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Research Article

A Novel Enhanced Oil Recovery Technology Using Pore-scale Elastic Microspheres after Polymer Flooding

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Abstract: In this study, a novel enhanced oil recovery method using pore-scale elastic microspheres after polymer flooding was proposed. Using single-tube sand pack models, the resistant coefficient of polymer flooding and elastic microspheres profile control and flooding was contrastively studied. Then the resistant coefficient of injecting elastic microspheres after polymer flooding was studied. At last, physical simulation of elastic microspheres flooding after polymer was conducted. The results show that polymer and elastic microspheres have synergistic effect; the polymer can make the migration of elastic microspheres easily; the elastic microspheres can prevent polymer from crossing flow along the high permeability channel and extend the polymer output time of oil well. Compared to polymer flooding (1000 mg/L) and (2000 mg/L), elastic microspheres flooding (1000 mg/L) after polymer flooding (1000 mg/L) can enhance oil recovery by 5.6 and 4.4%, respectively. The results confirm that elastic microspheres can enhance oil recovery effectively after polymer flooding. This novel technology will become an effective technical measure for polymer flooding oilfield to enhance oil recovery further.

Keywords: Elastic microspheres, enhanced oil recovery, physical simulation, polymer flooding, resistant coefficient, synergistic effect

INTRODUCTION

Many flooding technologies have been used to enhance oil recovery for water flooding oilfield. As a mature technology, polymer flooding has been used in Daqing, Shengli and Dagang Oilfield in China successfully and become a very important technical measure for sustained high and stable yield of China petroleum (Wang *et al*., 2001; Sun, 2006; Jin *et al*., 2002). However, polymer will go along with water flooded layers with high permeability too early. Besides, now many polymer flooding oilfields in China have entered recovery time of water-cut and the effect of polymer flooding will decrease in ultra-high water cut stage (Ji *et al*., 2009). Therefore, how to improve the recovery further after polymer flooding has become a severe challenge.

In recent years, a new profile control and flooding agent “elastic microspheres” is invited and has received extensive concern (Zhao *et al*., 2005; Sun *et al*., 2006; Lei and Zheng, 2007). Elastic microspheres are spherical elastic bodies with three-dimensional cross-linked network structure and the design principle is that according to micro-scale feature of reservoir rock’s pore throats, elastic microspheres matching with pore throats were composed; using mechanism of "migration, sealing, elastic deformation and then migration, then blocking" in porous media of reservoir, elastic microspheres can plug and transport in high permeability layer constantly and enter the deep at last so as to increase swept volume of oil-rich region and enhance oil recovery. Studies show that elastic microspheres have advantages of higher resistance on temperature and salinity, stronger intensity of profile control, high resistance coefficient and residual resistance coefficient, lower cost and better applicability and so on. Besides, it has obtained better effect on profile control and flooding (Lei, 2011).

In this study, a novel enhanced oil recovery method using pore-scale elastic microspheres after polymer flooding was proposed. Using single-tube sand pack models, the resistant coefficient of polymer flooding and elastic microspheres profile control and flooding was contrastively studied. Then the resistant coefficient of injecting elastic microspheres after polymer flooding was studied. At last, physical simulation of elastic microspheres flooding after polymer was conducted.

MATERIALS AND METHODS

The materials used in this study include polymer (molecular weight: 22 million, degree of hydrolysis: 27%, provider: Tuode Science and Technology Co., Ltd., Dongying, Shandong, China), elastic microspheres

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(size: 10~60 μm, provider: China University of Petroleum (East China)), distilled water and sand (70~100 mesh) from Gudao in Shengli oilfield formation.

The main equipment used in this study are as follows: displacement pump (LP-20C, Beijing Satellite Manufacturing Factory); pressure sensor (Qingdao Keeasy Biotech Co., Ltd.); measuring cylinder and sand pack models ($\varphi = 2.8$ cm, $L = 35$ cm) packed with sand (70~100 mesh) from Gudao in Shengli Oilfield formation.

The resistant coefficient experiment process is as follows: firstly, the pressure (P_0) of injecting water was measure and the water was injected for 0.5 PV; then the polymer (1.5 PV) or elastic microspheres (2.0 PV) or polymer and elastic microspheres (1.0 PV and 2.0 PV) was injected; at last only water was injected for 1.0 PV and in the injecting process, the injecting pressure (P_i) was measured. The injection rate was 1.0 mL/min and the experimental temperature was 20°C. The resistant coefficient (F_r) can be obtained by equation:

$$F_r = (P_i - P_{out}) / (P_0 - P_{out}) \quad (1)$$

where,

P_{out} = The pressure of exit end

The physical simulation experiment process is as follows: firstly, the water was injected for 2.0 PV; then six injection programs were designed and they were:

- Injecting water for 1.5 PV
- Injecting polymer (1000 mg/L) for 1.5 PV
- Injecting polymer (2000 mg/L) for 1.5 PV
- Injecting polymer (500 mg/L) for 0.5 PV and elastic microspheres (1000 mg/L) for 1.0 PV
- Injecting polymer (500 mg/L) for 0.5 PV and elastic microspheres (2000 mg/L) for 1.0 PV
- Injecting polymer (1000 mg/L) for 0.5 PV and elastic microspheres (1000 mg/L) for 1.0 PV; at last only water was injected for 1.5 PV and in the flooding process, the oil volume displaced was measured. The injection rate was 1.0 mL/min and the experimental temperature was 20°C.

RESULTS AND DISCUSSION

Resistant coefficient of injecting polymer: In this experiment, the polymer concentrations were 500, 1000, 2000 mg/L, respectively and the permeability of sand packs was 1.72, 1.84, 1.65 μm^2, successively.

Figure 1 shows the resistant coefficient of injecting polymer. It can be seen that while injecting polymer, the resistant coefficient increases to a high level quickly; however, in succeeding water injection, the resistant coefficient decrease obviously; as the concentration of polymer injected increases, the maximum resistant coefficient increases too. The results indicate that polymer can plug large pores to force water up into the small pores and displace the

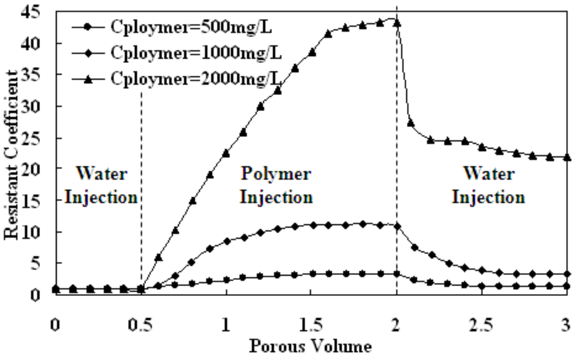

Fig. 1: The resistant coefficient of injecting polymer after water flooding

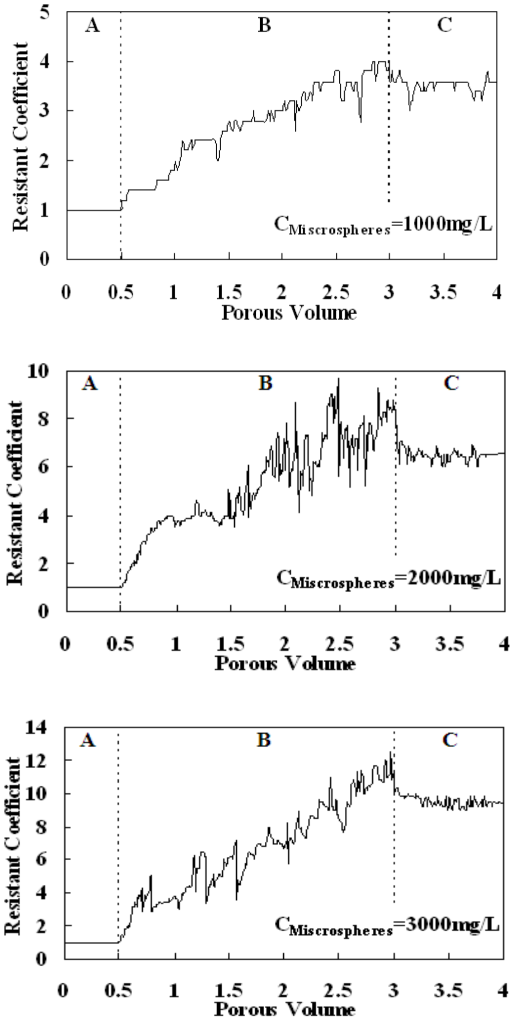

Fig. 2: The resistant coefficient of injecting microspheres after water flooding
A: Water injection; B: Elastic microspheres injection; C: Water injection

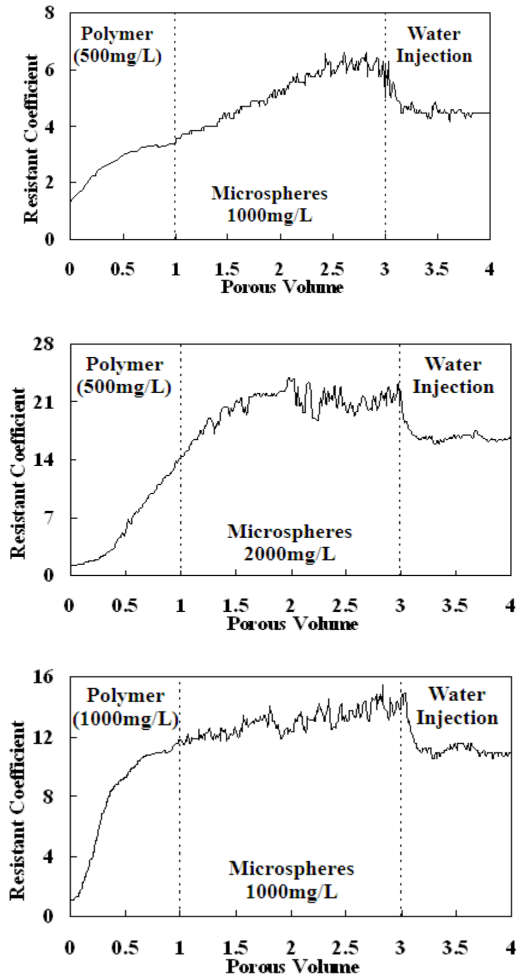

Fig. 3: The resistant coefficient of injecting polymer and elastic microspheres

residual oil. However, the plugging strength of polymer is lower, the polymer will go along with water flooded layers easily. Increasing the concentration of polymer can improve the displacement effect. However, exorbitant concentration will reduce the injectivity of polymer.

Resistant coefficient of injecting elastic microspheres: In this experiment, the elastic microspheres concentrations were 1000, 2000, 3000 mg/L, respectively and the permeability of sand packs was 1.85, 1.85, 1.71 μm^2 successively.

Figure 2 shows the resistant coefficient of injecting elastic microspheres. It can be seen that while injecting elastic microspheres, the resistant coefficient changes significantly and presents feature of “non-continuous wave-type variation”; while subsequence water flooding, the resistant coefficient keeps this characteristic with resistant factor over 3 times than before. As the concentration of elastic microspheres increases, the maximum resistant coefficient and residual resistant coefficient increase too. Compared with the resistant coefficient of polymer with same concentration, elastic microspheres shows better injectivity and migration ability. That is because elastic microspheres are spherical elastic bodies with better viscoelasticity and capacity of deformation migration.

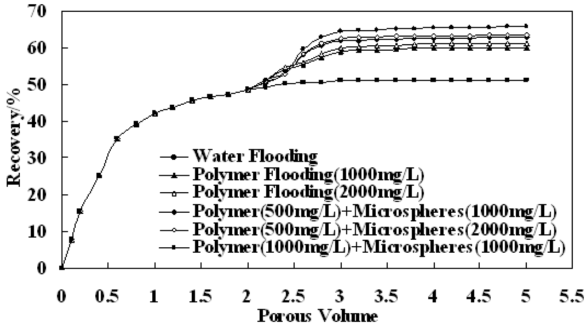

Fig. 4: The recovery of elastic microspheres flooding after polymer flooding

Resistant coefficient of injecting elastic microspheres after polymer flooding: In this experiment, three injection programs were designed and they were (a) polymer (500 mg/L, 1.0 PV) and elastic microspheres (1000 mg/L, 2.0 PV); (b) polymer (500 mg/L, 1.0 PV) and elastic microspheres (2000 mg/L, 2.0 PV); (c) polymer (1000 mg/L, 1.0 PV) and elastic microspheres (1000 mg/L, 2.0 PV). The permeability of sand packs was 1.77, 1.75, 1.71 μm^2 successively.

Figure 3 shows the resistant coefficient of injecting elastic microspheres after polymer flooding. It can be seen that the effect of injecting elastic microspheres after polymer flooding is better than injecting polymer or elastic microspheres independently.

The phenomena of ultra-resistant coefficient and difficult injection in experiment did not appear and resistant coefficient is in a state of constant fluctuation in the injecting process. The results indicate that polymer and elastic microspheres have synergistic effect. On the one hand, polymer with higher viscosity can carry elastic microspheres and polymer adsorption can reduce roughness of pore throats which make the migration of elastic microspheres easily; on the other hand, elastic microspheres has higher plugging strength so as to prevent polymer from crossing flow along the high permeability channel and extend the polymer output time of oil well.

Physical simulation of elastic microspheres flooding after polymer flooding: In this experiment, the permeability of sand packs was 1.78, 1.80, 1.75, 1.81, 1.85 1.82 μm^2 successively.

Figure 4 shows the recovery of elastic microspheres flooding after polymer flooding. It can be seen that compared to water flooding, polymer flooding (1000 mg/L) can enhance oil recovery by 9.0%;

polymer flooding (2000 mg/L) can enhance oil recovery by 10.2%; polymer (500 mg/L) and elastic microspheres (1000 mg/L) flooding can enhance oil recovery by 11.8%; polymer (500 mg/L) and elastic microspheres (2000 mg/L) flooding can enhance oil recovery by 12.5%; polymer (1000 mg/L) & elastic microspheres (1000 mg/L) flooding can enhance oil recovery by 14.6%; compared to polymer flooding (1000 mg/L) and (2000 mg/L), polymer (1000 mg/L) and elastic microspheres (1000 mg/L) flooding can enhance oil recovery by 5.6 and 4.4%. The results indicate that polymer and elastic microspheres coupling profile control and flooding can enhance oil recovery effectively.

CONCLUSION

In order to improve oil recovery further after polymer flooding, a novel enhanced oil recovery method using pore-scale elastic microspheres after polymer flooding was proposed. Polymer and elastic microspheres have synergistic effect. The polymer can make the migration of elastic microspheres easily; the elastic microspheres can prevent polymer from crossing flow along the high permeability channel and extend the polymer output time of oil well. Compared to polymer flooding (1000 mg/L) and (2000 mg/L), polymer (1000 mg/L) and elastic microspheres (1000 mg/L) flooding can enhance oil recovery by 5.6 and 4.4%. Polymer and elastic microspheres coupling profile control and flooding can enhance oil recovery effectively.

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