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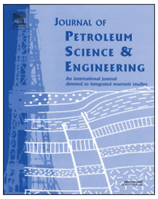

The study on permeability reduction performance of a hyperbranched polymer in high permeability porous medium

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ABSTRACT

This paper was focused on the permeability reduction performance of a hyperbranched polymer in high permeability porous medium. Water solubility, rheological property, viscoelasticity, and filtration experiments were adopted for investigating the solubility and injectivity of the hyperbranched polymer. Atomic force microscope (AFM), scanning electron microscope (SEM), and shear experiments were conducted for studying the microscopic structure, adsorption behavior, and shear resistance, respectively. Besides, resistance factor (RF), residual resistance factor (RRF), and displacement experiments were adopted for investigating the permeability reduction performance and enhanced oil recovery (EOR) ability of the hyperbranched polymer. It was found that the hyperbranched polymer exhibited acceptable water solubility, remarkable shear resistance, perfect permeability reduction and EOR ability. It was also found that the hyperbranched polymer owned higher apparent viscosity, viscosity retention rate, and adsorption retention due to the special network structure of polymer molecular chain.

1. Introduction

In the process of water flooding, the injected water may flow along the high permeability zone due to heterogeneity, oil–water viscosity differences, and irrational injection-production rate, etc. (Mungan et al., 1966; Hou et al., 2011; Yuan and Shapiro, 2011). Polymer flooding as an important technique for enhanced oil recovery (EOR), can significantly reduce the permeability of high permeability zone, improve unreasonable mobility ratio, expand sweep volume of injected water, and eventually enhance oil recovery (Romero-Zerón et al., 2009; Wang and Dong, 2009).

At present, linear polymer partially hydrolyzed polyacrylamide (HPAM) is widely used to reduce the permeability of the high permeability zone, while the effectiveness of the linear polymer in high permeability porous medium is worthy of further enhancement (Mungan et al., 1966; Rho et al., 1996; Hou et al., 2011). One of the commonest methods is using a linear polymer with higher molecular weight. However, the high molecular weight linear polymer exhibits poor shear resistance (Rho et al., 1996; Xue et al., 2005; Ye et al., 2013; Zhang et al., 2013). The apparent viscosity and the adsorptive capacity may greatly reduce when this linear polymer passes through the perforation and the immediate vicinity of wellbore at high velocity (Ye et al., 2013; Zhang et al., 2013). As a result, the permeability reduction ability of the high molecular weight linear polymer is greatly reduced.

Compared with the linear polymer, the hyperbranched polymer with unique structure have been reported widely in many applied fields, such as medicine, food, environmental protection, cosmetics and dye industry (Achilleos et al., 2006; Adkins and Harth, 2008; Xu et al., 2008; Voit and Lederer, 2009; Schwenke et al., 2011). Although there are no reports about the application of the hyperbranched polymer in polymer flooding, we believe it has great potential in EOR.

2. Experiment

2.1. Materials

HPAM (degree of hydrolysis: 25%, viscosity molecular weight: 22×10^6; about 3500 dollars per ton) and the hyperbranched polymer (degree of hydrolysis: 22%, viscosity molecular weight: 15×10^6; about 3800 dollars per ton; see Fig. 1; Shi et al., 2012) were purchased from Sichuan Guangya Polytron Technologies Inc. Sodium chloride (NaCl), magnesium chloride hexahydrate ($MgCl_2 \cdot 6H_2O$), calcium chloride anhydrous ($CaCl_2$), potassium chloride, sodium sulfate, sodium carbonate, and sodium bicarbonate were analytical reagent. Water was doubly distilled and deionized

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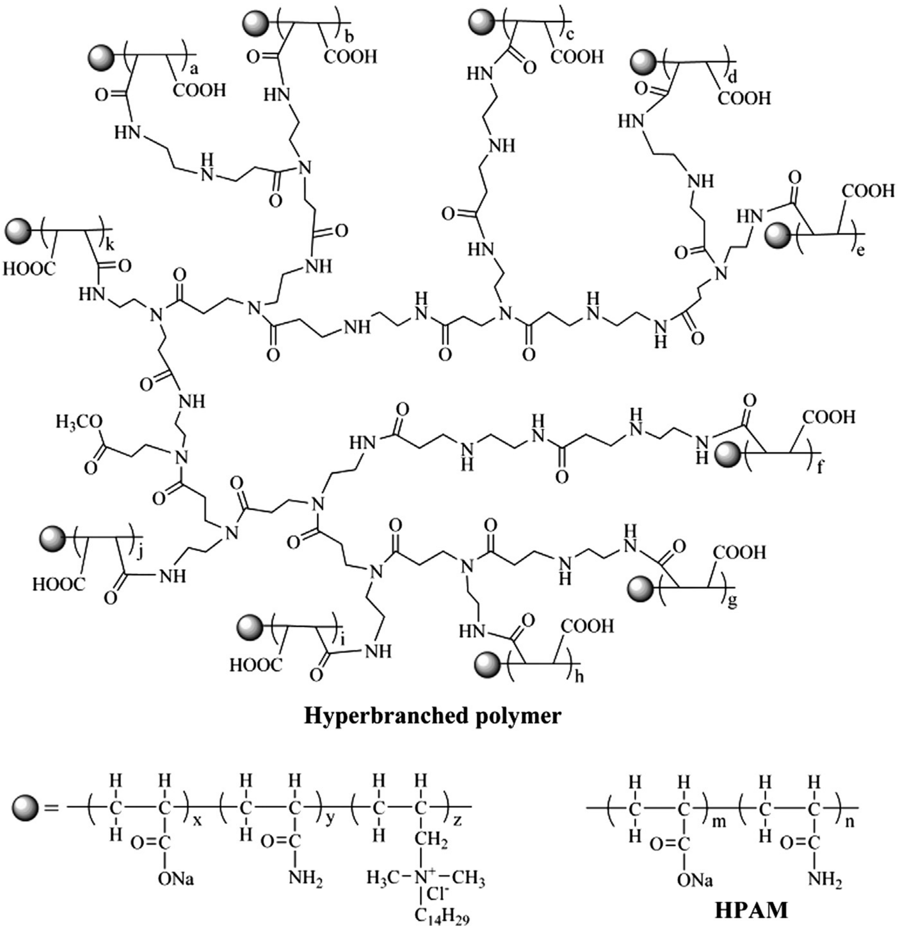

Fig.1. The structure of the hyperbranched polymer and HPAM.

Table 1
The ionic composition of the brine.

Ionic composition	Na^+, K^+	Ca^{2+}	Mg^{2+}	$CO_3{}^{2-}$	$HCO_3{}^-$	$SO_4{}^{2-}$	Cl^-
Content (mg/L)	3092.0	276.2	158.7	14.2	311.5	85.3	5436.3

by passing through an ion-exchange column. The rock used for drilling out cores was sandstone. The ionic composition of brine was shown in Table 1.

2.2. Microscopic structure

The microstructures of the hyperbranched polymer solution and HPAM solution were observed through an atomic force microscope (AFM) at room temperature and atmospheric pressure. A single crystal quartz probe was used in the experiment, and the length of micro cantilever was 100 μm, while the force constant was 0.12 N/m (Roiter and Minko, 2005; Zhang et al., 2005). Images were gotten in constant force mode. The experiment methods were as follows:

1. Preparation of polymer solution samples: the polymer solutions (500 mg/L) were prepared with the distilled water, and then these solutions were sheared by Waring Commercial Laboratory Blender for 60 s at 11,000 r/min shear rate.
2. Preparation of sheet mica absorbed polymer: the fresh cleavage sheet mica was put into the samples for 2 h in order to reach the adsorption equilibrium on mica surface, and then mica surface was rinsed with distilled water and dried with high purity nitrogen gas.

2.3. Temperature tolerance

The hyperbranched polymer and HPAM solutions (500 mg/L) were prepared with the brine. The apparent viscosity of these polymer solutions were measured via a PROGRAMMABLE DV-III+ viscometer at different temperatures.

2.4. Salt tolerance

The hyperbranched polymer and HPAM solutions (500 mg/L) were prepared with the distilled water. The salt tolerance of the polymers was tested by increasing salt (NaCl, $CaCl_2$, $MgCl_2 \cdot 6H_2O$) concentration, and the apparent viscosity of these polymer solutions was measured using a PROGRAMMABLE DV-III+ viscometer at 65 °C.

2.5. Rheological property and viscoelasticity

The samples were prepared with the brine. Rheological property and viscoelasticity of these hyperbranched polymer and HPAM solutions (500 mg/L) were studied in a HAAKE MARS MODULAR ADVANCED RHEOMETER SYSTEM at 65 °C. The measuring geometry was P60TiL. The shear rate was 1–1000 s^{-1} in rheological measurements, and the frequency was 0.1–10 Hz in viscoelasticity measurements.

2.6. Shear resistance

A series of different concentration solutions of the hyperbranched polymer and HPAM were prepared with the brine.