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RESEARCH PAPER

Deep profile adjustment and oil displacement sweep control technique for abnormally high temperature and high salinity reservoirs

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Abstract: To improve water flooding sweeping efficiency and oil displacement efficiency in reservoirs with abnormally high temperature and high salinity during late development stage, taking Gasikule $E_3{}^1$ reservoir as the research object, lab study and field test of sweep control technique (SCT) were conducted. Performance evaluation and field test results of soft microgel (SMG) agent show that: SCT has good thermal stability in the target reservoir and an effective period of 100–120 d in the field test, and the success rate of SCT can be greatly increased by adjusting particle size and concentration of the gel. Unlike polymer flooding or polymer-gel flooding which improves oil recovery by enhancing sweep efficiency, SCT can improve oil displacement and water sweep efficiency, and its displacement mechanisms have been confirmed by the lab experiment and field test. The SCT has been applied in six well groups in the target reservoir, resulting in a cumulative oil increment of 1.03×10^4 tons, water production drop of 4.79×10^4 m^3, and an input-output ratio of 1:2.09. But when international oil price is low, SCT project may have high failure risk in application to reservoirs with abnormally high temperature and high salinity.

Key words: high temperature high salinity reservoir; soft microgel; sweep control technology; deep profile control; oil displacement mechanism; economic benefit

Introduction

In the late waterflooding development stage of heterogeneous reservoirs, due to heterogeneity and various development factors, more scattered and complicated in distribution, the remaining oil is mostly left in low permeability zones unswept by water and microscopic pores or throats[1–7]. Although polymer flooding and polymer gel flooding can achieve effective sweep control and enhance oil recovery, they had shortcomings in field test like poor thermal stability of polymer in high temperature and high salinity environment, and formation damage of polymer gel to non-target layers[8–14]. Wu Xingcai proposed a new improved oil recovery (IOR) method, Sweep Control Technology (SCT)[15], different from conventional polymer flooding or polymer gel flooding in IOR/EOR mechanism which enhance oil recovery mainly by enlarging sweep volume, in SCT, a new high temperature and salinity resistant soft micorgel (SMG) is injected into the deep zones of reservoir to improve sweep factor and oil displacement efficiency[15–17]. Since 2010, the SCT has been field tested and applied in many medium to high temperature, high salinity oil reservoirs in the Liaohe, Dagong and Huabei oilfields, ect, and achieved satisfactory results [15, 18, 19].

In this study, the SCT field test in the $E_3{}^1$ block in Gasikule oilfield with abnormally high temperature (126 °C) and high salinity ($17–18\times10^4$ mg/L, Ca^{2+} and Mg^{2+} concentration 2 350 mg/L) has been investigated, to get a better understanding on its IOR mechanisms.

1. Properties evaluation for SMG

1.1. Size distribution and expansion property

Filtered formation water was used to prepare SMG solution at a concentration of 5 000 mg/L, which was then put into an oven at a constant temperature of 126 °C for 15 days. The particle size of the solution was measured by laser particle

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size analyzer (SYMPATEC GmbH, Germany) to analyze SMG's hydration expansion property.

The initial particle size of micrometer SMG is 1–30 μm, with a median diameter of 6.24 μm. After expanding in formation water for 15 days, the particle size reaches 10–200 m, with a median diameter of 69.02 μm, 8–10 times the original size, which indicates under reservoir condition of high temperature and high salinity, the SMG has good expansion property (Figs. 1 and 2).

1.2. Blocking performance

Two sand-packed pipes 50 cm long and 2.5 cm in diameter with a permeability of 2 720×10^{-3} μm^2 and 870×10^{-3} μm^2 respectively were used to evaluate blocking performance. SMG solution of different pore volume multiple at a concentration of 5 000 mg/L was injected into the two pipes at 0.5 mL/min, and the changes in resistance factor was observed to evaluate the blocking performance and injectivity of SMG.

The test results show that the SMG solution had good blocking performance in both high permeability and low permeability sand-packed pipes. After 1.3 PV SMG was injected into the high permeability sand-packed pipe, the resistant factor reached 8.5, and was around 6 in the follow-up water flooding process. After 0.4 PV SMG was injected into the low permeability sand-packed pipe, the resistant factor reached 10, and was 12 in later waterflooding. During the injection of SMG into the high permeability sand-packed pipe, resistant factor increased gradually with the increase of pore volume injected (Fig. 3a), which indicates SMG was migrating into the deep zone of the high permeability sand-packed pipe to realize blocking. For the low permeability sand-packed pipe, due to small pore throat radius, SMG achieved blocking more easily, after a small amount of SMG was injected, resistant factor increased rapidly, then reached a relatively stable value between 6 to 11 (Fig. 3b), and the resistant factor in the follow-up water flooding process was also quite ideal. This shows that SMG has good injectivity and conformance control capacity.

1.3. Oil displacement efficiency

Single pipe and dual-pipe parallel sand-packed models were used to evaluate displacement efficiency of micrometer SMG.

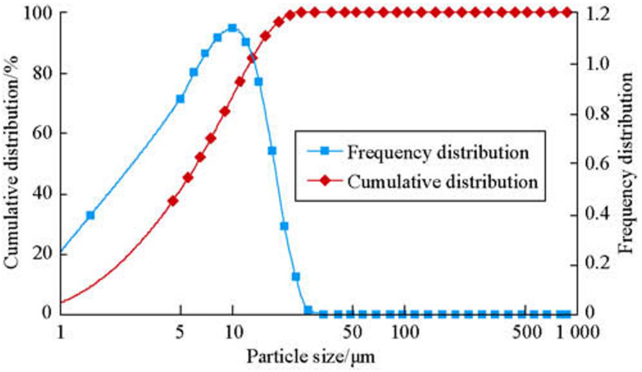

Fig. 1. Initial particle size distribution of micrometer SMG before hydration expansion.

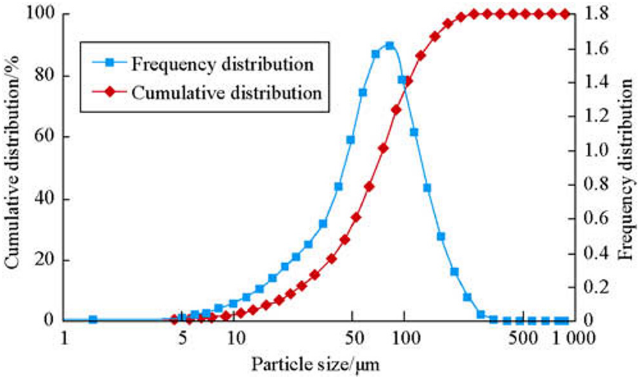

Fig. 2. Particle size distribution of micrometer SMG after hydration expansion for 15 days.

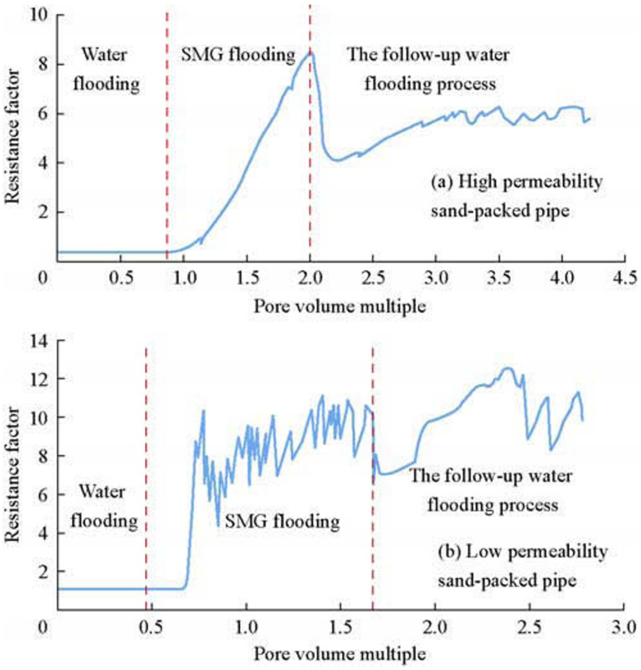

Fig. 3. Resistant factor vs. PV injected.

The models were vacuumed for six hours and saturated with filtered formation water, and the porosity and water permeability were measured. Afterwards, the sand-packed models were saturated with diluted formation oil, and the initial oil saturation was calculated by recording water produced. The sand-packed models were flooded by filtered formation water till the water cut at the outlet reached 98%, and oil recovery of water flooding of each model was calculated. Then, micrometer SMG solution (5 000 mg/L) was injected into the sand-packed models, and the models were put into an oven at a constant temperature of 126 °C for 15 days. Then water flooding was followed after SMG's hydration expansion. The experimental results are listed in Table 1. The single-pipe and the parallel dual-pipe physical simulation model are both 50.0 cm long and 2.5 cm in diameter.

For the dual-pipe parallel model, the water flooding oil recovery of low permeability pipe was 23.87%, lower than that of high permeability pipe. After being injected into the parallel model, SMG solution entered the high permeability pipe first. With the increase of SMG solution in the high