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Study on selective plugging characteristics and oil displacement mechanism of microsphere in porous media

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Abstract. Microspheres are widely used as profile control and water plugging products at present. However, the current research on microspheres is mainly focused on oil displacement experiments. In order to solve this problem, based on the Bohai sea in the BZ of inhomogeneous reservoir conditions, this article has done the matching study on particle size and hole roar and the seepage research in porous medium by means of particle size analysis, pressure tests, single-phase block experiments, and the double tube parallel oil displacement experiments, revealing the characteristics of oil & water selective plugging and the mechanism of oil displacement in porous media. The results show that the average particle size of the microspheres increases from 4.857μm to 24.53μm, and the maximum expansion factor reaches 5.03 times after 72h of swelling in BZ25 oilfield water at 75 C. In the two-pipe parallel oil flooding experiment with the permeability of 1000mD and 3000mD respectively, the comprehensive recovery rate after the first water flooding is 28.06%, and the two-pipe average recovery rate is increased by 1.58% after the injection of 2000ppm microsphere with 0.3PV, and there is no significant increase in oil displacement efficiency. The comprehensive recovery rate reached 38.6% and increased by 8.99% after 4PV of subsequent water flooding, indicating that microsphere flooding effectively improved the water sweep efficiency of subsequent injection.

1 Introduction

Microspheres are a kind of profile control and water shutoff products that are currently used more frequently. Generally, common microspheres are small in size and can be expanded several times in a short period of time. After being injected into the formation, they can easily enter the deep part of the formation. The microspheres can be sealed after expansion [1-2]. It is precisely because of these characteristics of microspheres that the formation of pores and pores are plugged, so that microspheres can be used as profile control and water shutoff agents and used in major oilfields at home and abroad.

Lou [3] had also confirmed through field experiments that the injection pressure was

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increased, the swept volume was improved and the oil well was significantly increased when the reservoir was injected with controlled displacement microspheres. At the same time, many scholars have done a lot of experiments on the control and drive mechanism of microspheres. Zhou [4] used nuclear magnetic resonance to study the flow control mechanism of polymer microspheres. He found that polymer microspheres control flooding can effectively use the remaining oil in different pore diameters in the core, and concluded that micron-sized microspheres are mainly suitable for high permeability. For cores, nano-scale microspheres are mainly suitable for understanding low-permeability cores. Al-Sharji. [5] proposed that elastic microspheres flow through the porous medium can produce the control and displacement effect due to mechanical trapping, surface adsorption, hydrodynamic trapping and the interaction between elastic microsphere particles. The pore surface and the pore roar of the medium produce retention phenomenon. Yao et al. [6] further studied the microscopic mechanism of elastic microsphere-controlled flooding through microscopic visual control flooding experiments, which are mainly reflected in the selective sealing mechanism of large pores, the diversion mechanism after plugging and four aspects. The mechanism of pressure drainage and the convergence of oil droplets is an oil flow mechanism. Most researches at home and abroad focus on the experimental study of microspheres displacing oil in porous media, but the understanding of the selective plugging laws of oil and water in porous media by microspheres is insufficient.

In this context, this paper takes the conditions of the BoZhong heterogeneous high-permeability reservoir as the research object, adopts particle size analysis, steering pressure test, oil-water single-phase plugging experiment, and double-pipe parallel flooding experiment to carry out particle size analysis. The study of matching with pore roar and the study of porous media seepage revealed the oil-water selective plugging characteristics of microspheres and the oil displacement mechanism in porous media.

2 Experimental

2.1 Experimental reagents and instruments

Reagents and equipment required for experiments include polymer microspheres (it was provided by CNOOC Tianjin Branch), BZ25 oilfield water(salinity of 8700mg/L), experimental oil (the viscosity is 60mPa.s at 65°C), KYPAM-10 (partially hydrolyzed polyacrylamide, relative molecule Quality: $18\sim21\times10^6$, degree of hydrolysis 15~20%), HYDRO2000 (APA2000) laser particle size analyzer, (British MALVERN company), DHG-9240 electric heating constant temperature blast drying oven(Chengdu ShengJie Technology Co., Ltd.), multifunctional core displacement Device/Multi-point sand-filling tube (length 60cm, diameter 2.5cm), Leica/Leica Instruments Co., Ltd.

2.2 Particle size analysis

The HYDRO2000 (APA2000) laser particle size analyzer was used to analyze and determine the particle size distribution of the microspheres before absorbing water and swelling. Use BZ25 oilfield water to prepare a solution of microspheres with a mass concentration of 2000 ppm, and place them in a constant temperature oven at 50, 60, 65, 65 and 75°C. Take a certain sample every 24 hours and place it under a polarizing microscope to observe the expansion of the microspheres.

2.3 Evaluation of microsphere flooding

The sand-filled tube and the experimental flow chart for the experiment are shown in Figure 1. Specific steps are as follows: Connect the experimental equipment as shown in the Figure 1, and saturate the sand-packing pipe with formation water and then saturate the simulated oil. Then start the first water flooding to high water cut and inject 0.3PV microspheres. After aging in oven at 105 C, start the subsequent water flooding to high water cut.

Fig. 1. Experimental equipment.

The experimental device consists of two sand-packing pipes with different permeability, in which the sand-packing pipes have two pressure measuring points, and the pressure changes are monitored by electronic pressure gauges

3 Experimental Results and Discussion

3.1 Research on expansion mechanism

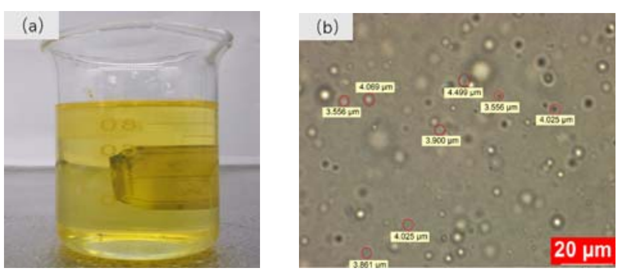

Fig. 2. Photos of Microsphere and initial particle size.

The elastic microspheres used in this experiment are light yellow with a density of 1.03g/cm^3. **Fig 3**. is a graph of the initial particle size distribution of elastic microspheres observed by a laser particle size analyzer. It can be seen that the initial particle size distribution range of the elastic microspheres is 1.5-20μm, and the average particle size is 4.857μm, which is consistent with the results measured by the polarizing microscope.

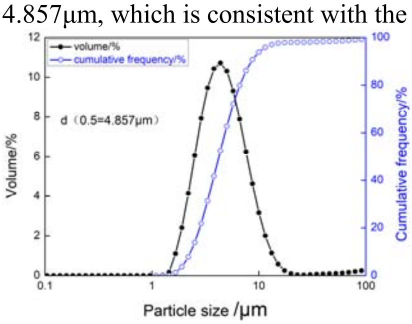

Fig. 3. Initial particle size distribution.

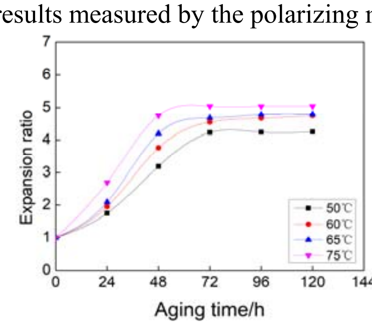

Fig. 4. Expansion times at different tempertures.

The expansion factor of the microspheres at 75 C is 5.03. It is shown that the expansion ratio of the microsphere system increases with the increase of the ambient temperature [7-9]. According to the explanation of the effect of temperature on the expansion performance of polymer microspheres in Flory theory [10], because the increase of temperature will promote the further hydrolysis of the amide group in the microspheres, and the increase of the degree of hydrolysis will increase the charge concentration on the microspheres.

3.2 Double-pipe parallel flooding experiment

The results of the double-pipe flooding experiment are shown in Table 1. It can be seen that after injection of microspheres and water flooding again, the recovery rate in the low-permeability sand-packing pipe is increased by 12.55%, and the recovery rate in the high-permeability sand-packing pipe is increased by 5.43%, which indicates that the microspheres have a good effect of profile control.

Table 1. Experimental results of double-pipe parallel flooding.

Sand filling pipe	permeability /mD	original oil saturation /%	primary waterflood recovery /%		Injection microsphere recovery factor /%		Secondary water flooding/%		Total recovery /%
			Single-tube	average	Single-tube	average	Single-tube	average	
A	1055.65	82.06	7.86	28.06	0.67	1.58	12.55	8.99	38.63
B	3107.25	84.01	48.25		2.49		5.43		

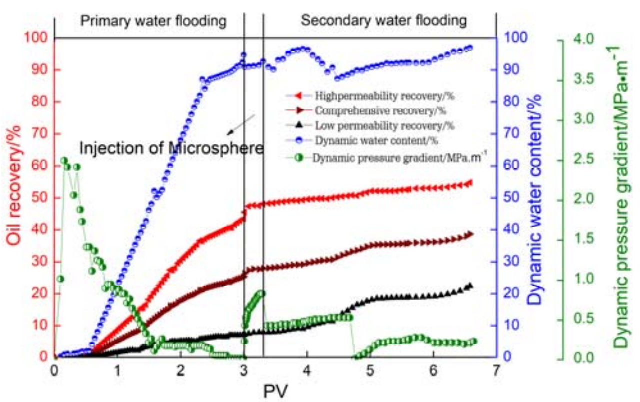

Fig. 5. Experimental results of double-pipe parallel flooding.

It can be seen from **Fig 5** that in the first water flooding stage, the dynamic pressure gradient increases rapidly, and the liquid flow breaks through rapidly in the high-permeability tube. At the same time, the dynamic pressure gradient begins to decrease rapidly again and stabilizes at about 0.015MPa/m. It is an anhydrous oil recovery period when the initial value is 0. As the volume of water flooding increases, the high-permeability pipe has been broken through firstly. After the water flow breaks through, the dynamic water cut increases rapidly. At the end of the first water flooding, the water flooding recovery rate of high-permeability sand-packing pipes was 48.25% and the water-flooding recovery rate of low-permeability sand-packing pipes was 7.86%. Most of the fluid flows out of the hyperpermeable channel due to the poor permeability between the two parallel sand-packing tubes. In the microsphere injection stage, the pressure gradient began to rise to about 0.81MPa/m when the polymer microspheres were injected. When the microspheres were injected, the water content also decreased to a certain extent, which also indicated that the polymer microspheres had the effect of blocking water. In the subsequent water flooding stage, the increase of the recovery factor in the low-permeability pipe is greater than that in the high-permeability pipe, and the dynamic water cut increases slowly and stabilizes at about 98%. At the end of the subsequent water flooding, the cumulative recovery rate of water flooding with high-permeability pipes was 56.17%, and the cumulative recovery rate of water-flooding with low-permeability pipes was 21.08%. The cumulative recovery factor of the permeable sand-filling pipe is 1.67 times of the incremental value (7.92%), and the final comprehensive recovery factor is 38.63%.

The study of porous media seepage shows that when the microspheres were injected into heterogeneous formations, they preferentially enter the dominant water flow channels and swell in the formation. Then microspheres begin to migrate and plug leakage, migration and plugging again in high-permeability reservoirs. More water flow was diverted into the small pores of the low permeability layer improving the vertical or horizontal contradiction of the reservoir and producing more remaining oil [11-15].

4 Conclusion

Microspheres have good swelling properties in seawater. The initial particle size of the microspheres is 4.5 μm, and the maximum expansion factor is 5.03 in seawater at 75 °C. The results of the double-pipe parallel flooding experiment further prove that the injection of microspheres into a heterogeneous reservoir can divert the liquid flow into small pores during the subsequent water flooding process, and improve the recovery of the remaining oil in the low-permeability reservoir.

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