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Oil Optimizing Recovery in Heterogeneous Reservoir with Mobility Control of Surfactant-Polymer Flooding

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Summary

As one of the mostly applied method, polymer flooding is essential for further improve oil recovery after previous flooding. But the heterogeneity of reservoir has enhanced by flooding, leaving limitations on the result of conventional second-polymer flooding. To break these limitations, mobility control is adopted here in reservoir numerical simulation for its ability to expand effecting areas volume, which can further improve the driving efficiency of flooding. Also, with coupling with physical test, optimization taking remaining oil and recovery efficiency as key factors is accomplished.

Introduction

With the development of polymer flooding in China, sections once applied flooding have entered a stage with high water content, and based on a good amount of case studies, 40 to 50 percent oil is remaining after flooding, showing a great potential to be recovered. On the other hand, reservoir after flooding shows an intensified heterogeneity and scattered remaining oil. Under this circumstance, how to effectively improve oil recovery has become a problem await to be solved.

Surfactant-Polymer flooding is an option to solve this for its ability to preclude the scaling problem and difficulties in oil-water separation caused by alkali. But still, if sole Surfactant-Polymer flooding is injected, flooding fluids may cross flow in high permeability layer and barriers may show up to initiate remaining oil in the low permeability layers. Thus, mobility control is applied in this work to work on this.

Theory and/or Method

Surfactant-Polymer Flooding

Recovery efficiency rate E_{R} largely lies on the swept region and displacing efficiency of the displacing agent:

$$E_{\mathrm{R}} = \frac{N_{\mathrm{P}}}{N} = E_{\mathrm{V}} \times E_{\mathrm{D}} \qquad (1)$$

In formula (1), N_{P} is the output quality, N is the initial reserve, E_{V} stands for swept coefficient and E_{D} is the displacing efficiency.

Higher viscosity of Polymer Flooding can overcome the viscous fingering phenomenon in flooding process, and thereby increase the swept coefficient in vertical direction, which is followed by increase in oil recovery rate. Also, the absorption of polymer blocks the flowing of water, leaving relative higher oil permeability than water permeability under the same oil saturation. With surfactant, oil-water interfacial tension is reduced, which can reduce the adsorption capacity of oil and increase water's displacing ability. From capillary pressure formula (2), it is obvious that decreasing in oil-water interfacial tension will decrease the capillary pressure formula, which in turn amplifies the flowing ability of oil.

$$P_c = \frac{2\sigma\cos\vartheta}{r} \qquad (2)$$

From microscope displacing test, the process of Surfactant-Polymer Flooding can be observed: Remaining oil was dragged into drop and filament (shown in Figure1 and 2), with the variation of flow velocity caused by viscosity effect of Surfactant-Polymer Flooding, which thereby can be displaced by flooding.

Physical Experiment

Mobility Control is introduced here to preclude cross flow in high permeability layer and barriers to initiate remaining oil in the low permeability layers. Heterogeneous models with different permeability contrast are established based on two parallel cores experiments to determine the optimized surfactant-polymer system respectively from several system designs: A mobility control scheme of slug combination of a high concentration of polymer and surfactant-polymer systems is designed with the principle that high concentration polymer solution is firstly injected to block the high permeability layer so that improve the Swept volume, then the subsequent solution can be injected into the low-permeability layer , initiate the remaining oil in low permeability layer, thereby improving recovery. Experiment scheme and rock parameters are shown in From 1, all parameters are selected based on experimental data analysis.

Permeability Contrast	Effective Permeability （$\times 10^{-3}\mu m^2$）	Initial Oil Saturation （%）	Experiment Scheme
1：5	200	71.0	Water drive+ polymer flooding + high-concentration polymer （0.3PV） + Surfactant-Polymer Flooding （0.2PV）
	1000	78.7	
1：10	200	74.5	
	2000	78.9	

Form 1. Experiment Scheme and Rock Parameters

Numerical Modeling

The theory numerical modeling based is also mobility control: two parallel cores model is established with 1: 5 and 1: 10 as permeability contrast respectively. In vertical direction, 7 layers are divided, taking 1.5cm as the effective thickness. As ineffective layer, the 4th layer divides these layers into two groups. Layer 1to 3 share the same effective permeability and the effective permeability from layer 5 to layer 7 is the same. Average porosity adopted is 0.25, the ground water viscosity is 0.6mpa • s, oil viscosity is10mpa • s, meshing generation is 20×3×7 and one - well injection and one - well production is utilized here. The model sketch is shown in Figure 3. For different permeability contrast, various flooding scheme were simulated (shown in Form 2).

Permeability Contrast	Scheme
1:10	0.3PV high-concentration polymer +0.2PV Surfactant-Polymer Flooding
	0.2PV high-concentration polymer +0.3PV Surfactant-Polymer Flooding
	0.1PV high-concentration polymer +0.4PV Surfactant-Polymer Flooding

1:5	0.3PV high-concentration polymer +0.2PV Surfactant-Polymer Flooding
	0.2PV high-concentration polymer +0.3PV Surfactant-Polymer Flooding
	0.1PV high-concentration polymer +0.4PV Surfactant-Polymer Flooding

Coupling

With data obtained by previous two steps, black-oil simulator E100 of Eclipse, Cartesian coordinate system and block-centered grid are adopted to fulfill the coupling of recovery rate and moisture content (shown in Figure 4 to 7). To optimize oil recovery, efficiency of water drive, polymer flooding, and high-concentration polymer and Surfactant-Polymer Flooding were compared and analyzed.

Examples

Take coupling result of and Surfactant-Polymer Flooding with 1: 5 and 1: 10 permeability contrast as example：Mobility control scheme combined high-concentration polymer and Surfactant-Polymer Flooding is utilized here. The effect on chemical flooding result caused by high-concentration polymer slug size I studied by decreasing the size of Surfactant-Polymer slug with slug injection as a constant. When permeability contrast is 1: 10, oil recovery rate after chemical flooding increases with the injection of high-concentration polymer, the size of such injection influences more on lower permeability layer than higher one. When the slug size varies from 0.1PV to 0.2PV, the recovery increases 4.3%, from 0.2PV to 0.3PV, it increases1.4%, suggesting optimal value for enhancing oil recovery exists in the range from 0.2PV to 0.3P-V(shown in Figure 8 and 9). Figure 10 and 11 show the distributing rate: 95% in high permeability layer and 5% in low, meaning most water cross flow along high permeability layer, leaving a low sweep efficiency on low permeability layer.

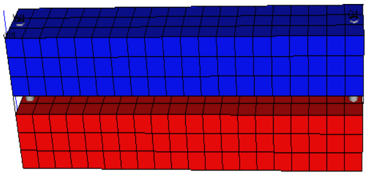
In flooding stage, the distribution rate in low permeability layer increases, meaning positive influence on profile controlling, but the difference on high and low permeability layers with 1: 5 permeability contrast is less than those with 1: 10 permeability contrast because low viscosity of conventional polymer flooding has limited control on mobility, especially on reservoir with strong heterogeneity. While Surfactant-Polymer Flooding is added, the distribution rate in low permeability layer increases along with the slug size of high-concentration polymer in model with 1: 10 permeability contrast and distribution difference largely decreases. This suggests that injection of high-concentration polymer has fulfilled the mobility control task: more liquid has been absorbed in low permeability layer, the swept volume is increasing and the blocking is successfully undertaken in high permeability layer. When the slug size of high-concentration polymer reaches 0.3PV, the difference in distribution rate is minimum, showing the best mobility control effect. When slug size of high-concentration polymer reaches 0.2PV, distribution rate difference in low permeability layer decreases and then stays stable along with the slug size of high-concentration polymer in model with 1: 5 permeability contrast, suggesting success in mobility control.

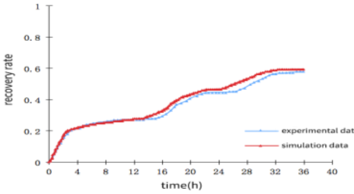
Conclusions

Two parallel cores model is established in this work for experimental data collection and couplings were done between numerical simulation result and experimental data on recovery rate and moisture content to optimize Surfactant-Polymer Flooding scheme for different permeability contrast. For 1: 10 permeability contrast, with the increase of slug size of high-concentration polymer and SP, recovery rate caused by chemical flooding shows increasing trend, especially on low permeability layers. The optimized scheme is 0.3PV high-concentration polymer +0.2PV SP, which improved 17.9% oil recovery. For 1: 5 permeability contrast, with the increase of slug size of high-concentration polymer and SP, recovery rate increases at first and then decreases, the optimized scheme is 0.2PV high-concentration polymer +0.3PV SP, which improved 14.5% oil recovery. Result verifies that Surfactant-Polymer flooding (high-concentration polymer and Surfactant-Polymer) with mobility control can further improve 12%~20% oil recovery rate in heterogeneous reservoir.

Figure 1

Figure 2





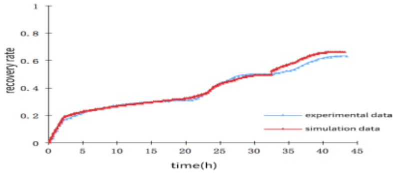


Figure 3

Figure 4

Figure 5

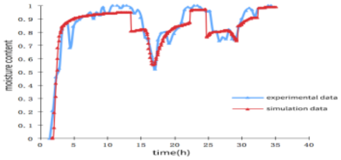


Figure 6

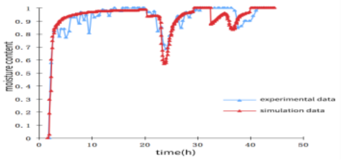


Figure 7

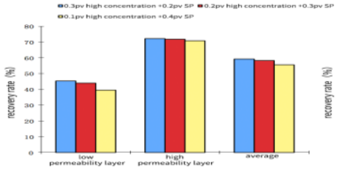


Figure 8

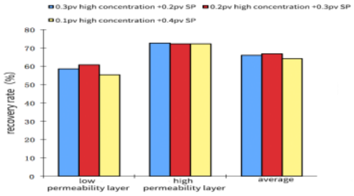


Figure 9

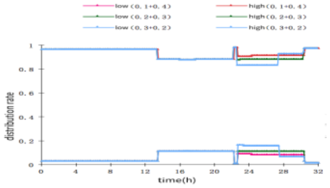


Figure 10

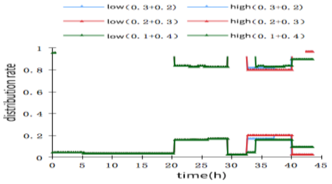


Figure 11

Acknowledgements

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