Application of Polymeric microspheres in extra low permeability reservoir in Huabei Oilfield

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Abstract: Aiming at the problems of low water displacement recovery effect in extra low permeability reservoir of Fault-block B10 in Huabei oilfield, the oil recovery technique of surfactant flooding under polymeric microspheres was proposed in this paper. According to the features of polymeric microspheres deep profile control technique, expansion, plugging capacity and migration ability of two samples were evaluated. On the basis of these, a polymeric microspheres matched with the B10 reservoir was selected and tested in the field. Field application indicated that average pressure elevation of each well was up to 4 MPa, corresponding wells efficiency were 88%, comprehensive water was decreased by 6.6% and cumulative incremental oil production was 3350t.

Fault block B10 in Huabei Oilfield had an average porosity of 17.6% and an average permeability of 3.5×10⁻³μm². It belonged to a low porosity ultra-low permeability reservoir. The surface crude oil viscosity was 90mPa.s, which belonged to ordinary heavy oil reservoir. Many years of water injection had formed a fixed water flow channel in the formation. The water injection wave and volume were not balanced, and the problem of inefficient or ineffective water injection circulation was becoming more and more prominent. At present, the comprehensive water cut had reached 90%. After surfactant flooding in some well groups, due to the serious heterogeneity of reservoir, displacement fingeri ng was obvious and the implementation effect was poor. As a new type of deep profile control and flooding agent, polymer microspheres can form step-by-step plugging after entering the low-permeability reservoir, and greatly adjust the water flooding flow field and expand the sweep volume [1]. In order to explore the adaptability of polymer microsphere to B10 reservoir, a polymer microsphere suitable for B10 reservoir was selected by static expansion of microsphere and dynamic physical model plugging experiment of core. Field application showed that the polymer microsphere had good adaptability in B10 fault block.

1. Plugging mechanism of polymer microspheres
At present, the commonly used profile control and driving microspheres are based on acrylamide and polymerized with other functional monomers. The spherical core is cross-linked polymer gel and the outer layer is hydration layer. After dispersing in water for a period of time, it is easy to occur
hydration expansion, showing the characteristics of rapid expansion in the initial stage and slow expansion in the later stage [2]. Due to its expansion characteristics, the viscosity of the microsphere solution is low and the injectability is good when it is injected into the formation. After entering the formation expansion, it will stay and accumulate in the matching channels, forming a plugging, and make the injection water flow to the low permeability layer. Because the expanded microsphere has certain elasticity, when it exceeds a certain pressure, the microsphere can deform and move to the depth of the formation to form plugging, so as to realize the gradual plugging control of the formation [3].

2. Experiment and discussion

2.1. Experimental equipment

Experimental instruments: la-950s2 laser particle size analyzer, antonpaar302 rheometer, constant temperature blast drying oven, CMW-Ⅲ long core physical model displacement device, Olympus Bx-41, etc. Experimental water: reinjection water in B10 combined station. Experimental drugs: polymer elastic microspheres A (particle size 0.5μm), B particle size (10μm).

Basic parameters of long core: 100cm × Φ3.8cm long cylindrical sand filled core, porosity of core 1 was 20.29%, water permeability was 17.5mD, porosity of core 2 was 17.11%, and water logging permeability was 13.1mD.

2.2. Experimental methods

2.2.1. Microsphere size test.

A certain amount of reinjection water was weighed, and the micro filter paper of negative pressure suction filter was used to filter the reinjection water to remove the suspended solids in the water. At the rotation speed of 400rpm, quantitative microsphere solution was dropped into the filtrate, stirred and dispersed evenly to prepare 3000mg/L water dispersion solution. The samples were put into sealed glass container and baked in 58℃ constant temperature drying oven. The samples were taken out at 1th day, 10th day and 20th day, and detected by laser particle size analyzer and microscope.

2.2.2. Microsphere plugging and migration performance test.

Ø 3.8cm × 100cm sand filling pipe model with three pressure measuring points (the entrance of the model was No.1 pressure measuring point, the middle part was No.2 pressure measuring point, and the tail end was No.3 pressure measuring point). The core was filled with 50, 120 and 200 mesh sand according to a certain proportion. The instrument was connected and vacuumized. The saturated water was saturated at the speed of 0.5ml/min until the pressure was stable, then continue to inject water to 2pv, and inject 3000mg/L microparticle with 1pv concentration of 1ml/min. The ball solution was placed at 58℃ for 10day, and water drive was carried out at the speed of 1ml/min. when the pressure was stable, the experiment was finished and the plugging rate was calculated. Among them, the porosity of II 1 andII 2 sand groups in B10 fault block was 15% ~ 20%, and the permeability was 0.05 ~ 18mD.

2.3. Experimental results and discussion

2.3.1. Swelling property analysis of polymer microspheres.

Firstly, the microscopic morphology of microsphere solution in different time periods was observed by microscope. The micro morphology of microspheres A and B was shown in Fig 1 and Fig 2.
It can be seen from Figure 1 that after 10 days of constant temperature storage, the particle size of microspheres A increases significantly, from the original small particles to regular spheres. After 20 days of constant temperature storage, the micro morphology of microspheres had no obvious change compared with that of 10 days.

It can be seen from Figure 2 that after 10 days of constant temperature storage, the appearance and particle size of microspheres had changed significantly, from the original dispersed small microspheres to irregular polyhedrons and gathered together. After 20 days of constant temperature storage, the micro morphology of microspheres was further increased compared with that of 10 days, and the morphology had no obvious change.

The laser particle size analyzer was used to scan the particle size distribution of the two kinds of microsphere solutions at different time periods. The change of particle size distribution was shown in Fig. 3 and Fig. 4.

It can be seen from Fig. 3 that after the microsphere A solution was placed at a constant temperature at 58 °C, the median particle size of the microspheres changes from 0.535 μm at 1d to 12.243 μm at 10d, and the particle size expanded by nearly 20 times. When the solution was kept at
20d, the median particle size changed to 13.554 μm, which had little change compared with that at 10d. The results showed that the diameter of microspheres was close to the maximum size after 10 days of expansion.

![Graph showing particle size distribution](image)

**Fig. 4 Change of particle size distribution of 3000mg / L microsphere B under constant temperature**

It can be seen from Fig. 4 that after the microsphere B solution was placed at a constant temperature at 58 ℃, the median particle size of the microspheres changed from 14.158 μm at 1d to 898.467 μm at 10d, the expansion was close to 60 times, and the frequency peak of particle size appeared double peaks, the distribution range of small value was 0.1 ~ 1 μm, and the distribution range of high value was 80 ~ 150 μm. The particle size difference was large, indicating that the microspheres were not uniform. In the experiment, clear stratification can be seen. The upper layer was clear liquid, and the lower layer was the emulsion of lamellar aggregate. After 20 days of storage, the median particle size changed to 906.328 μm, and there was only a single peak, indicating that the particle size distribution of the microspheres was relatively concentrated, and the median particle size did not change significantly compared with 10 days. The median pore diameter of B10 fault block reservoir was 0.389 μm. According to Koenig’s empirical formula, the expanded microsphere A and B were higher than the median pore size of the formation, which can seal the reservoir pores.

2.3.2 **Plugging effect analysis of polymer microsphere solution.** According to the plugging test method of microsphere solution, core 1 was used for microsphere A and core 2 was used for microsphere B. the plugging rate was calculated according to the data of each pressure measuring point. The calculation formula of plugging rate was follows:

\[ \eta = \frac{(K1-K2)}{K1} = 1-2P1/P2 \]

- K1: saturated water permeability, P1: saturated water pressure;
- K2: primary water drive permeability, P2: primary water drives pressure;

The pressure of each pressure measuring point varies with the injection multiple, as shown in Fig. 5 and Fig. 6.

![Graph showing pressure variation](image)

**Fig. 5 Variation curve of pressure at each pressure measuring point of No. 1 core with injection multiple**

As can be seen from Fig. 5, with the injection of microsphere A after the completion of saturated
water, the pressure at No. 1 point risen slowly. When the injection amount of microsphere approaches 0.4pv, the pressure rises rapidly; this indicated that with the accumulation of microsphere at the inlet end, effective plugging gradually forms. When the microsphere continues to inject, the pressure continued to rise. When the microsphere plugging pressure was exceeded, the microsphere broke through the pore and migrated to the deep core, and No. 2 and No. 3 moved the pressure at the pressure measuring point began to rise and the pressure at the inlet end began to decrease. When the new plugging was formed again, the inlet pressure starts to rise again, and the microsphere goes through the process of plugging, breakthrough, deepening and replugging in the core pores, and the inlet pressure rose and fallen in a wavy manner [4] [5]. After 10 days of constant temperature water flooding, the initial water injection pressure was high. With the water driven microspheres continue to migrate to the deep core, the water injection pressure at the inlet end decreases slowly, and the pressure at No.2 and No.3 positions risen slowly. When the injection quantity of primary water drive reached 1.2pv, the pressure of each pressure measuring point basically kept constant. According to the change of water injection pressure at each pressure measuring point, the plugging rate of microsphere A at pressure measuring point 1 was 82.45%, that at pressure measuring point 2 was 60.75%, that at pressure measuring point 3 was 51.52%, and that to core 1 was 86.58%.

As can be seen from Figure 6, with the injection of microsphere B after the completion of saturated water, the pressure at No. 1 pressure measuring point risen rapidly, which indicated that the sealing of microsphere B was formed quickly at the inlet end, and the pressure measuring point 2 risen slowly at first, and basically remains unchanged after the injection amount of microspheres reached 0.3pv, indicating that there were few microspheres migrating to pressure measuring point 2. The pressure of No.1 pressure measuring point kept rising during the injection process, indicating that the microspheres were basically blocked at the inlet. After the first water flooding, the pressure of No.1 pressure measuring point began to drop slowly, the pressure curve showed wave like advance, and the pressure of pressure measuring point 2 slowly increased, which indicated that microsphere B began to migrate to the core depth under the action of water drive. After the primary water drive volume reaches 1pv, the pressure at each pressure measuring point was basically stable, the pressure at No. 1 pressure measuring point was always kept at a large value, and the pressure at No. 3 pressure measuring point had no obvious change in the whole process, indicating that microsphere B had not effectively blocked the position of pressure measuring point 3 [6]. According to the change of water injection pressure at each pressure measuring point, the plugging rate of microsphere B at pressure measuring point 1 was 91.89%, that at pressure measuring point 2 was 38.45%, that at pressure measuring point 3 was 0, and that to core 2 was 95.04%.

Comparing the pressure changes of two cores and the plugging rate of each pressure measuring point, the overall plugging effect and deep migration performance of microsphere A were better than those of microsphere B under the condition of approaching the reservoir of B10 fault block. It was recommended that microsphere A was used for field profile control and displacement of B10 fault block.
3. Field application

3.1. Overview of the test area
Three well groups (b10-1, b10-14 and b10-8x) in the middle of B10 fault block were selected for the test. The oil-bearing area was controlled to be 0.37km³, the cumulative recovery degree was 17.38%, and the comprehensive water cut was as high as 92.52%.

3.2. Site implementation process
Three slugs were designed to inject. The first slug was mainly used for the displacement of residual oil in the main channel, and 20000 mg/L oil displacement surfactant was injected into the second slug. The main purpose of the second slug was profile control and plugging, and 3000mg/L polymer microspheres were injected to block the large pores and expand the sweep efficiency. The third slug was mainly used for oil displacement, and 5000mg/L high-efficiency viscosity reducing surfactant was injected to improve the crude oil fluidity. The construction was carried out in March 2018 and the expected design objectives were achieved. The construction design data of each well group were shown in Table 1.

| Well group | 1st slug | 2nd slug | 3rd slug |
|------------|----------|----------|----------|
|            | Daily     | Stage     | Daily     | Stage     | Daily     | Stage     |
|            | injection | injection | injection | injection | injection | injection |
|            | m³/d      | m³        | m³/d      | m³        | m³/d      | m³        |
| B10-1      | 50        | 800       | 45        | 5500      | 50        | 5000      |
| B10-14     | 40        | 1000      | 30        | 6000      | 40        | 6500      |
| B10-8X     | 50        | 1000      | 40        | 6300      | 50        | 6000      |
| Total      | 2800      | 17800     | 17500     |           |           |           |

3.3. Test effect
After microsphere flooding, the average pressure of three profile control wells increased by 4MPa before and after microsphere injection, corresponding to 9 oil wells, 8 wells achieved results, and the main oil increase stage was the third slug injection stage and even the subsequent water drive stage. Before the effect of 8 effective wells, the daily liquid production was 150 tons, and the daily oil production was 10.5 tons. After the effect, the daily liquid production was 154.3 tons and the daily oil production was 20.98 tons. The comprehensive water cut decreased by 6.6%. According to the law of oil well production decline, by October 2019, a total of 3350 tons of crude oil will be increased.

4. Conclusion
i. Under the same hydration conditions, the swelling properties and aggregation morphology of different microspheres were different.
   ii. For B10 low porosity and ultra-low permeability reservoir, the initial particle size was about 0.5 μm, and the particle size after hydration expansion was about 10 μm. Polymer microspheres had good plugging and profile control effect. The particle size of microspheres was too large, which was not conducive to the injection and deep migration of microspheres.
   iii. The development effect of B10 fault block had been further improved through surfactant microsphere profile control and flooding. The water cut and oil increase effect of the reservoir showed that surfactant microsphere profile control and flooding was feasible in B10 fault block.

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