Research and Application of Polymeric Gel Dam Technology to Control Water Channeling in Horizontal Wells of Tight Fractured Sandstone Reservoir

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ABSTRACT

To address the challenge of water channeling in water flooding of Honghe oilfield, a tight fractured sandstone reservoir characterized by extensive fractures, experimental study on polymeric gel and field trial of constructing a polymeric gel dam had been conducted. Numerous performance indices of a formula of polymer gel were examined including anti-aging, salinity tolerance, plugging rate and anti-flushing resistance. The experimental results showed superior performances of the plugging agent. The field trial performed in two horizontal wells indicated that with the application of gel dam technology, the oil production rate of producers increased due to the decreased water cut. The accumulated increased oil was up to 102 t, and water cut dropped from 99.0% to 92.3% with effective duration of over 217 days. The gel dam technology shows great potential to solve the water channeling and to enhance the oil recovery during water flooding in tight fractured reservoir.

Keywords: water channeling, horizontal well, tight fractured oil reservoir, gel dam, plugging agent

1 INTRODUCTION

Honghe oilfield is a typical low porosity and ultralow permeability tight sandstone reservoir with extensive natural fractures, which is located at the southern edge of Ordos basin of China. The oilfield is mainly developed by horizontal drilling and multi-stage hydraulic fracturing technology. Despite the high oil production rate in the first year, the annual decline rate can be up to 35% for the following years. Thus, water flooding had been performed to enhance the recovery. However, the water injected from horizontal injectors tends to channel into the horizontal producers or other injectors rapidly along the network composed of natural and artificial fractures. The statistics showed that the producers occurring water channeling can be up to 54.5%.

To address the aforementioned challenge, the technique of placement of dam of polymeric gel was proposed in recent years. With the horizontal well interposed among the injector-producer group as injection entry, the chemical shutoff agent is injected into the fractures and thus a gel dam of shutoff agent is constructed around the horizontal section of the well. By this way the sweep efficiency of waterflooding is improved and in turn oil recovery is enhanced [1-4]. Yuzhang, Liu, et al found that recovery rate can be increased by up to 20% if constructing gel dam along the primary flow path of waterflooding by physical simulation experiments [4-9]. With several years of water flooding in Honghe oilfield, a certain amount of horizontal producers are shut off or used as injectors due to high water cut, which constitutes ideal condition for the exploration of the application of gel dam technology.

2 EXPERIMENTAL

2.1 Materials and Apparatus

The experimental materials include anionic polymer, cross-linking agent A, cross-linking agent B, pH value modifier, metal ion shielding agent, sodium bicarbonate (analytical grade), sodium carbonate (analytical grade), sodium chloride (analytical grade), anhydrous calcium chloride (analytical grade), and magnesium chloride hexahydrate (analytical grade). The water used is the simulated formation water and the injection water adopted in the oilfield.

The experimental instruments include Germany's HAAKE MARS II rheometer, core flooding apparatus, sand filling pipe, electronic mass balance, agitator, constant temperature oven.

2.2 Experimental Method

In this work, a formula of polymeric gel as water shutoff agent developed specifically for the Honghe oilfield is adopted, which is composed of 0.15%-0.30% of polymer + 0.04%-0.08% of crosslinking agent A + 0.01%-0.02% of crosslinking agent B + 0. 0.01%-0.03% pH value modifier + 0.01% metal ion shielding agent.

The polymeric gel solution is prepared by the following procedure. Firstly, a certain amount of water is measured and pour into a beaker. Then, the anionic polymer, the crosslinker A, the crosslinker B, the pH value adjuster, and the metal ion shielding agent is added in order. The solution is stirred during the whole preparation process.

Anti-aging performance test is conducted by the following procedure. Firstly, thirteen samples of the polymeric gel solution of the same concentration are prepared and then placed in the oven set at 70 °C. Then, the viscosity of the samples is measured with the aging duration of one month, two months, three months, etc., respectively with the rheometer to evaluate the effect of aging time on the viscosity. The longest aging duration is thirteen months.

Salinity tolerance test is conducted by the following procedure. Firstly, it is prepared NaCl solution of different mass concentrations and $CaCl_2$ solution of different Ca^{2+} mass concentration. Then, these saline solutions are used to prepare polymeric gel solution. Finally, the viscosity of the polymeric gel after gelation is evaluated.

Evaluation of plugging performance is conducted by the following procedure. Firstly, several sand filling pipes of 300-800 mD is made and a polymeric gel solution is prepared. Then, the original porosity and permeability of the sand filling pipe are measured by water flooding at a displacement rate of 1 mL/min. Subsequently, the polymeric gel solution of one pore volume (PV) is injected into the pipe. The pipe is put in the oven set at 70 °C until gelation. Finally, the pipe is injected 10, 20, 30, and 50 PV of water in series to measure the permeability of the sand filling pipe after varying flushing volumes and thus the performance of anti-flushing of the polymeric gel.

3 RESULTS AND DISCUSSION

3.1 Anti-aging Performance

Figure 1 shows that the viscosity of the polymeric gel gradually decreases with the aging time. Despite the reduction rate of viscosity increases with time, the viscosity retention rate after aging for thirteen months is still over 85%. This shows that the polymer gel exhibits superior anti-aging performance, and the stability period can be up to 13 months.

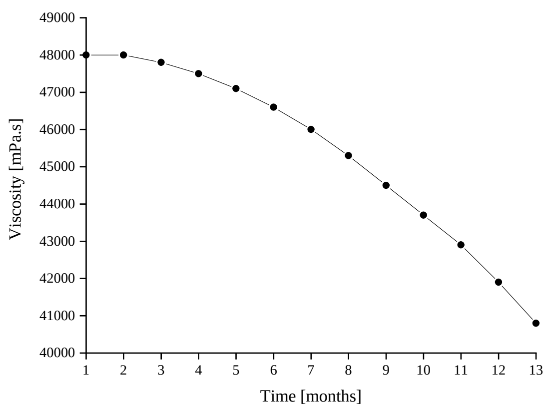

Figure 1: Viscosity of polymer gel under varying aging time

3.2 Salinity Tolerance Performance

Polymeric gel solutions are prepared with NaCl solutions of different mass concentrations and $CaCl_2$ solutions of different Ca^{2+} mass concentrations, and their viscosity after gelation are tested. Figures 2-3 show that the viscosity of the polymeric gel decreases with the NaCl and Ca^{2+} mass concentration. The viscosity is relatively stable when the NaCl mass concentration is less than 1×10^5 mg/L, and the Ca^{2+} mass concentration is less than 8000 mg/L, which indicates that the salinity tolerance of the polymeric gel to NaCl can be up to 1×10^5 mg/L, and the tolerance to Ca^{2+} can be up to 8000 mg/L. The performance can meet the requirements for gelation under the formation fluid conditions of the Honghe oilfield. The average salinity and mass concentration of divalent cation of the formation water is 60608 mg/L, 7000 mg/L, respectively.

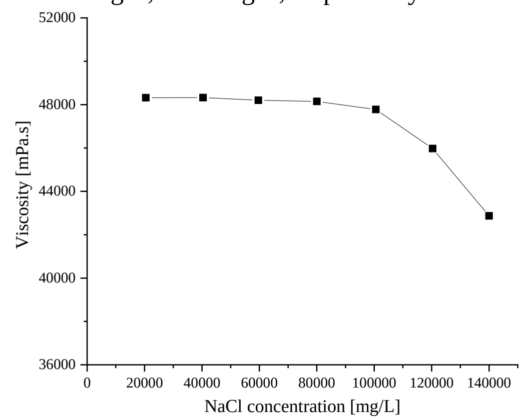

Figure 2: Effect of mass concentration of NaCl on viscosity of polymer gel

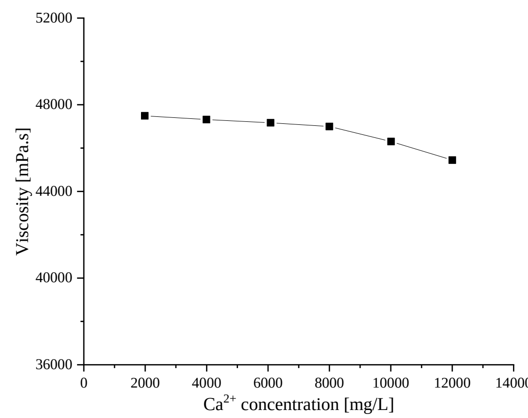

Figure 3: Effect of mass concentration of Ca^{2+} on viscosity of polymer gel

3.3 Plugging Performance

Table 1 summarizes the evaluation results of the plugging performance of the polymeric gel with seven sand filling pipes of different permeability. It is showed that the average residual resistance coefficient of the polymeric gel, which is defined as the initial water phase permeability of the sand filling pipes divided by the water phase permeability after plugging, is around 30, and the plugging rate is over 95%, which can meet the requirements of plugging the water channel for field trial.

Table 1: Plugging performance of polymeric gel in sand filling pipes.

Number	Water phase permeability, mD		Residual resistance coefficient	Plugging rate, %
	Before plugging	After plugging		
1	332.11	10.33	32.15	96.89
2	602.08	21.2	28.4	96.48
3	712.12	24.59	28.96	96.55
4	490.41	15.67	31.3	96.81
5	785.36	23.51	33.4	97.01
6	390.44	19.32	20.21	95.05
7	516.37	14.4	35.87	97.21

Table 2 shows the evaluation results of the anti-flushing performance of the polymeric gel. The plugging rate of the polymer gel remains approximately unchanged with the pore volume of displacement water. After 50 PV of water injection, the plugging rate is still over 94%. This suggests that the polymeric gel can exhibit strong capability of adsorption and retention on the sandstone surface, showing superior anti-flushing ability.

Table 2: Anti-flushing performance of polymeric gel in sand filling pipes.

Displacement volume, PV	Water phase permeability, mD		Plugging rate, %
	Before plugging	After plugging	
10	785.36	23.61	96.99
20	785.36	25.82	96.71
30	785.36	33.62	95.72
50	785.36	44.73	94.3

4 FIELD TRIAL

The polymeric gel dam technology have been applied in two horizontal wells in the Honghe Oilfield. The cumulative oil increase is 102 t, the cumulative water production is reduced by 685 m^3, and the effective duration is over 217 days. The field trial result is illustrated using the well HH37P13 as an example.

Well HH37P13 is a horizontal oil producer in the HH37P12 well group which is composed of one injector (i.e. HH37P12), and four producers (i.e. HH37P13, HH37P11, HH37P39 and HH37P14). All the four wells are horizontal well with artificial fractures. The oil production rate of HH37P13 is 0.2 t/day and the water cut is 97%. The mass concentration of the chloride ion in produced water from HH37P13 decreased from initial 37223 mg/L to 8933 mg/L, which is a strong indicator of water channeling between the injector and this well since the concentration of the chloride ion of water from injector (1649 mg/L) is much lower than that of the formation water (60608 mg/L).

Well HH37P11 is an oil producer located just outside of HH37P13. The oil production rate of HH37P11 is 0 t/day and water cut is 100%. Produced water analysis indicates that the injected water from the HH37P12 channeled to the HH37P13, and then channeled to the HH37P11.

To enhance the production of the HH37P11, it is proposed to construct a gem dam by injecting polymeric gem solution into the network of artificial fractures and natural fractures around well HH37P13, which is considered as the dominant channel. By this way, the water from injector HH37P12 can divert and displace oil into HH37P11. The well spaces between HH37P13 and HH37P12, HH37P11 are 370m and 450m, respectively. The designed blocking depth of the polymeric gel is 150 m. During the hydraulic fracturing operation in the HH37P13, ceramic proppant of 264 m^3 was injected and the average filling porosity was 42.0%. Thus, the estimated porous volume of artificial fractures was 103 m^3. According to the fracture plugging engineering algorithm, the capacity of natural fractures was 400 m^3. Therefore, the total injection volume of 500 m^3 was designed. In order to prevent the polymeric gel solution from leaking into the fractures during operation, 100 m^3 of pre-crosslinked polymeric gel particles with particle size of 0.5 to 3.0 mm were first injected as the pre-positioning section, then 300 m^3 polymeric gel solution was injected as the main plugging section, and finally a sealing section of 100 m^3 with relatively high concentration was injected close to the well wall.

After the application of polymeric gel dam technology, the oil production rate of HH37P11 increased from 0.03 to 0.41 t/day, and the water cut decreased from 99.0% to 92.3%. The cumulative oil increase was 59 t. The effective duration was over 217 days.

5 CONCLUSIONS

The polymeric gel dam technology showed promising effects in enhanced oil recovery of water flooding in fractured oil reservoir given the extensive application of horizontal drilling and multi-stage hydraulic fracturing in the petroleum industry in recent years. This is achieved by building a polymeric gem dam around a horizontal well between an injector and a producer to prevent water channeling. The optimized formula of polymeric gel is suitable for reservoir conditions of Honghe oilfield. It shows superior resistance to high salinity along with high plugging rate of over 95%. In order to further improve the effectiveness of polymeric gel dam technology to shut off the water channeling, it is proposed to conduct physical simulation experiments and numerical simulation studies of application of polymeric gel dam to horizontal well in tight fractured reservoirs to optimize the design and operation parameters.

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