Performance of Chromic Acetate-HPAM Gel for Flue Gas Mobility Control in Low-Permeability Reservoir

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Abstract. Chromium acetate-HPAM gel is developed to solve the gas channeling problem in low-permeability flue gas flooding reservoirs. Polyacrylamide with low molecular weight of 2 million is optimized as the main agent to construct an organic chromium gel system. The acid resistance performance and blocking capacity of the gel system are evaluated afterwards. It is revealed by the tests that acid components in flue gas have a severe impact on the gelation time, strength as well as long-term stability of the cross-linked gels. Rheological tests show that the gel system embodies with high elastic modulus in flue gas environment at 42℃, which ensures its favorable performance in core flooding tests. After gel application in cores, the permeability reduction can reach up to 99% and 97% separately while water flooding and flue gas flooding. The chromium acetate-HPAM gel exhibits perfect mobility control ability and possesses immense potential as regulating blocking system in low-permeability flue gas flooding reservoirs.

1. Introduction
Gas injection is one of the important ways to improve the recovery of low-permeability reservoirs[1~3]. Flue gas is the combustion product of natural gas, crude oil ,coal or other organic matter. The main components of flue gas are N₂ (80% ~ 85%), CO₂ (15% ~ 20%) and a small amount of carbon monoxide, hydrogen sulfide, nitrogen oxides, etc. Using flue gas for oil displacement can not only realize the underground storage of CO₂, carbon monoxide, and nitrogen oxides, but also solve the problem of water injection difficulty in low-permeability oilfields. However, gas channeling is prone to occur during flue gas injection, which greatly reduces the sweep coefficient and poses severe impact on gas flooding [4~7]. Studies [8~14] show that polymer gel agent is one of the effective methods for gas mobility control. In this paper, a preliminary study on chromic acetate-HPAM gel agent is carried out to solve the problem of gas channeling in low permeability flue gas flooding reservoirs. Low-molecular-weight polyacrylamide with lower viscosity is selected as the main agent to construct the gel system. The influence of acid components in flue gas on the gel performance are evaluated. The blocking performance of gel are studied to provide theoretical support for the effective implementation of gas mobility control in low permeability flue gas flooding reservoirs[15-16].

2. Materials and methods

2.1. Materials
HPAM (the viscosity-average molecular weight is 2 million and the degree of hydrolysis is 4%) is supplied by SNF Floerger company. Chromic acetate cross-linker is obtained from Dongying Tongkun
Industry. Artificial cores, 2.5cm in diameter and 8cm in length, made of quartz sand and epoxy resin cement, are supplied by Beijing Jiadeibang petroleum company. Simulation flue gas (80% N₂, 17% CO₂, 3% O₂) is supplied by Qingdao Tongda company. The TDS of the formation water is 5392.82 mg·L⁻¹.

2.2. Experimental methods

2.2.1. Gel rheological property test. The gelant is made up by adding HPAM solution and cross-linker. The gelant viscosity is tested at 42°C (reservoir temperature) with a shearing rate of 7.34 s⁻¹ by Anton Paar MCR92 rheometer. Elastic modulus of the gelant is measured according to SY/T 6296-1997 “Determination of polymer gel strength for oil recovery, rheological parameters method”.

2.2.2. Acid gas resistance performance test. (1) Gelation performance Put the gelant into a glass bottle and saturated with acid gas for 30 mins. Then settled in oven for 3 days. The gelation time and strength of cross-linked gels are measured with Anton Paar rheometer. (2) Gel long-term stability Put the gelant into a pressure-resistant tank and let the gelant form into gel with a sufficient time (Fig.1). Inject acid gas till the pressure reaches a certain value. Then settle the tank in oven for 180 days at 42°C. The gel strength is measured by rheological tests.

2.2.3. Gel blocking performance test. (1) Coreflood apparatus is placed in an oven at 42°C. (2) Saturate the core with formation water, calculate the porosity. (3) Core permeability is determined with water flooding. (4) Inject 2 PV of gelant solution, and place it in the oven for a certain time until the gel is formed. (5) Inject formation water into one core to calculate the breakthrough pressure gradient and permeability reduction. (6) Inject flue gas into another core to calculate the breakthrough pressure gradient and permeability reduction.

Fig.1 Pressure resistant tank that can withstand 10 MPa.

3. Results and Discussion

3.1. Polymer gel formula performance
Polymer molecular weight has an important effect on polymer injection performance in low-permeability (10~500mD) reservoirs. The molecular weight of polymer used by traditional gel for mobility control is generally more than 10 million. However, the injection pressure will increase dramatically due to the large viscosity in the low-permeability reservoir, and the injection progress will be deteriorated. Therefore, 2 million molecular weight HPAM is optimized to ensure that the polymer has a better injection performance in low permeability cores.

Chromium acetate-HPAM gel is prepared with HPAM as main agent and chromium acetate as crosslinking agent. In order to solve the problem of weak gelation performance at low temperature, a small concentration of nano-SiO₂ particles is added to the gelant solution to form a stable three-dimensional network structure and improve gel strength. The gelation performance and long-term stability are investigated (Fig.2, Fig.3). It shows that the chromium acetate-HPAM gel composed by 2 million molecular weight HPAM has good gelation performance and long-term stability. The initial viscosity of the gelant solution is 23.62mPa·s at 42°C. Then the gel viscosity reaches up to 1000mPa·s within 6h. A high strength gel is obtained 72h later. The elastic modulus of the gel can be 17Pa. Besides, the gel strength can still remain more than 13 Pa after 180 days.
accompanied by the dehydration rate of 3%.

Figure 2. Gel viscosity and strength vs. gelation time.

Figure 3. Gel Strength and dehydration rate vs. time.

3.2. Effect of flue gas on polymer gel gelation performance

The acidic components CO$_2$, H$_2$S and SO$_2$ in the flue gas have a severe impact on the performance of polymer gel[17-18]. Simulated flue gas is consisted of 80 vol% N$_2$, 17 vol% CO$_2$ and 3 vol%O$_2$. The influence of gas composition on the gelation performance and long-term stability are investigated. Gelation performance under different gas atmosphere is presented in Fig.4 and Fig.5. The gelation time of chromium acetate-HPAM gel under CO$_2$ environment has been largely prolonged. Meanwhile the gel strength has been weakened significantly.

Figure 4. Effect of gelation performance with different gas.

Figure 5. Gelation performance after 3 days.

3.3. Effect of flue gas on polymer gel stability

Simulation flue gas is injected to evaluate the effect on polymer gel long-term stability. The results are shown in Fig.6 and Fig.7. The gel formed in pressure-resistant tank has an elastic modulus of 16.1 Pa after 3 days. After 2 MPa flue gas injected, the strength of the gel decreases slowly with aging time. After 180 days, the elastic modulus of the blank sample and the flue gas injected gel system is 13.5 Pa and 9.4 Pa, respectively. Fig.7 shows that after 180 days, the structure of the gel still maintains complete and it would be defined as medium-high strength gel, which meets the oilfield requirements and is suitable for flue gas flooding reservoirs.
3.4. Performance of polymer gel for flue gas mobility control

Efficient mobility control is the key to ensuring the implementation of flue gas flooding in low permeability reservoirs. Polymer gel based blocking agents can increase the flow resistance in high permeability layer by means of physical interactions such as blocking, trapping and adsorption, thus prevent gas from channeling along the high permeability layer. Then the injected gas will enter into the low permeability layer to improve the sweep efficiency. Cores with 100mD are adopted to evaluate the core blocking performance of the chromium acetate-HPAM gel. Core flooding tests are conducted at 42℃. The displacement results are shown in Fig.8 and Fig.9. As can be seen, the maximum pressure difference during the water flooding can reach up to 3.14MPa and the breakthrough pressure gradient can be 39.25MPa/m. The permeability reduction can reach up to 99%. The maximum pressure difference can be 1.592MPa when subsequent flue gas flooding operated. The breakthrough pressure gradient is about 19.2MPa/m. The injection pressure is sharply decreased after breakthrough and the permeability reduction is 97% after injected with 10PV of flue gas, which indicates that the chromium acetate-HPAM gel has perfect blocking capacity and long-term eroding resistance.

4. Conclusion

(1) Chromium acetate-HPAM gel is prepared with 2 million low molecular polymer as the main agent and chromium acetate as the cross-linking agent, the gelation strength can reach up to 17Pa. Besides, the gel strength can still remain more than 13 Pa after 180 days accompanied by the dehydration rate less than 5%.

(2) The gelation performance of chromic acetate-HPAM gel is severely affected by acid components in flue gas. The acid components could decrease the pH of gelant and then retard the
hydroxyl bridge action, which results in a negative influence on the gelation time and strength of the chromium crosslinking gel. The gel could remain medium-high strength in flue gas environment, which meets the long-term stability requirements in oilfields.

(3) Core flooding experiments show that the permeability reduction can reach up to 99% and 97% after water flooding and flue gas flooding, which indicates that the chromium acetate-HPAM gel has perfect blocking capacity and long-term eroding resistance. Considering the weak acid resistance of gelation performance and desirable mobility control capacity, it is recommended that the gelation should be injected first and after it forms into gel, flue gas flooding would be performed.

Acknowledgments

Financial funds supported by “the Fundamental Research Funds for the Central Universities” (No.18CX06017A) and “National Key Research and Development Program of China” (NO. 2018YFA0702400) are gratefully acknowledged.

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