Study on Influencing Factors of Heavy Oil Waterflooding Development

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Abstract. In this paper, the influence factors of development effect of heavy oil reservoir by water flooding are analyzed and studied by numerical simulation technology. The results show that: (1) with the increase of crude oil viscosity, reservoir recovery decreases gradually and development effect becomes worse; (2) for heavy oil reservoirs with different viscosities, recovery increases at first and then decreases slowly with the increase of permeability; (3) water injection development is carried out under different formation pressure maintaining horizontal conditions, the results show that the maximum development efficiency of reservoir recovery is achieved under saturated pressure conditions. The results show that there are optimal injection velocities for different permeability reservoirs, such as 0.06 PV/a for 100 md reservoir, 0.10 PV/a for 500 md reservoir and 0.04 PV/a for 1000 md reservoir.

1. Preface
As a relatively efficient development method, water flooding is widely used to develop common heavy oil reservoirs. Compared with thin oil reservoirs, heavy oil is difficult to develop and has high development cost. When water flooding is carried out, there are predominant seepage channels. Injection water is prone to channeling, which reduces the sweep volume of the reservoir and affects the recovery factor of the reservoir. In this paper, the influence of crude oil viscosity and reservoir permeability on heavy oil waterflooding development is firstly clarified by numerical simulation technology. Secondly, the timing of water injection and energy replenishment under different pressure levels is determined on the basis of understanding the law. Finally, the optimal injection rate for heavy oil reservoir development by water flooding is determined. This paper has certain guiding significance for the efficient development of heavy oil reservoir by water flooding.

2. Establishment of numerical simulation
CMG is used to establish the numerical simulation model. Five-point method is used to build the well pattern with a well spacing of 150 m and permeability of (100, 200, 500, 800 and 1000) md, respectively. On this basis, follow-up numerical simulation is carried out.
Different relative permeability curves are used for different permeability reservoirs.

Figure 1 Single-layer plane homogeneous model

Figure 2 Oil-water relative permeability curve of reservoirs with different permeability

3. Analysis of Influencing Factors

3.1. Analysis of Viscosity Effect of Crude Oil

For reservoirs with permeability of 500 md, numerical simulation schemes with crude oil viscosities of (100, 200, 500, 1000 and 2000) mpa_s are carried out respectively. The influence of crude oil viscosities on heavy oil waterflooding development is determined by comparing the recovery methods of different schemes. The calculation results show that with the increase of crude oil viscosity, the influence on the initial recovery rate is small, but when the viscosity reaches 500 mpa_s, the recovery rate decreases obviously, and the effect of water flooding development becomes worse. Therefore, the influence of
crude oil viscosity should be taken into account when choosing water flooding development for heavy oil reservoirs.

![Recovery curves with the same permeability and different crude oil viscosities](image)

**Figure 3** Recovery curves with the same permeability and different crude oil viscosities

### 3.2. Analysis of Reservoir Permeability Impact

The influence of reservoir permeability on heavy oil waterflooding development is analyzed. The crude oil viscosity is 200 mPa∙s and the permeability is (100, 200, 500, 800 and 1000) md, respectively. The recovery changes under different permeability schemes are counted. The results show that with the increase of permeability, the recovery rate increases gradually, but when the permeability is too high, the recovery rate has a downward trend. The reason is that with the increase of permeability, the swept volume of water flooding has been significantly expanded and the recovery rate has been improved. But when the permeability is too large, although the swept volume has been expanded to a certain extent, there is a more obvious phenomenon of water channeling in the later stage of water flooding development, which reduces the recovery rate.

![Recovery curves with the same crude oil viscosity and different permeability](image)

**Figure 4** Recovery curves with the same crude oil viscosity and different permeability

### 3.3. Optimum injection timing

According to the research and analysis of water injection timing, the crude oil viscosity is 200 mPa∙s and reservoir permeability is 500 md. Water injection development is carried out under different formation pressure retention levels, such as original formation pressure 9.8 MPa, saturation pressure 7.3 MPa, 6.3 MPa, 5.3 MPa and 4.3 MPa, and the recovery changes of different schemes are counted. The results show that for the single layer model, when the formation pressure is near the saturation pressure, the recovery rate is the best. With the decrease of formation pressure, the recovery rate decreases gradually and the development effect becomes worse. The reason is that when the formation pressure is
higher than the saturation pressure, the oil viscosity increases with the formation pressure. Considering the influence of the oil viscosity on the development of heavy oil reservoir by water flooding, the recovery factor decreases gradually. But when the formation pressure is lower than the saturation pressure, with the formation pressure decreasing, the oil degassing, the oil viscosity gradually increases, and the recovery factor also decreases gradually. In heavy oil water drive reservoir, the water injection development effect is the best when the formation pressure is near the saturation pressure.

![Figure 5](image1.png)

**Figure 5** The recovery curve under different water injection timing

### 3.4. Optimum selection of water injection rate

According to the research and analysis of water injection rate, crude oil viscosity 200 mpa-s, reservoir permeability (100, 200, 500, 800 and 1000) md, water injection development is carried out near the saturated pressure. The working system of oil and water wells is that the injection-production ratio is 1, the formation pressure is maintained near the saturated pressure, and the changes of recovery rate of different schemes are counted. The results show that there is an optimal injection rate for reservoirs with different permeability, and the optimal injection rate increases first and then decreases with the increase of permeability. For example, 100 md reservoir is 0.05PV/a, 500 md reservoir is 0.10 PV/a, and 1000 md reservoir is 0.04 PV/a. The reason is that, because the oil-water viscosity ratio is quite different, with the increase of permeability, increasing the water injection intensity properly is conducive to expanding the sweep volume, but when the permeability is too large, water channeling is easy to occur and sweep volume is reduced by adopting larger water injection intensity, thus affecting the development effect.

![Figure 6](image2.png)

**Figure 6** Optimum water injection intensity curve of reservoirs with different permeability
4. Conclusion

(1) With the increase of crude oil viscosity, the swept volume and recovery of reservoir decrease gradually, and the development effect becomes worse.

(2) For heavy oil reservoirs, recovery increases first with the increase of permeability. This is because sweep volume increases gradually with the increase of permeability, but with the increase of permeability, water channeling occurs in the subsequent injection water, which reduces the sweep volume of the whole reservoir, and the recovery rate decreases. Therefore, there is an optimal permeability for reservoirs with different viscosities.

(3) Water flooding is carried out under the condition of different formation pressure keeping level, and the results show that the effect of water flooding is the best under the condition of saturated pressure.

(4) For different permeability reservoirs, there is an optimal injection rate, and with the increase of permeability, the optimal injection rate increases first and then decreases. For example, 100 MD reservoir is 0.06PV/a, 500 MD reservoir is 0.10 PV/a, and 1000 MD reservoir is 0.04PV/a.

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