Peformance evaluation on the temporary plugging performance of magnetic responsive hydrogel in hydraulic fracturing of hydrocarbon reservoirs

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Abstract

In this study, we designed a magnetic responsive hydrogel, also known as magnetorheological gel (MRG), based on a carbonyl iron particle@polyacrylamide (CIP@PAM) composite and a water-soluble PAM matrix to use as a temporary plugging agent (TPA) in the hydraulic fracturing of unconventional hydrocarbon reservoirs. The CIP@PAM composite was synthesized and characterized by Fourier transform infrared spectrometry (FT-IR), scanning electron microscopy (SEM), laser particle size analysis (LPSA) and vibrating sample magnetometry (VSM). The results show that a thin and uniform PAM layer was successfully coated on the surface of the CIPs, which plays a key role in enhancing the antioxidant capacity of the CIPs. Meanwhile, the CIP@PAM composite possesses a high saturation magnetization (148.8 emu/g). MRG as a TPA has a high gel strength and magnetorheological effect under a magnetic field intensity of 1 T, providing a breakthrough pressure up to 38.13 MPa at room temperature. Compared with the conventional temporary plugging agent, MRG as the temporary plugging agent possesses high magnetic responsiveness to easily control, good degradability and recyclability, providing great potential application in hydraulic fracturing.

Background

In the process of temporary plugging fracturing, gel is widely used as a temporary plugging agent (TPA) to block the original fractures in near-well areas and to reduce the damage of the working fluid to the original layer. However, gel is mainly cross-linked by polymer or vegetable gum, and its bearing strength, cross-linking time and gel-breaking performance are difficult to control accurately.

The emergence of magnetorheological (MR) materials provides a new basis for improving the performance of temporary plugging gels. Potential applications of MR materials in oil and gas development include clean procedure applications in oil production, plug setting control in oil and gas wells, and MR dampers for semisubmersible drilling platforms. Magnetorheological gel (MRG) is a new type of MR material, which, as a smart fluid, responds to stimulation by an external magnetic field and quickly adjusts and adapts to the corresponding treatment. The unique magnetorheological characteristics of MRG, which can be transformed from a flowable to a solid state under the influence of an external magnetic field, renders its application in temporary plugging fracturing potentially useful.

A magnetically responsive hydrogel as a kind of TPA was designed and prepared. MRG was prepared by a chemical reaction method based on the polymerization and crosslinking of CIP@PAM and acrylamide (AM). Finally, with the aid of a gel strength-testing instrument and multifunctional core displacement system, the temporary plugging performance of the magnetic responsive hydrogel was in detail studied.

Methods

MRG strength was measured using a gel strength tester. In this study, gel strength was determined using the compressive strength obtained by a probe penetrating the MRG samples under various magnetic field strengths. Meanwhile, the microstructure of the MRG samples used in the experiment was demonstrated by SEM.

The breakthrough pressure of the MRG samples was measured using a multifunctional core flooding system with an isotropic magnetic field generator, as shown in Fig. 1. First, flowable MRG was injected into the fractures of the cores (shale). Then, the MRG in the cores was crosslinked and magnetized for 60 min with a magnetic field. Finally, 1% brine was injected into the core holder while maintaining the magnetic field strength until liquid appeared in the recovery vessel. The maximum pressure (or breakthrough pressure) recorded during the experiment was taken as the temporary plugging pressure that the MRG can bear.

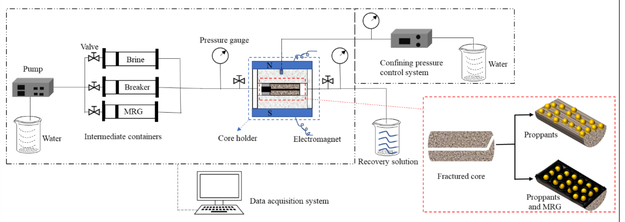

Fig.1 Schematic diagram of the experimental setup for temporary plugging tests

Results

◆ ***MRG-injection performance***

As shown in Fig. 2(a), the MRG sample shows a flowable weak colloidal state before crosslinking, providing good injectability into core fractures. Fig. 2(b) shows that a hanging gel state appears after crosslinking. Under the action of polymerization and a magnetic field, a solid-like state with a spatially oriented and fixed internal structure is formed, as shown in Fig. 2(c).

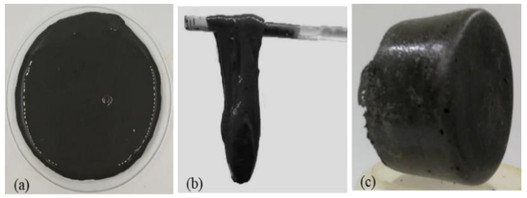

Fig.2 Physical state of the samples: (a) colloid-like state, (b) crosslinking state, (c) solid-like state

The variation curve of MRG injection pressure with injection time is shown in Fig. 3. When the crosslinking time (t_c) is short, the initial injection pressure is very small, indicating that MRG has high fluidity. However, when t_c reaches 60 min, the injection pressure increases linearly and even exceeds 35 MPa in a short time, suggesting that the MRG is in a solid-like state in the intermediate container without injection capacity. Therefore, the optimum crosslinking time is less than 30 min, while the MRG has high fluidity and is suitable for injecting fractures.

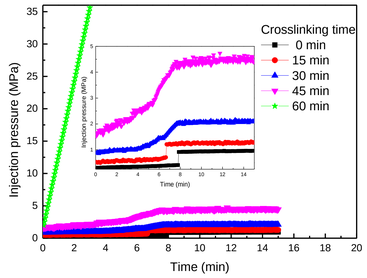

Fig.3 Injection pressure as a function of injection time

◆ ***Gel strength and micrographs of MRG under magnetic field***

The gel strength and SEM micrographs of MRG with different magnetic field intensities are shown in Fig. 4. MRG strength increases rapidly with increasing magnetic field intensity and reaches 17.37 MPa at 0.5 T. Fig. 4(c) shows that, after treatment with a magnetic field of 0.1 T, the magnetic particles in MRG have a certain orientation and form a chain structure. As shown in Fig. 4(d), under an applied magnetic field of 0.5 T, the chain effect between particles becomes more obvious.

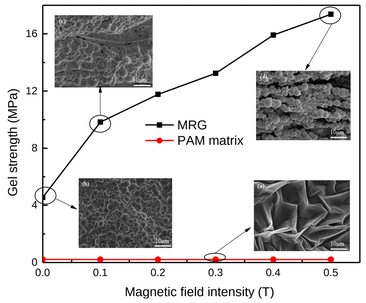

Fig.4 Gel strength and SEM images of the samples: (a) PAM matrix without particles, (b) MRG in zero magnetic field, (c) MRG in 0.1 T, (d) MRG in 0.5 T

◆ ***Breakthrough pressure***

As shown in Fig. 5, the breakthrough pressure of MRG increases rapidly with increasing magnetic field intensity (≤0.5 T). When the magnetic field intensity is 1 T and the temperature is 25, 60, and 95 ℃, the corresponding breakthrough pressures are 38.13, 38.03 and 37.91 MPa, respectively, indicating that MRG has good temperature resistance under a strong magnetic field. The temporary plugging pressure is much higher than 25 MPa, providing a potential in temporary plugging fracturing.

The breakthrough pressure is mainly attributed to the proppants combined with MRG in the fracture forming a stable structure of organic combination with a large skeleton (proppants) + small skeleton (magnetic particles) + matrix (polymer), as displayed in Fig. 6. Before crosslinking, high-fluidity MRG is injected into the fracture to fill the pores among proppants. After crosslinking and curing under a magnetic field, the pores are blocked, and a breakthrough barrier is formed with solid-like MRG and proppants to effectively prevent the working fluid from entering the fracture.

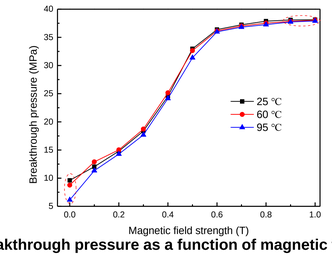

Fig.5 Breakthrough pressure as a function of magnetic field strength

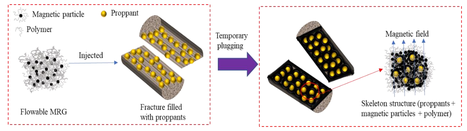

Fig.6 Schematic diagram of the breakthrough-barrier structure of MRG for temporary plugging in an external magnetic field

Conclusions

MRG as a TPA has a high gel strength and magnetorheological effect under a magnetic field intensity of 1 T, providing a breakthrough pressure up to 38.13 MPa at room temperature. Compared with the conventional temporary plugging agent, MRG as the temporary plugging agent possesses high magnetic responsiveness to easily control, good degradability and recyclability, providing great potential application in hydraulic fracturing.

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