Evaluation of a robust Gel System for Water Shutoff in Large Aperture Fractures

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Abstract. Polymer gels for water shutoff usually base on high concentration and high molecular weight of hydrolyzed polyacrylamide (HPAM). It would lead to a high injection pressure during blocking the large aperture fractures in tight reservoirs. The in-situ polymerization of monomer gel (IPMG) has been investigated in this study. The properties of high strength and long-term thermal stability could greatly extend gel conformance control duration. The gelation time of IPMG can up to 24 hours at the temperature of 65℃. In addition, the gel strength with formulations based on Na montmorillonite (Na-MMT) was much better than that without it. The flooding experiments have shown that the robust gel has a high rupture pressure when blocking the fractures. Another benefit of the gel is a long-lasting decrease permeability of the fracture even after experiencing long time flooding.

1. Introduction
Oil recovery in fractured sandstone reservoir is often low due to water channeling. Polymer gels are usually method during water-shutoff applications in fractured reservoir, and gel treatments have proven to be a successful and economical method to alleviate the adverse effect of heterogeneity of fractured reservoir and then improve sweep efficiency of chase-floods [1-2].

Gel technology exists for a variety of treatments and is controllable over a wide range of reservoir conditions. The application of this technology can assist with controlling water production, significantly increasing oil production, and extending the economic life of a reservoir. Polyacrylamides based polymers have been the most commonly used to prepare gels. In general, polymers can crosslink with either inorganic or organic cross-linkers. Inorganic cross-linkers crosslink with polymers by ionic bonds, while organic cross-linkers crosslink with the polymers by covalent bonds [3]. The inorganic cross-linkers are known to be toxic and environmentally unacceptable. Moreover, inorganically cross-linked gels typically have poor thermal stability and short gelation time at high temperatures, its application is greatly restricted

Partial formed polymer gels and preformed particle gels (PPG) are the most commonly used for conformance control in fractured reservoirs. Partially formed polymer gel is one of the most widely used gel which has sufficient gel structure so as not to substantially enter the near-wellbore reservoir matrix [4]. However, the quality of block effect of these gels is poor and provides little resistance to post-water flooding and it is easy to displace from the fractures. Furthermore, the sizes of the PPG are extremely difficult to be tailored to the varied apertures of fractures [5-6].

A polymer gel based on monomer was developed for conformance modify in fractured reservoirs. The radicals produced by the initiator molecules activate a monomer molecule and form a reaction centre. These reaction centres quickly grow in size. Due to a very short gelation time, the application of in-situ
monomer reacting with cross-linkers to form three-dimensional structure for profile control or water shutoff in the reservoirs is limited. Besides, when the temperature of the formation is slightly high, the reaction rate between the monomer and cross-linker significantly enhance.

The ultimate purpose of the study is to development a novel gel that can efficiently block the fractures to increase oil recovery and reduce water production. The new system should fulfill several requirements. First, the gel should be thermally and chemically stable in the oil field. Secondly, the gel should fill the full fractures and rarely permeate into matrix. Thirdly, the gel should be able to sustain the high injection pressure in the fractures during chase flooding [7-8]. In this study, we focused on evaluating the potential of a robust gel with high rupture pressure for water shutoff in fractured tight sandstone reservoirs, which could largely contribute to the success of a gel treatment in large aperture fractures.

2. Materials and methods

N, N’-Methylene-bisacrylamide (MBA) was purchased from Amresco and it is reagent grade. 4,4’-Azobis (4-cynovaleric acid) (V501) is a kind of water-soluble azo initiator. The experimental clay is sodium-based bentonite, and the purity of montmorillonite is 80% -100%, which was purchased from Halliburton Baroid. Partially hydrolyzed polyacrylamide (HPAM), G3515, supplied by Jucheng Fine Chemicals Co. (China, Anhui), with the molecular weight of 13~15×106 Daltons and a 13% degree of hydrolysis. Chromium(Ⅲ) acetate (12.5% aqueous solution) was prepared from a 50% commercial solution adding distilled water. The other chemicals used in this study were analytical reagent grade and all purchased from Sinopharm Chemical Reagent Co. (China, Shanghai).

Bottle tests were conducted to determine gelation time at 65℃, which also can be used to detect the gel stability in long-term. In this experiment, gelation time was defined as the gel dose not flow to the bottle cap upon inversion. When the gel is completely gelation, there is no gel surface deformation upon inversion and that is a rigid gel according Sydansk gel strength code. The gel in the bottle was placed in the constant temperature water bath of 65℃ for one year to examine its syneresis and stability. The storage modulus (G’) was used to determine the gel strength. The rheometer (Anton-Paar MCR 92) with a parallel-plate was used for rheology measurement. The dimension of the parallel plate is 25 mm×25 mm, and the gap between two plates is 1.0mm. The gel samples were placed between two parallel plates and the Oscillatory Model was used for measurement.

Stainless steel tubes models and fracture cores were utilized to investigate gel performance in fractures. It consists of a pump, a core holder, differential pressure transducers, a temperature control system and a data acquisition system. The measured data are collected in a data acquisition system which is connected to a computer, as shown in figure 1. Flood experiments were all performed at 65℃. The diameters of these tubes were 0.4, 0.6, 1.0, 1.2, 1.0, 1.5, 2.0, 2.5, and 3 mm, respectively. The tubes were 1 m long. The aperture of fractured core is 1mm, the width and length were 5 cm and 15cm, respectively. The experiment procedures were shown as following: fractures were injected with brine before injection of gelant. The gelant or water was injected from a stainless-steel transfer vessel equipped with a piston by pumping DI water into the bottom of the cylinder. The pressure sensor was assembled at the inlet of the tube to determine the injection pressure. After gelant injection, the inlet line was cleaned and the core set-up was shut-in to allow the gel to mature at the 65℃. After aging the gel for 3days, the brine was injected into the plugging fracture and the injected pressure was monitored by the computer.
3. Results and discussions

The influence of the shear rate on the viscosity was investigated and the result was shown in Figure 2. A rotational viscometer was used to measure gel viscosity at constant shear rate 5 s⁻¹ at 65 ℃. It can be seen that the viscosity of the gel solution decreased with the increasing shear rate. The gelation time of the thixotropic gel is approximately 10 ~ 30 h under the control of retarder at a temperature of 60℃. For a given gel system, the gelation time increases as elevated temperature. Moreover, the gelation time is very sensitive to retarder content. The addition of clay can greatly accelerate the gelation of gel and it was helpful to the formation of stable three-dimensional structures. When the gel is completely gelation, there is no gel surface deformation upon inversion and that is a rigid gel according Sydansk gel strength code (Sydansk 1998).

![Figure 1: Schematic of equipment for conducting flow experiments (the core model is a vertical fracture and the fracture aperture is 1mm)](image)

![Figure 2: Flow curves of the gel system: a) viscosity vs shear rate, b) viscosity vs time.](image)

The storage modulus (G’) of gels was determined by a rheometer with parallel plates geometry with 1 mm gap. The results of the G’ of the gels showed that the strength of gels increased with the increasing the curing time of gel up to 120 days at the 60 ℃ and then slightly decreased with the time goes, as shown in figure 3. However, the gel still has a high strength after aging for more than one year. In addition, no syneresis was observed in the laboratory conditions.
The effect of aperture on gel rupture pressure is shown in Figure 4 (a). Nine different tubes were used for this experiment, i.e., 0.4, 0.6, 1.0, 1.2, 1.0, 1.5, 2.0, 2.5, and 3 mm, to model the fracture apertures. Moreover, the gel sample was prepared with 5 wt.% AM, 0.1 wt.% MBA, 0.05 wt.% V501, 0.04 wt.% retarder and 0.2 wt.% polymer and 2 wt.% clay. The rupture pressure was found to be increased with increase of the aperture of tubes, and then decreased. The pressure gradient can reach more than 4 MPa/m when the aperture of tubes is more than 3 mm.

The results indicate that the rupture pressure of gel is adequately high for gel treatment in fractured reservoirs. During these experiments, the brine was continuously injected after brine breakthrough, and the pressure data were recorded to observe the residual resistance until a steady-state pressure was achieved. As shown in Figure 4 (b), the impaired gel-filled cores still has high plugging efficiency after experiencing long-lasting brine flooding.

4. Conclusion
Based on the study conducted in this paper, some conclusions can be drawn: 1) The gel has a good shear thinning property, which is benefit for being pumped and propagating in reservoir conditions. 2) the gel system has a high strength and long-term stability. 3) and the high rupture pressure and substantial permeability reduction factors after brine breakthrough the gel-filled fractures are beneficial for conformance control in fractured reservoirs.
References

[1] Seright, R.S., Lane, R.H., Sydansk, R.D. 2001. A Strategy for Attacking Excess Water Production. Paper SPE70067 presented at the SPE Permian Basin Oil and Gas Recovery Conference, Midland, Texas, 15-17 May.

[2] Simjoo, M., Dadvand Koohi, A., Vafaie-Sefti, M., Zitha, P.L.J., 2009. Water Shut-off in a Fractured System Using a Robust Polymer Gel. Paper SPE 122280 presented at the SPE European Formation Damage Conference held in Scheveningen, The Netherlands, 27-29 May.

[3] Dai, C., Chen, W., You, Q. et al. A novel strengthened dispersed particle gel for enhanced oil recovery application. Journal of Industrial and Engineering Chemistry, 2016, 41:175–182.

[4] Ganguly, S., 2009. Rupture of polyacrylamide gel in a tube in response to aqueous pressure gradients. Soft Materials, 7(1), pp.37-53.

[5] Imqam, A., Bai, B., Al-Rammdan, M. et al. 2015. Preformed Particle Gel Extrusion through Open Conduits during Conformance Control Treatment. SPEJ. 20 (5): 1083-1093. SPE-169107-PA.

[6] Bai, B., Li, L., Liu, Y., Liu, H., Wang, Z. and You, C., 2007. Preformed particle gel for conformance control: factors affecting its properties and applications. SPE Reservoir Evaluation & Engineering, 10(04), pp.415-422.

[7] Liu, Y.; Dai, C.; Wang, K.; Zhao, M.; Zhao, G.; Yang, S.; Yan, Z.; You, Q. New insights into the hydroquinone (HQ)–hexamethylenetetramine (HMTA) gel system for water shut-off treatment in high temperature reservoirs. Journal of Industrial and Engineering Chemistry. 2016, 35, 20–28.

[8] Sydansk, R.D. 1998. A New Conformance Improvement Treatment Chromium (III) Gel Technology. Paper SPE/DOE 17329 presented at the SPA/DOE Enhanced Oil Recovery Symposium, Tulsa, April 17-20.