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The Application of Performed Particle Gel for Water Shutoff and Flooding in Severe Heterogeneous Reservoir

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Abstract
The success of in-depth fluid diversion and enhancement of the pay zones production are hot issues in long term water flooded oilfields. However, the effect of most chemical-based water cut technologies and conformance-control treatments on fluid profile conformance are normally useful surround near wellbore zones. In addition, chemical particles can probably result in formation damage on low permeable parts of pay zone and the other potential drawbacks. Comparing to general chemical agents such as cross linker, polymer gel, foam fluid and so forth. A water shutoff plugging agent called PPG (Performed Particle Gel) show its advantage in strength-control, size-control and environment-friendly. PPG is a type of gel and synthesized with aqueous, acrylamide, cross linker and the other additives, which can be prepared at surface rather than in the wellbore, thus it is not so sensitive to high temperature and high salinity. A series of studies and field experiments through core flooding were investigated in this paper. The results indicate PPG can significantly achieve in-depth conformance in sever heterogeneous formation and can be widely applied in mature water flooded oil fields.

Key words: Heterogeneous; Performed particle gel; Water shutoff; Recovery

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INTRODUCTION

Oilfield operators present numerous water control treatments for the great water productivity problem and many of them have been deploying successfully in mature water flooded reservoirs. The water flooding stimulation mainly performs before the EOR/IOR process, and according to the water injected, the vertical and lateral heterogeneity in formations become more and more serious, thereby resulting in fins integration, sand production, and among others. More importantly, the stimulating efficiency of remaining oil in low permeable part of a thick layer is still undesirable even if implement of EOR/IOR stimulations. Therefore, high water production has become an urgent work in water flooding oilfields. Broadly speaking, water shutoff treatments can be divided into chemical placements and mechanical placements. As for relatively low cost and easy in-situ operation, a series of chemical-based technologies of reducing the high water production, especially selectively water plugging methods, have been commonly applied in many oil fields[1]. Among numerous chemical-based plugging agents, the cross linked polymer gel plugging agents express its promise in combination of water shutoff and recovery enhancement. Normally, these novel plugging agents can be classified into two categories according to happening zones of chemical reaction. Typical in-site plugging agents are weak bulk gel (BG) and colloid dispersion gel (CDG), and the chemical reaction usually occurs in the wellbore nearby; However, the polymer gelation is greatly affected by shear in the injection and as an in-sit gel system, it hard to control the exact gelation time and strength, while the thermal and salt resistance only depends on polymer properties[2-4]. The systematical lab and filed studies on various plugging agents has been researched and extended by a wealthy of literatures. Authors presented the application of PPG in EOR/IOR recovery[5-7]. The PPG treatment in water shutoff and conformance control also was studied[8].

Particle performed gel (PPG) is a performed water control which quite suitable for the developing oilfields in middle or high water cut stage or reservoir formations with complex high permeability contrasts. The mechanism of PPG in water cut is the great swelling capacity in water and coagulate together due to the microsphere structures with positive and negative poles[9-10]. After the PPG totally being soluble in water, the shell part of the PPG's expansion is relatively slow, therefore positive and negative poles of the microspheres structure can adsorb each other at pore surface and gradually formed as the string, group or larger material structure, so that it can reduce the cross-sectional area of the pore throat; As the plug happens in pore throat, it can result in liquid diversion, and the road of subsequent solution to seepage channel will be blocked. Figure 1 illustrates the process of PPG swelling and assembling.

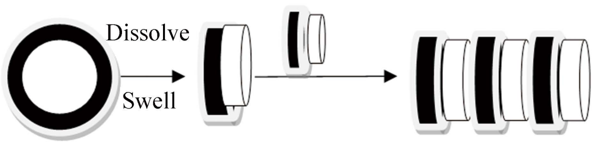

Figure 1
The Process of PPG Swelling and Assembly (White Represent Core, Black Represent Shell)

1. EXPERIMENTAL

1.1 Materials

(a) Rock. Normal sand packs were prepared in this experiment, which sand mesh is between 60 and 120. The length and diameter of the sand pack are 60 cm and 2.54 cm, respectively. Two pressure measuring apparatus were set up at the both ends, so that data can be collected instantaneously by the electronic information acquisition system.

(b) Crude oil. Oil used in all experiments was taken from experimental reservoir in Shengli oilfield, China, and the viscosity is approximate 1,470 cp at 70℃, and increase to 740 cp at 80℃.

(c) Surfactants and deionized water. Surfactants were provided by Shandong Dongying Hengye Company and core flooding fluids of PPG and deionized water were injected. The deionized water was made by the distillation method and a short time water flooding experiments were conducted before other flooding ways.

(d) PPG materials in these experiments are 3D polymer clay composite gel that made in China and the partial size is less than 3 μm.

1.2 Experimental Apparatus

A dynamic flow apparatus was designed to investigate the sealing capacity of PPG. The flow apparatus includes Teledyne ISCO pump, core holder, high pressure vessels, nitrogen bottle, pressure gauge, oven, back pressure valve and pipelines, etc. The size of sand pack was 8 cm × 100 cm (bassoon) and 2.5 cm × 60 cm (incher). The permeability was about 0.5-0.6 μm^2 through the measurement of mini water flooding. The oil saturation ranged from 35% to 40%. The injection pressure was set between 5.2 MPa and 9.0 MPa. The temperature kept at an interval from 60℃ to 90℃.

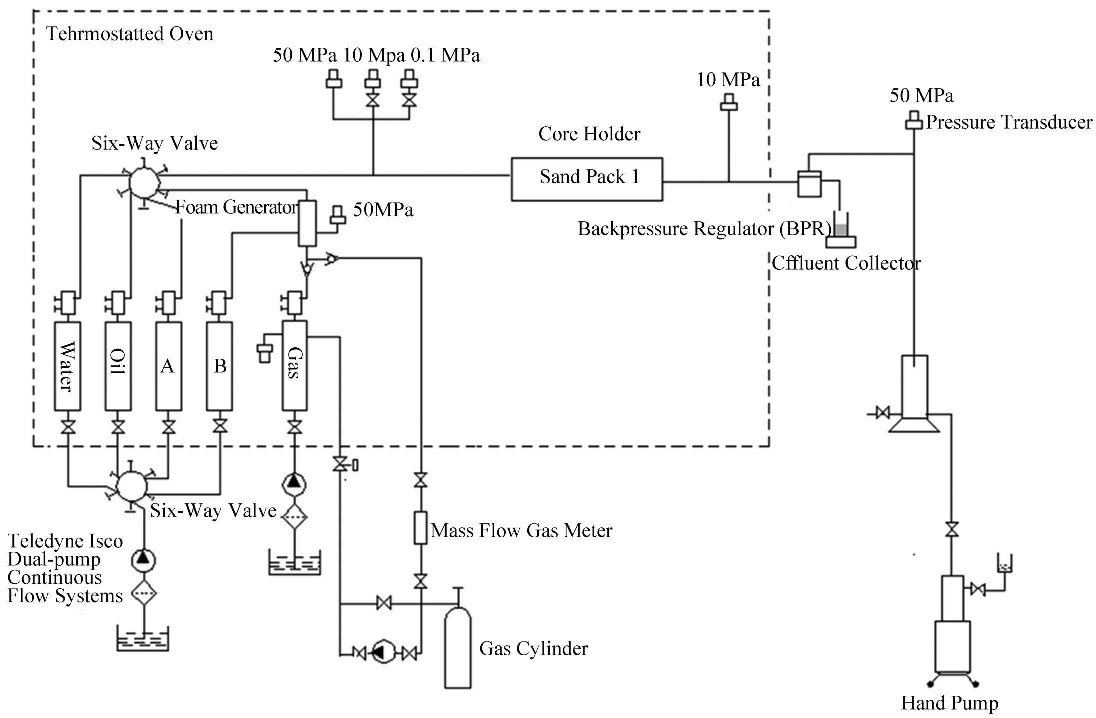

Figure 2
Schematic of the Experimental PPG Core Flood Setup

1.3 Experimental Procedures

(a) Preparation for PPG. The type of PPG selected in the experiment is a microcrystalline material and need a short time to swell. In order to enhance the PPG solution stability, HPAM is added to PPG agent solutions, and followed by about 4 hours at room temperature and atmospheric pressure with blender.

(b) Evacuate the sand pack (incher) and water is injected at the rate of 0.5 ml/min. When water content ratio is 98%, PPG agent at different concentrations is injected to core by generator. The pressure difference between two points is measured in real time and resistance coefficient is calculated as well. Resistance coefficient (Rf) refers to vital target of evaluated PPG sealing capacity, the ratio differential pressure established in core double ends to differential pressure only injected water when the PPG solution migrates to balance in the core.

(c) Oil displacement evaluation. Three natural cores are used to investigate the efficiency of PPG solution flooding. For each core flooding test, the permeability of the core is determined by injecting the produced water at a constant flow rate of 1 mL/min. Then, the oil is injected into the core to establish irreducible water saturation. Next, water flooding is conducted until the oil production becomes negligible. After that, PPG slug is injected, followed by water flooding until the oil production becomes negligible. The oil production and liquid production are recorded during the whole process.

2. RESULTS AND DISCUSSIONS

2.1 The Effect of Concentration on PPG Swelling Capacity

As Figure 3 reflects, the swelling capacity increase highly with the raise of PPG concentrations. Another important result is that the initial particle size of PPG increases at low rapid ratio in short time but as the time increases (as shown in Figure 3), the swelling ratio has a relationship with its concentration. Thus, the particle size of PPG exists an optimum concentration if time can be determined.

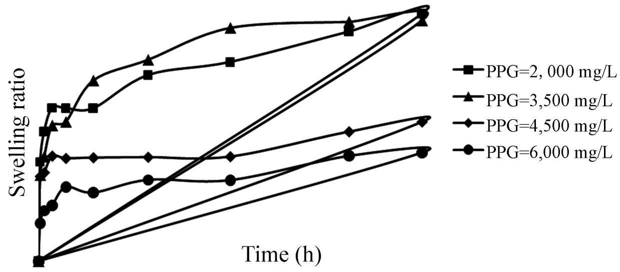

Figure 3
The Sealing Effect of Injected 0.3 PV for 6 Different Sizes

2.2 The Sealing Effect of Injected

2.2.1 The Sealing Effect of Injected 0.3 PV

Blender 0.3 PV volume (about 22 ml) of 2% PPG and 0.2% gel ball in the core, and water flooding for 30 minutes while tighten valve. After that, keep the constant temperature at 60℃ in water bath for 5 days, and then take out and inject water reversely according to the measurable permeability at the same pump speeds. At last, watch the pressure change, and calculated the sealing effect and the permeability change.

Table 1
The Sealing Effect of Injected 0.3 PV for 6 Different Sizes

0.3 PV	A	B	C	1#	4#	6#
Initial permeability/dc	2.79	2.88	3.45	2.88	2.74	2.08
Initial permeability/dc	1.14	2.12	0.81	1.85	2.12	1.05
Sealing effect/%	59.24	30.56	76.07	37.21	22.63	62.88

As Table 1 reflects, the sealing capacity of PPG type is: C > 6# > A > 1# > B > 4#, the curve lines of pressure change.

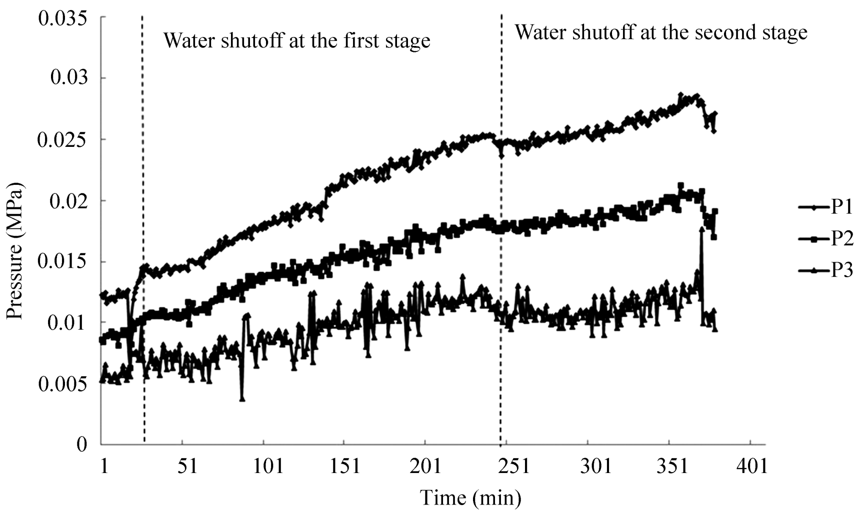

Figure 4
The Pressure Change Curve vs. Water Flooding Time for PPG A

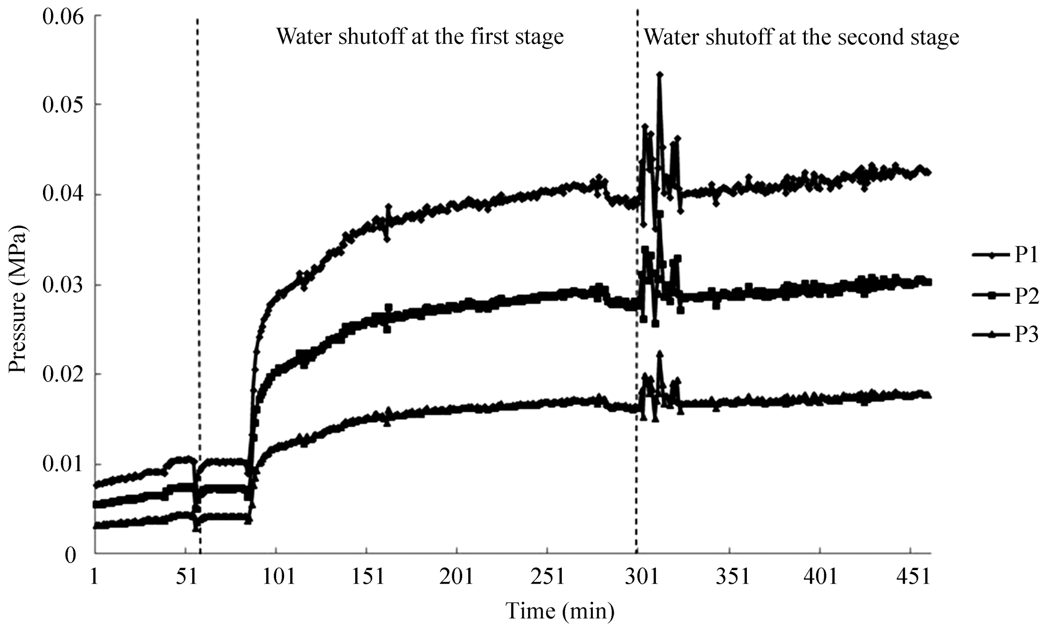

Figure 5
The Pressure Change Curve vs. Water Flooding Time for PPG C

As Figure 4 and Figure 5 reflect, the injection pressure is basically a zigzag and ascending process and because of injecting rate is 2 ml/min, so we can calculate the sealing effect of PPG after injected 10 PV.

As Figure 6 and Figure 7 reflect, we can see the sealing effect of PPG C and PPG A when injected volume increases to 0.1 PV. Furthermore, the best sealing effect was equal to normal plugging agent injected with approximately 1-3 PV.

2.2.2 The Sealing Effect of Injected 0.4 PV

Table 2
The Sealing Effect of Injected 0.3 PV for 6 Different Sizes

0.4 PV	A	B	C	2#	3#	5#
Initial permeability/dc	5.22	2.93	4.05	2.54	3.09	2.93
Initial permeability/dc	0.71	0.69	0.44	0.83	1.35	1.10
Sealing effect/%	86.37	76.62	89.12	67.92	56.34	62.55

As Table 2 reflects, the sealing capacity of PPG type is: C > A > B > 2# > 5# > 3#, the curve lines of pressure change.

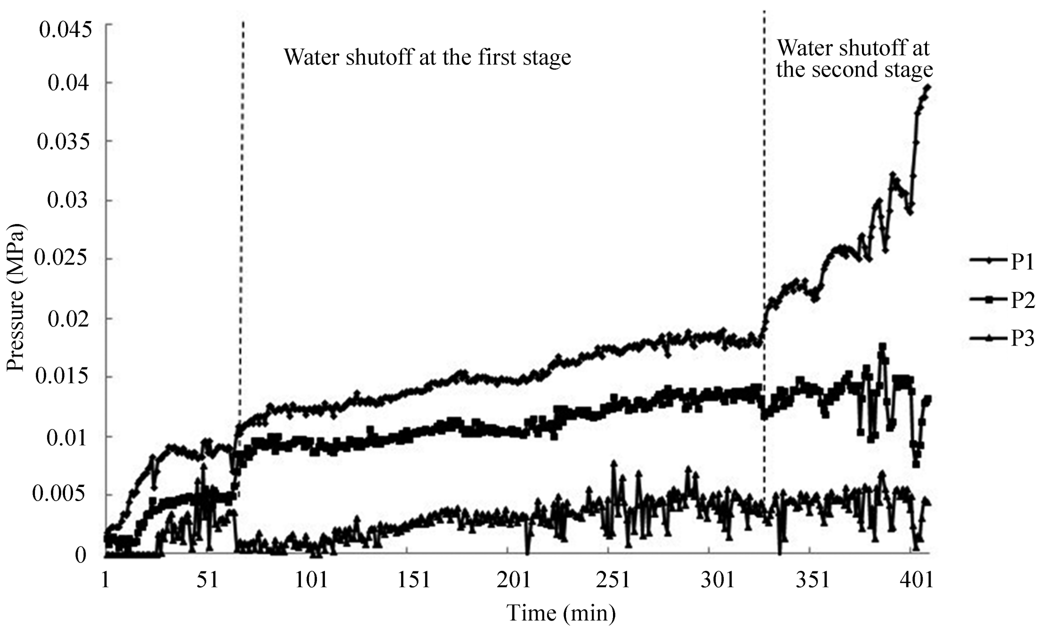

Figure 6
The Pressure Change Curve vs. Water Flooding Time for PPG A

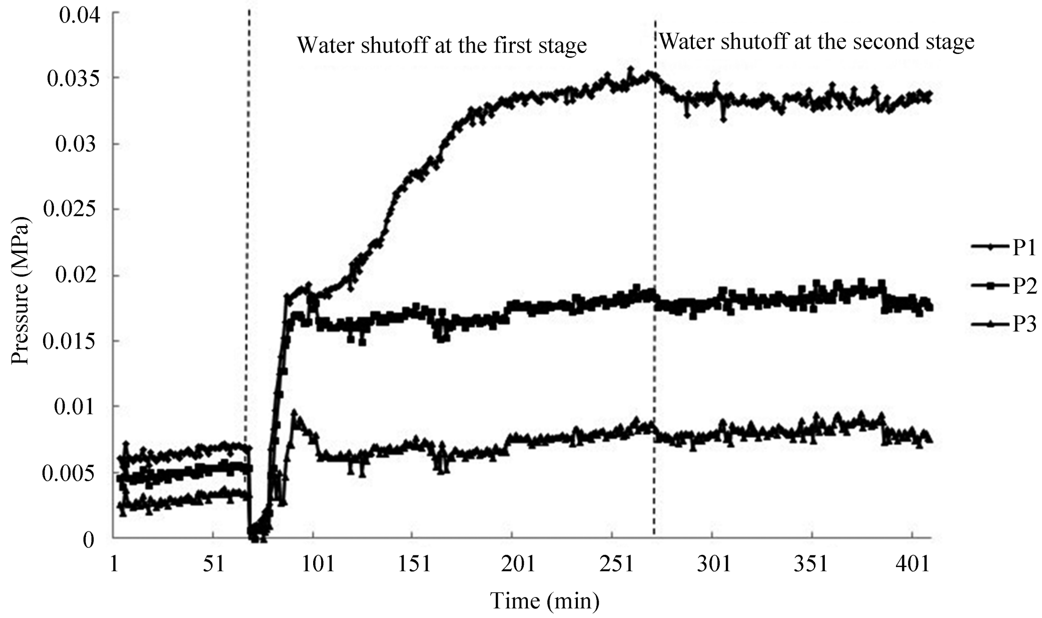

Figure 7
The Pressure Change Curve vs. Water Flooding Time for PPG C

3. THE RECOVERY OF PPG FLOODING

It can be observed from Figure 8 that displacement efficiency increased with the increase of PPG slug sizes. Because of the transformation of PPG, no matter what the permeability is high or low, the oil recovery can keep growing after 1 PV and especially for the sand pack with high permeability, it showed that the oil recovery rate was the highest since the PPG can shut off the water efficiently and create a beneficial environment for the sequent water flooding. The Figure 8 also showed that the oil displacement efficiency in the sand pack with low permeability was not evident, which represented the application of PPG for water shutoff was a selective water shutoff technology. The comprehensive oil recovery kept increasing with the increase of PPG slug size, which was approximate 5 times than that at first phase of water injection.

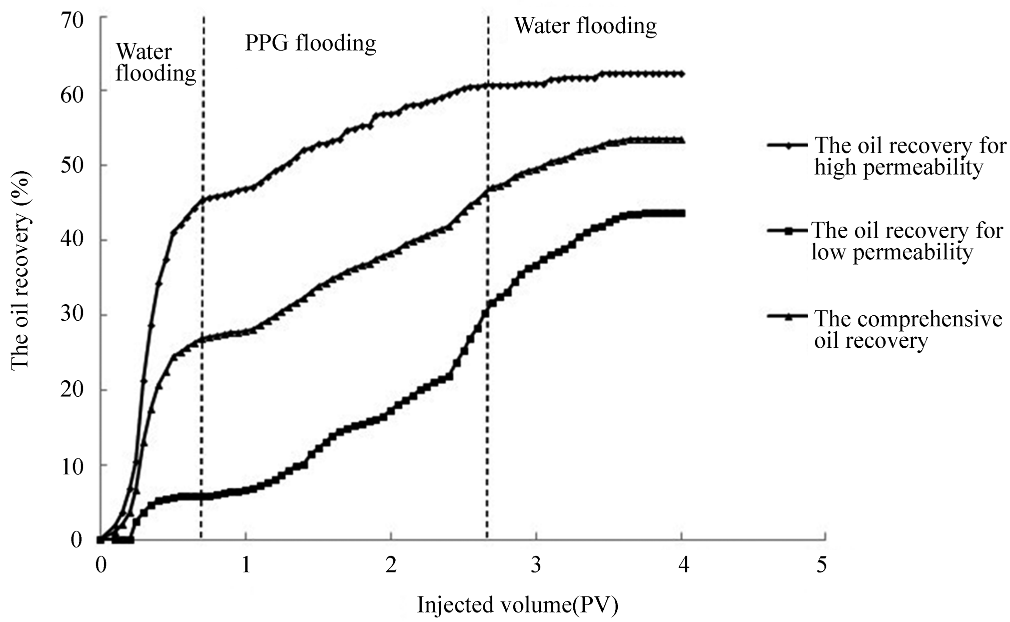

Figure 8
The Relationship Between the Injected Volume of PPG and Oil Recovery

4. FIELD EXAMPLE

Experiments had carried out to study the application of PPG for oil displacement in reservoirs and IOR, and the selection rule has been summarized below. The target reservoirs are sandstone reservoirs with high or super high permeability due to long-term water flooding. With the application of PPG technology, the recovery can be enhanced greatly while the water production can decrease. Before the PPG treatment, the total liquid volume approached to 18.9 m^3 and average oil production per day was only 1.3 t, and water ratio was about 93.2%. After about three months, the water ratio dropped substantially, and the total liquid volume was 26.7 m^3. Otherwise, the average oil production per day was 5.8 t and water ratio was 78.4%. The flooding results showed that the oil production increased approximately 4.5 t, while water production decreased to the 14.8%. In addition the effect of applying PPG flooding for oil production enhancement was apparent and the well working fluid level picked up greatly. The final cumulative oil production was 748.8 t after one year with the PPG treatment.

CONCLUSION

The results illustrate that the PPG is of super water shutoff capacity and quite suitable for serious heterogeneous reservoir with big fractures or channels. As a cross linked polyacrylamide particle, it is formed on surface with the advantage of size and strength controlled features, especially for its high temperature and salinity resistance and environmentally, thus PPG (Particle Performed Gel) can be regarded as a promising in-situ gel treatment for profile control and water control. The benefits of PPG in the water shutoff and flooding mainly result from the bridge mechanics, and the PPG can migrate with the pressure variation in pore media. Considering the economic factor and comprehensive PPG characteristics, the limited resistance factor is 30 when the injected volume is 0.8 PV but the residual resistance factor can keep steady when the PV value is higher than 0.4PV. According to the results in Figure 2 and Figure 5, it demonstrates the pressure in sand pack increase in an unsteady trend due to the transportation of PPG while the profile control exists obvious difference thereby achieving the in-depth flooding. Moreover, owing to the advantage of super-high strength, PPG can be available for long-term salinization and shear failure. Both of the field studies and the lab experiments show that the application of PPG is more suitable for the severe heterogeneous formations where permeability is between 10 μm^2 and 2 μm^2, and well depth is better controlled below 12,000 ft and the formation temperature and salinity should be not surpass 130℃ and 2×10^6 ppm at reservoir condition.

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