Research on Performance Evaluation of PPG/Polymer Flooding System

Ruibo Cao¹, Wei Yan², Yanfu Pi³, Jinxin Liu⁴, Hao Chen⁵
¹E&D Research Institute Daqing Oilfield Company Ltd, Daqing, Heilongjiang, China
²E&D Research Institute Daqing Oilfield Company Ltd, Daqing, Heilongjiang, China
³Corresponding author’s e-mail: caoreibo@petrochina.com.cn

Abstract. Aiming at the PPG/polymer flooding system developed by Daqing Exploration and Development Research Institute, this paper conducts research on its viscosity increasing, viscosity stability, rheological properties, viscoelasticity and seepage ability. The experimental results show that: PPG has a thickening effect on the system, and the thickening range is between 37% and 66%; the viscosity retention rate of the PPG/polymer system is higher (88%) than the ordinary 25 million polymer solution (75%); Under the same shear rate conditions, the apparent viscosity of the PPG/polymer system is higher than 25 million pure polymer; the PPG/polymer system has a resilience effect, and its G’ and G” values are greater than that of a pure polymer solution; PPG/The polymer system can migrate to the deep part of the oil layer and still maintain high seepage resistance, which can realize deep profile control.

1. Introduction
After polymer flooding, the remaining oil is small and highly dispersed, which is equivalent to "fishing oil in water and scraping oil through holes". It is difficult for microscopic remaining oil to activate and coalesce [¹], and it is urgent to break through the research and development technology of high-efficiency oil displacement system. For this reason, Daqing Oilfield Exploration and Development Research Institute has developed a PPG/polymer flooding system. In order to determine whether the system meets the requirements of further enhancing oil recovery after polymer flooding, this paper carries out relevant laboratory experiments to conduct performance evaluation research. The results for the promotion of the system are significant.

2. Experimental part
2.1. Experimental materials
(1) The expansion ratio of PPG (pre-crosslinked gel particles) is 3, and the particle size is 0.15-0.3mm. Its concentration in the system is 500mg/L, produced by China Daqing Exploration and Development Research Institute [²];
(2) Partially hydrolyzed polyacrylamide HPAM, with a relative molecular mass of 2500×10⁴, produced by PetroChina Daqing Refining and Chemical Company;
(3) Sewage, produced by the third factory of PetroChina Daqing Oilfield;
(4) 3 artificial homogeneous cores with a core size of 4.5×4.5×100cm, with core gas permeability of 4000, 2000, 500×10⁻³μm; 1 artificial homogeneous core with a core size of 4.5×1.8×30cm, with core gas The measured permeability is 4000×10⁻³μm.
2.2. Experimental equipment
(1) DV-II+Pro digital display viscometer, produced by Brookfield Company;
(2) Physica MCR 301 rotary rheometer, produced by Haake Company in Germany;
(3) GTL-1 thermostat, produced by Nantong Zhongjing Machinery Co, Ltd;
(4) ZR-3 intermediate container, produced by Hai'an Yueda Petroleum Laboratory Equipment Fittings Factory [3];
(5) Waring LB20EG laboratory stirrer, produced by Wu Yin Company in the United States;
(6) Hand-operated ring pressure pump, produced by Hai'an Petroleum Scientific Research Instrument Co,Ltd;
(7) ISCO pump, produced by American Bollefei Company;
(8) 1000mL and 500mL beakers, 50mL graduated cylinders, etc.

2.3. Experimental steps
(1) A fixed PPG concentration of 500mg/L, respectively formulating 800mg/L, 1000mg/L, 1200mg/L, 1400mg/L, 1600mg/L, 1800mg/L PPG polymer flooding system, and adopting DV-II+Pro Type digital display viscometer to measure viscosity;
(2) Prepare a 500mg/LPPG solution with wastewater from the third factory, place it in a thermostat at 45°C for 30 days, and measure the viscosity value every certain number of days;
(3) The wastewater from the third factory was used to prepare a PPG/polymer flooding system (the PPG concentration was 500 mg/L, and the polymer concentration was 1400 mg/L). As a comparison, a polymer solution with the same concentration of 25 million molecular weight was prepared. Place in a thermostat at 45°C for 30 days, and measure the viscosity value every certainly number of days [4];
(4) The above-mentioned PPG/polymer flooding system was also prepared, and the Physica MCR301 rotary rheometer was used to measure the viscosity of the system at different shear rates and G′ and G” at different oscillation frequencies;
(5) Using 100cm and 30cm artificial homogeneous cores respectively, water flooding until the pressure is stable, then PPG/polymer flooding system is injected until the pressure is stable, and finally the subsequent water flooding until the pressure is stable.

3. Experimental results and analysis
3.1. Evaluation of viscosity increasing performance and viscosity stability
The PPG/polymer flooding system with different polymer concentrations and 25 million molecular weight polymer solutions were prepared respectively, and the measured viscosity-concentration curves are shown in Figure 1. It can be seen from Figure 1 that at the same polymer concentration, the viscosity of the PPG/polymer flooding system is higher than 25 million polymers, indicating that the addition of PPG has a viscosity-increasing effect, and the increase range is between 37% and 66%.

![Viscosity curve of PPG/polymer flooding system and 25 million polymer system](image1)

![Viscosity stability curve of PPG particles](image2)
The wastewater from the third factory was used to prepare PPG particles, and the stability of the particles in the wastewater was investigated. Figure 2 shows the stability of PPG in sewage. It can be seen from Figure 2 that PPG has certain viscosity-increasing properties in sewage, and the viscosity gradually increases to stable with time. Formulate the PPG/polymer flooding system and investigate the viscosity stability of the system. The change curve of the viscosity of the measuring system with time is shown in Figure 3. It can be seen from Figure 3 that the viscosity of the PPG/polymer system gradually decreases to be stable over time. PPG has a certain viscosity increasing effect on the system, and the viscosity retention rate is higher (88%), which is higher than the ordinary 25 million polymer solution (75%). This performance feature is conducive to reducing the amount of polymer [5].

3.2. Rheology
The PPG/polymer flooding system was prepared with wastewater from the third factory, and the Physical MCR301 rotational rheometer was used to investigate the relationship between the viscosity of the system and the shear rate. The rheological curve of the system is shown in Figure 4. The PPG/polymer system follows the principle of "shear thinning". Under the same shear rate, the apparent viscosity of the PPG/polymer system is higher than 25 million simple polymers.

3.3. Viscoelasticity
The PPG/polymer flooding system was prepared with wastewater from the third factory, and the effect of PPG on the viscosity and elasticity of the system was investigated through the Physica MCR 301 rotary rheometer. The viscoelastic curve of the system is shown in Figure 5. With the increase of the oscillation frequency, the G' and G'' of the system increase, that is, the solution exhibits "bouncing properties". Under the same oscillation frequency and the same concentration of polymer, the G' and G'' of the PPG/polymer system The value of G'' is greater than that of a pure polymer solution [6].
3.4. Evaluation of seepage capacity of PPG/polymer flooding system

In order to evaluate the profile control and injection capabilities of the PPG/polymer flooding system in the reservoir, core flow experiments were carried out [7].

Evaluation of seepage capacity of 1m man-made core. It can be seen from Fig. 6 of the variation curve of PPG injection pressure and injection volume of cores with different permeability that PPG particles with an expansion ratio of 3 and a particle size of 0.15-0.3 mm can be smoothly injected into air permeability of 4000, 2000, 500×10⁻³μm rock core.

Fig. 6 Variation curves of PPG injection pressure and injection volume in cores with different permeability
Evaluation of seepage capacity of different oil displacement systems in 30cm artificial core

It can be seen from Fig. 7 that the pressure rise of the PPG/polymer flooding system is much higher than that of the high-concentration polymer flooding, which shows that the PPG/polymer flooding system produces greater percolation in the oil layer resistance. When the injection volume of the PPG/polymer system is between 0.3 and 1.0 PV, the injection pressure of the system rises sharply [8]. When the injection volume is 1.0-1.6 PV, the injection pressure tends to be stable, showing a sawtooth fluctuation. 0.6 PV injection pressure is in stable fluctuation, indicating that it is not blocked at the injection end of the core, and it can migrate to the deep part of the oil layer and still maintain high seepage resistance. In the subsequent water stage [9], the PPG/polymer system has always maintained a higher injection pressure, indicating that the PPG particles have better shear resistance.

4. Conclusion
The performance of PPG/polymer system was evaluated by laboratory experiments, and the following conclusions were obtained:

- PPG has a viscosity-increasing effect, and the increasing range is between 37% and 66%;
- The viscosity retention rate of the PPG/polymer system is higher (88%) than the ordinary 25 million polymer solution (75%);
- The shear resistance of PPG/polymer system is higher than that of ordinary 25 million polymer solutions [10];

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