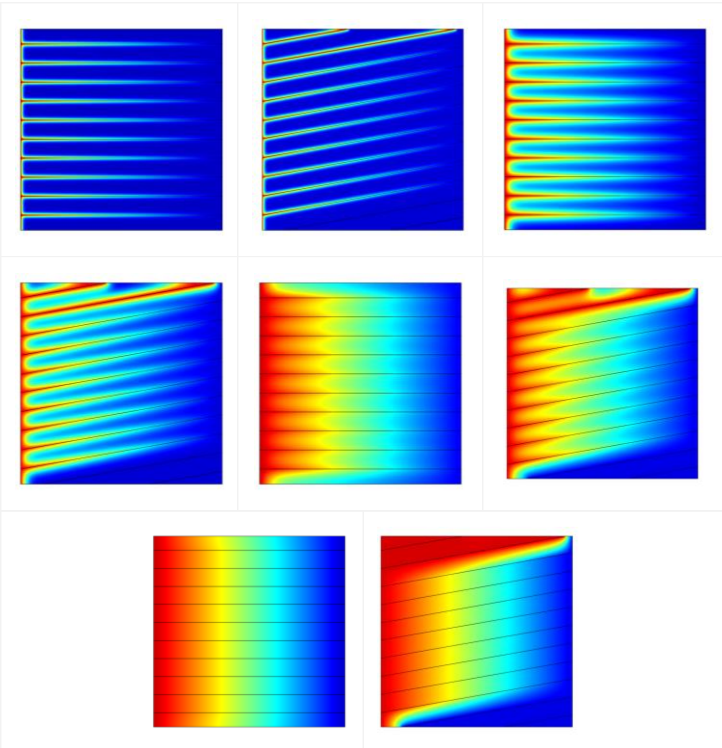

Figure 8. Pressure Propagation Path.

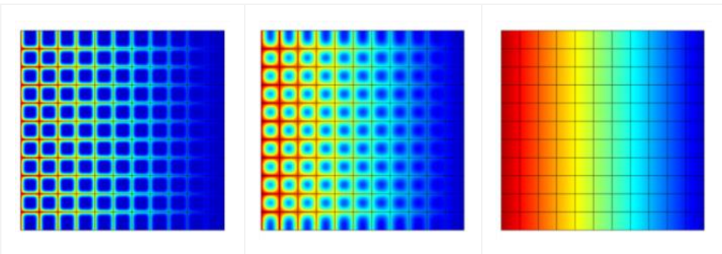

Figure 9. Pressure Field Distribution.

5. Conclusion

(1) In the low permeability heterogeneous reservoir, with the increase of the effective pressure, the permeability loss in low permeability layer is higher than that of in the high permeability layer. Low permeability fractured reservoir have strong pressure sensitivity, which is caused by the closure of fractures and the deformation of matrix. When the effective pressure is low, the closure of the fracture aperture causes the permeability decrease sharply. With the increase of the effective pressure, the fracture aperture decreases. When the fracture aperture is closed to a certain level, the matrix permeability also began to decrease. And the lower the matrix permeability is, the stronger the pressure sensitivity of the reservoir.

(2) The gas channeling in the low permeability fractured press sensitive reservoir is related to the fracture property. With the effective pressure increase, the fracture in different directions will occur varying degrees of closure , resulting in the gas transfer from the fracture to the matrix , thereby the use of oil in the matrix will increase. When the effective pressure is too high, it will lead to loss of permeability of the matrix, thereby reducing the production capacity of matrix. When the matrix permeability is low, the fracture core can obtain a high gas flooding efficiency with the effective pressure kept at a high level.

Acknowledgements

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