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Visualized study of thermochemistry assisted steam flooding to improve oil recovery in heavy oil reservoir with glass micromodels

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ABSTRACT

Steam channeling, one serious problem in the process of steam flooding in heavy oil reservoir, decreases the sweep efficiency of steam to cause a lower oil recovery. Viscosity reducer and nitrogen foam, two effective methods to improve oil recovery with different mechanism, present a satisfactory result after steam flooding. In this article, a 2D visualized device was introduced to investigate the synergistic development effect of two different chemical additives and intuitively study their flowing characteristic in porous media, as well as macroscopic and microscopic mechanism of improving heavy oil recovery by chemical additives after steam flooding. The results showed that the fingering phenomenon was generated obviously in the process of steam flooding, which restricted the swept area of steam. Due to decreasing oil-water interface tension, O/W emulsion with lower viscosity was formed to enhance the oil flow capacity and polish up the displacement efficiency of steam after injecting viscosity reducer. And the synergistic effect of viscosity reducer & foaming agent was more conductive to improve displacement efficiency of steam, with 4.3% of oil recovery higher than purely viscosity reducer assisting steam flooding in this process. Microscopic results indicated that thermal foams can be trapped in the porous media to improve injection profile effectively and displace the residual oil caused by steam flooding. The ultimate oil recovery of synergistic development is 65.6%, 11.0% higher than one additive (viscosity reducer). This article can provide reference for the study of thermochemistry assisted steam flooding in heavy oil reservoir.

1. Introduction

Recently, with the gradual depletion of conventional oil, the exploitation of unconventional crude oil has attracted much attention, and heavy oil, as a kind of important energy, accounts for a large proportion of oil and gas resources in the world [1–3]. However, with the remarkable characteristic of high viscosity, high density and low mobility, it is quite difficult to produce heavy oil economically efficient using conventional techniques [4–7]. In general, cyclic steam stimulation and steam flooding play a vital role in developing these resources at home and abroad, and steam flooding is an effective measure to improve oil recovery in the late period of steam huff and puff [8–11]. Also, SAGD is another attractive methods for heavy oil or oil-sands [12]. Unfortunately, due to the large difference of oil-water viscosity, the phenomenon of fingering is serious in the process of steam flooding, which forms preferential channeling passage and leads to the lower oil and gas ratio and limited swept area [13–14]. Nowadays, many experts had carried out plenty of investigations on how to improve heavy oil recovery.

Obviously, viscosity reducer is a good choice to reduce the viscosity and improve the mobility of heavy oil. Cash et al. [15] found that viscosity reducer had a strong capacity for reducing viscosity by changing viscous oil or water/oil emulsions into oil/water emulsions of which the viscosity is close to that of water. Yaghi [16] had presented in 2002 that the formation of the emulsions by the use of viscosity reducer forming an oil-in-water (O/W) emulsion could reduce the apparent viscosity. Ezeuko et al. [17] delivered that emulsion was a colloidal system of immiscible fluids, with one fluid as the dispersed phase (usually micrometer-sized drops) and the other as the continuous (non-dispersed) phase. Lu C et al. [18] studied the effects of viscosity-reducer (VR) concentration, salinity, water/oil ratio (WOR), and temperature on the performance of emulsions and found that high VR concentration, high WOR, and low salinity are beneficial to form stable oil/water emulsions and VR solution is beneficial for the oil dispersion and further viscosity reduction.

Steam override and steam channeling, two other significant

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problems which probably decrease the sweep efficiency of steam, could reduce the oil recovery in heavy oil reservoirs [19–20]. The use of foams to improve the mobility ratios of oil displacing agents arose from laboratory work in the 1950′s and 1960′s. In 1968, L.W. [21]described the mechanisms by which foams move through porous media. Friedmann F et al. [22,23] investigated the high-temperature surfactant foams by modifying gas-phase mobility in conventional thermal simulator and studied foam generation by leave-behind and snap-off as well as foam coalescence and trapping mechanism.

Pang [24] found that thermal foam flooding, an effective EOR method, presented a satisfactory and efficient production in laboratory and field pilot, because thermal foams could restrain steam injection from gravity override and steam channeling in reservoirs and foaming agent was an vital component of decreasing oil-water interface tension and increasing the stability of foam in thermal foam flooding. Furthermore, Zhang [25] selected N_2 and CO_2 as noncondensing gas injected respectively with self-produced foaming agent system called DQS and found two noncondensing gas could improve oil displacement efficiency greatly and CO_2 was the better choice compared with N_2 to be injected with DQS. And nitrogen-assisted CSS had been conducted in the Henan oil field, China, and achieved good results.

Although both viscosity reducer and foams can improve heavy oil recovery to some extent and attract more and more attention, to our knowledge, very little information is provided in the literature on the research of viscosity reducer and foams utilized together. In this paper, the objectives were to investigate the interact relations between different kinds of chemical agents and identify which developing method was suitable for field pilots. So, a two-dimensional visualization device with high temperature and high pressure was used to study the process of steam flooding development in heavy oil reservoir with different chemical agents, including viscosity reducer and foam agents. And the mechanism of different methods improving developing effects of steam flooding was discussed from macroscopic and microscopic phenomena.

2. Experimental apparatus and procedure

2.1. Materials

In this experiment, square quartz glasses with holes on four corners could withstand high temperature and high pressure. The thickness of the sand layer was determined by the mesh size of the glass bead. In this study, the glass bead with 420 μm (40 mesh) diameter was used to form unconsolidated transparent porous media as shown in Fig. 1. The stock tank oil obtained from Biqian10 area in Henan oil reservoir had a viscosity of 1250 mPa·s at 60 °C and a density of 0.951 g/cm^3 at 25 °C. The viscosity-temperature relationship curve of crude oil was shown in Fig. 2. Two kind of fluids used in this set of experiments were distilled water used to generate steam and brine with 5000 ppm of NaCl used to saturate the model. Industrial-grade nitrogen was used as gas with the purity of 99.99%. And a kind of hydrophilic VR called AE-121 and one foam agent called ADC were selected due to the best application effects in the field. For all processes in this study, the concentration of the injected VR and foam agent solution was kept at 0.5% by volume.

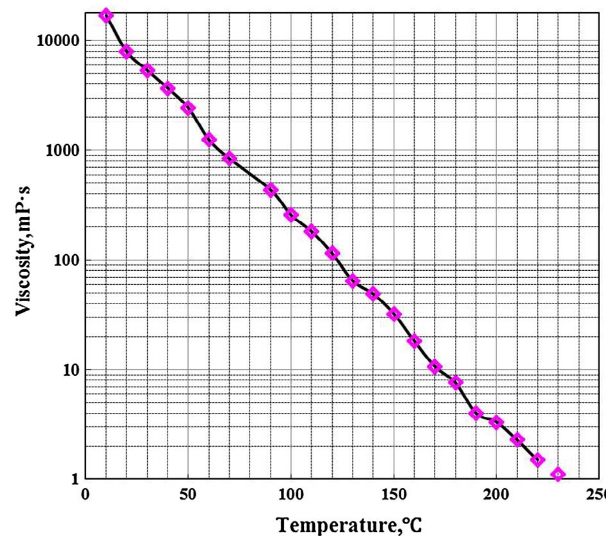
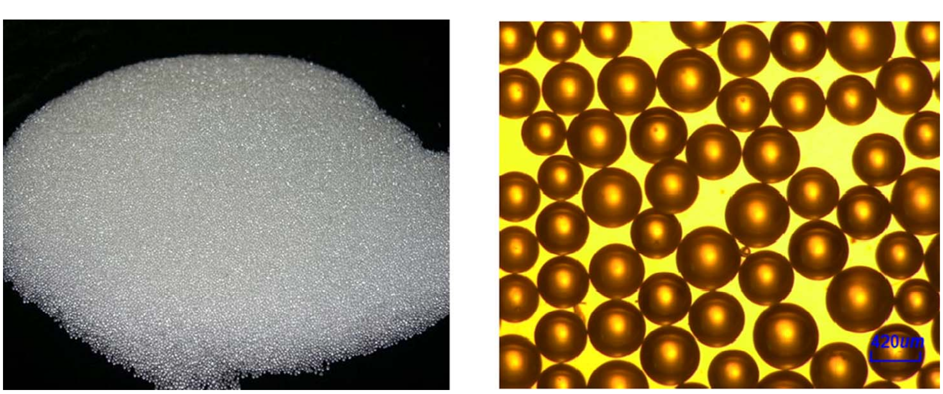


Fig. 2. Viscosity-temperature relationship curve of crude oil.

2.2. Experimental setup

The schematic diagram of the experimental setup was shown in Fig. 3. The whole equipment can be divided into three subsystems: fluid-supply system, 2D visualized displacement system, and data-acquisition system. The 2D visualized model contained two pieces of quartz glass plates and two layers of glass beads. The dimensions of the quartz glass plate with a good transparency were 250 mm × 250 mm × 30 mm, and it can endure the maximum pressure at 3 MPa and the highest temperature at 280 °C, as shown in Fig. 4. While the actual visual area is 200 mm × 200 mm, and the margin is sealed by high temperature resistant glass cement. The glass bead with 420 μm (40 mesh) diameter was used to form the effective thickness is 840 μm. Canon EOS70D digital camera and Sweden Optilia optical microscope (the largest magnification is 150 times) were installed above the model to observe the macroscopic and microscopic flow characteristics in the model. A plane light source was mounted under the model to make images much clearer. High temperature steam was generated by a steam generator which was able to produce a maximum of 300 °C steam. ISCO micro-gear pump was used to inject different fluids stored in different intermediate vessel into the visualized model.



(a) original glass beads (b) glass beads under microscope

Fig. 1. Glass beads used in this experiment.