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Evaluation of the performance of polymer gels mixed with asphalt particle as a novel composite profile control system

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ABSTRACT

This paper presents gels with asphalt particle (GAP) as a novel composite profile control system, which has better sealing effect for plugging channeling in fractured reservoir. This composite agent was prepared by modified asphalt particle and polymer gels served as suspension. Laboratory core–flood tests showed good injectiviy of GAP solution in high permeability zone with a high plugging rate. Also, the enhance oil recovery mechanism of GAP and polymer gels in fractured reservoir were compared by parallel core–flood test. Simulation results indicate longer response time and better enhance oil recovery for GAP than polymer gels in fractured system.

Introduction

Channeling is one of the major problems for water flooding and even polymer flooding reservoir in high water cut stage. With long terms of water flooding and application of fracturing or acidizing, the in-layer or interlayer heterogeneity of reservoirs is obviously intensified [1–3]. This often results in low displacement efficiency and sometimes makes water or polymer flooding project uneconomical [4]. Many profile control agents have been developed to solve channeling problems in deep formation, including inorganic solid particles (such as cement, clay), organic materials (such as polymer gels, volume expansion particle, starch), and newly developed nanomaterials [5–9]. However, field implementation of profile control projects in Fuyu oilfield indicates that gels treatment and mechanical particles plugging in natural fractured reservoir is less efficient [10–14]. Because of little bonding properties between volume expansion particles, mechanical particles have poor resistance to water flooding. Also, the response time of treatment by polymer gels is short because of polymer degradation and low plugging strength [15].

GAP (polymer gels mixed with asphalt particle system) is a newly proposed composite profile control system. Cross-linked polymer gels are used as the suspension, carrying asphalt particles deep into the formation. The role of GAP treatment mainly lies in two aspects. On one hand, mechanical blockage formed in high permeability zone by polymer gels and asphalt particle. One the other hand, asphalt particle cohered together to the fracture wall under reservoir temperature (>40 °C), achieving high sealing strength. Also, GAP solution has strong thermal stability and salt resistance ability, which is suitable for different salinity reservoir. The GAP solutions are generally combination of asphalt particle with size of 0.02–0.1 mm, 0.05–0.2% HPAM and 0.02–0.1% organic chromium cross-linker to fit different sizes of large pores or cracks.

Detailed adaptability study was carried out by a series of cores flooding. The objectives of this work are: (1) to determine the injectivity of this composite profile control system, (2) to examine the plugging performance of GAP solution, (3) to compare the enhanced oil recovery abilities with polymer gels in fractured formation.

Experimental studies

Material descriptions

All of the polymer gels used in this experiment were prepared by 0.1% HPAM and 0.05% organic chromium cross-linker (both made by ZYTK Company, China).The polymer solution was first

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prepared by dissolving the HPAM (average molecular weight of 17×10^6 Da) in distilled water using an electric stirrer for 6 h at room temperature. Then the organic chromium cross-linker was added and let stand for three days. The GAP solution was prepared by mixing asphalt particles into polymer gels using an electric stirrer for 10 min. The asphalt particles were also obtained from ZYTK Company, China, with size of 0.02 mm, 0.04 mm and 0.06 mm, respectively.

A total 16 artificial cores and 4 natural fractured cores with dimensions of 8 cm in length and 2.5 cm in diameter were used for core flood test. The artificial cores were made of epoxy resin and silica-sand, which will not react with injected fluids. The parameters of the cores were designed according to the rock properties of Fuyu oilfield. The average porosity was 0.22 and the permeability was ranging from 145 mD to 4350 mD. Four natural fractured cores from Fuyu oilfield were used to evaluate the plugging and recovery mechanism of GAP solution.

Thermostat was used to give an experiment environment similar to the real reservoir. The liquid collector is a metering tub with range from 0.0 mL to 5 mL. Besides, the nuclear magnetic resonance (NMR) detector was used to investigate oil production in pore scale. And its radio-frequency power is 300 W, the frequency is 1–40 MHz, dynamic range of radio-frequency receiver is 1–96 DB. The core to be analyzed is put into the NMR detector to collect signal after taken from core holder during flooding. Because NMR can detect hydrogen signal from both water and crude oil, fluorine oil (Type: 4380, made by SINOPEC Lubricants Company, with viscosity of 8 mPa s at 40 °C) was used in parallel core flood test, thus the signal is only from water [16,17]. In this way, we can differentiate distribution of the two liquid easily.

Experimental apparatus and procedure

Singular core–flood test

The singular core–flood tests were performed to examine the efficiency of the profile control system in plugging porous media by measuring the change in the water flooding permeability before and after injection of polymer gels with asphalt particle.

The water permeability of the sand-pack is calculated using Darcy's law [18]:

$$K = \frac{\mu LQ}{\Delta PA} \quad (1)$$

where μ is the viscosity of the fluid, A is the area of cross section of the column, Q is the flow rate of the fluid, ΔP is the differential pressure, and L is the length of the column.

Plugging performance of the profile control system was characterized by the plugging rate (that is permeability reduction), which is calculated using the following equation:

$$\eta = \frac{K_i - K_f}{K_i} \times 100\% \quad (2)$$

where K_i is water permeability before polymer flooding and K_f is water permeability after polymer flooding.

Fig. 1 shows a scheme of the core–flooding system used in this study. The following steps were applied:

(1) The core is put into core holder to be flooded by water for 30 min at the rate of 0.5 mL/min. Thus, permeability based on water-measured can be obtained.
(2) After that, 0.3 PV (pore volume) GAP solution was injected at the same flow rate. The pressure during injection was monitored.
(3) Stopping the flooding and shutting off the valves. And the core was maintained at 40 °C for about 48 h.
(4) Subsequent water flooding was performed until the pressure drop was stable again. The permeability was measured in the subsequent water flooding for the second time.

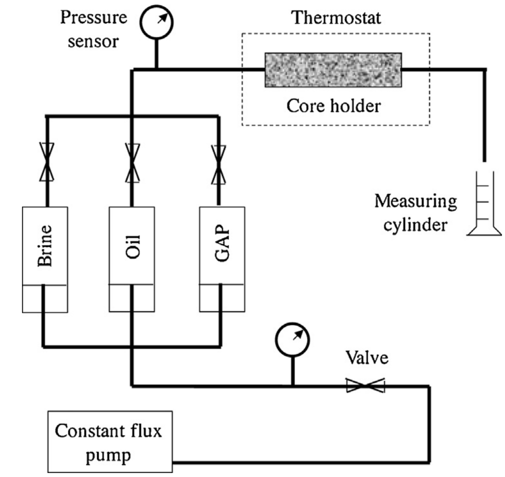

Fig. 1. Schematic diagram of the core flooding system.

Parallel core–flood test

Moreover, the parallel core–flood test was conducted to simulate the profile modification and recovery mechanism of GAP solution in a fractured formation. Comparison of the effects of GAP with polymer gels on enhance oil recovery were measured. The experimental procedure is described briefly as shown in Fig. 2. After being vacuumed, the cores were saturated first with brine and then with fluorine oil. A typical three-stage core–flood test was performed in the sequence of conventional water flooding, GAP/Gels injection, and subsequent water flooding.

Results and discussion

Injectivity of GAP solution

Injectivity test is an important part to evaluate the performance of a profile control agent. The injection pressure of the polymer gels with asphalt particle (0.04 mm, 2000 mg/L) system were measured in cores of different permeability under the injection rate of 0.5 mL/min. As shown in Fig. 3, the injection pressure increases significantly with the decrease of core permeability. For cores of permeability higher than 747 mD, the curves of injection pressure increase slowly and maintain stable at late time of injection, which indicate a good injectivity. While for the core with permeability of 145 mD, the injection pressure goes up quickly. This indicates the GAP solution is restricted in flowing into low permeability formation.

The size of asphalt particle is also an important factor affecting the injectivity of GAP solution. The injection pressure curves for GAP solution with different size of asphalt particle (2000 mg/L) are shown in Fig. 4 (permeability of the three cores are 1210 mD, 1352 mD and 1447 mD, respectively). Result shows GAP solution

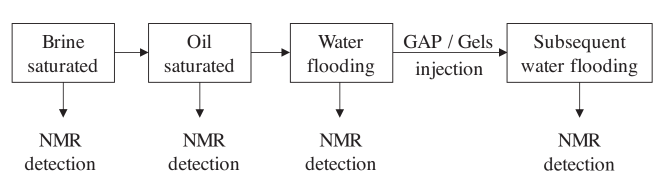

Fig. 2. Flooding procedure of the parallel core flood test.