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Experimental Evaluation of Water Control Agents in Low permeability Reservoir with Fractures

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Abstract: Several water control agents, including pre-linked gel particles, emulsion microspheres, continuous chromium gel with different viscosity and underground starch graft copolymer gel were evaluated in lab. The properties such as gelation time and gel strength of gel, and expansion of particles and microspheres were tested at high temperature. Also, the injection pressure, plugging strength and resistance factor were measured using the artificial low permeability cores with fractures.

It was shown that, for the particle type water control (pre-linked gel particles and emulsion microspheres), the particle size and distribution are crucial characters for the plugging property. The particle size should be must be adaptable with the fracture width, not be too big or small, which is very difficult to control. Also, for the continuous chromium with different viscosity, the added polymer concentration higher, the viscosity is higher, with higher plugging strength. Meantime, high polymer concentration will lead to poor injectivity (high viscosity on ground) and high cost. Therefore the plugging and strength should be coordinated. The starch graft copolymer can be generated underground, which on ground is thin solution. So it is easy to be injected into formation and has good plugging property. The results show that the underground starch gel is more suitable to be used for water control in low permeability formation.

Keywords: low-permeability; water control agents; Experimental evaluation; gel

1 Introduction

As for low permeability reservoirs with permeability under 50mD [Daopin (1997)], especially for the ultra-low permeability under 10mD, it is common that there exist fractures with high flow conductivity [Zhiwei (2011)]. In the process of water

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flooding, because of low conductivity and high resistance of matrix, the water is prior flowing along the fractures, which leads to the water breakthrough in short time [Hui and Daiyin (2008); Mingqiang, Yongle and Xiangui (2007)]. It is proved that injecting chemical water control agents into formation to partly plug the fractures is one of relatively effective and economic methods [Limin, Jirui and Xinmin (2006); Xianrong, Rui, (2004)]. Also, there are many challenges such as selection of agents with high plugging strength and good injectivity and injection parameters optimization [Hui and Daiyin (2008); Haitao, Guiyi, Qingchun, Hongtao, Yun, and Jianfa (2011)], which is crucial for low permeability formation with low oil well productivity. Therefore, feasibility evaluation of the frequently-used water control agents in tight formation is essential for the water control application.

2 Experimental Materials and Equipment

2.1 Materials

The examined water control agents include pre-linked gel particles, emulsion microspheres, continuous chromium gel and underground starch graft copolymer gel. The formulation of continuous chromium gel is provided in Tab. 1. The underground starch graft copolymer gel consists of modified starch 2.5%-4%, cross-linker 0.05%-0.15%, control agent 0.1%-0.25%, unsaturated monomers 2.5%-4.0%, PAM 0.2%. The experimental water used was produced water. The produced water could be used for sample preparation and water flooding after microfiltration.

Table 1: Formulation of continuous chromium gel.

additive	Polymer	Cross-linker A	Cross-linker B	Cross-linker D
%	0.3∼0.5	0.05	0.01	0.3

2.2 Equipment

The main equipment include electric mixer, high-temperature and pressure autoclave, BrookField viscometer, constant temperature oven, electronic balance, conventional glass apparatus, intermediate container, core holder, pressure sensor, constant voltage and speed pump, pipelines, six-way valves, hand pump, vacuum pump and computer.

3 Experimental Conditions

Produced water; 1 m length, diameter 2.5 cm filling sand tube; At temperature 64°C.

4 Results and Discussions

4.1 Static performance evaluation

Properties such as gelation time and gel strength of gel, and expansion of particles and microspheres were tested at high temperature. Tab. 2 shows the static property of pre-linked particles KL-1. It can be seen that the expansion time of KL-1 is 3 days. The particles' expansion times are more than 5.

The viscosity at different time at 64°C was measured to study the gelation time and gel strength of continuous chromium gel. The results are shown in Tab. 3. It shows that the viscosity of the base fluid before gelation is only 423mPa.s, and the viscosity reaches maximum after 24 hours, then it reduced. So, the gelation time of continuous chromium gel is about 24h, and the gel strength is more than 14000mPas.

Tab. 4 shows the viscosity of underground starch graft copolymer gel at different time at 64°C. It can be seen that the viscosity is very low before gelation, only 56.3mPas. After 8 hours, the viscosity sharply increased to 149871mPas. Then, viscosity changes very little. So, the gelation time of the water control agent is 8 hours, and the gel strength is more than 15000mPas.

Table 2: Property of pre-linked gel particles KL-1.

Particle Size and Roundness	2.0-4.0mm
Expansion Times	≥ 5
Expansion Velocity	6h-60%, 24h-87%, 48h-89%, 72h-90%

Table 3: Viscosity of continuous chromium gel at different time.

Time(h)	0	2	4	6	8	10	12	14	24	30	100
Viscosity (mPas)	423	2049	3000	4200	5732	7356	8500	9697	14336	10078	5618

Table 4: Viscosity of underground starch graft copolymer gel at different time.

Time(h)	0	2	4	6	8	10	15	20	40	75	100
Viscosity (mPas)	56.3	57	57	57	149871	152008	151009	150870	149865	139018	135001

4.2 Dynamic Performance Evaluation

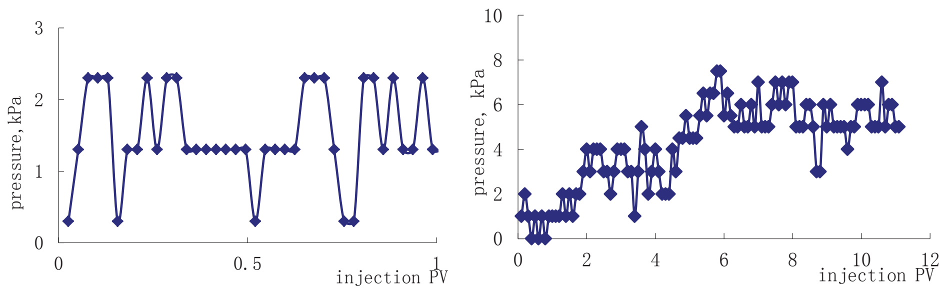
Series of core-flood experiments were carried out to study the dynamic performance of pre-linked gel particles, emulsion microspheres, continuous chromium gel and underground starch graft copolymer gel. The injection pressure, plugging strength and resistance factor were measured using the artificial low permeability cores with fractures.

4.2.1 Pre-linked gel particles dynamic performance evaluation

Fig. 1(a) $\sim$ Fig. 3(a) shows the pressure change across cores of different fracture permeability (50D/100D/150D) as a function of pore volume of injected pre-linked gel particle KL-1. The particle concentration is 5000mg/L. With the same injection rate (5ml/min) and the same injection volume (1PV), the injection pressure of the former two sets of experiments was very low (Fig.1 (a), Fig.2 (a)). For the core with fracture permeability of 150D, the injection pressure is low at the beginning. When the injection volume reached 0.7PV, the injection pressure sharply increased to 5000kPa. It can be found from Figure5, the particles (with particle size of 2-4mm) and the fracture (150D) have begun to appear matching signs, although the particles are not fully swollen. The particle size of 2-4mm can basically matches with the size of pore and throat.

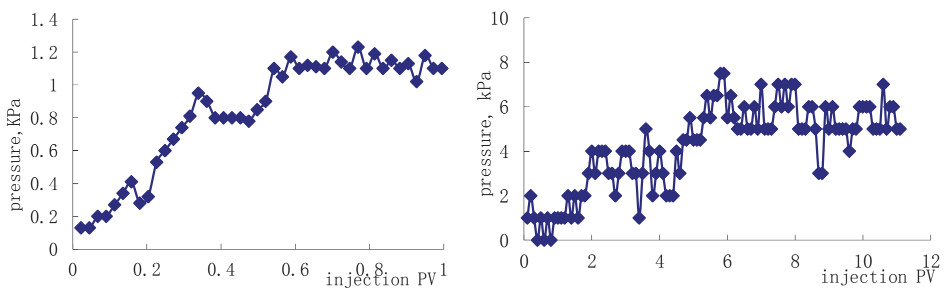
After 3 days, the particles fully expanded; subsequently, the water was injected. Fig. 1 (b) $\sim$ Fig. 3 (b) are the water-flooding pressure curves of the three cores with different fracture permeability. For the core, whose fracture permeability is 50D or100D, the differential between the displacement pressure and injection pressure is small. For the core that fracture permeability is 150D, the injection pressure increases significantly after fully swollen, and there is an obvious breakthrough pressure peak (4500kPa). Also, the final average injection pressure reaches 2000kPa. So, for the core whose fracture permeability is 150D, the particle system with particle diameter of 2-4mm has good plugging adaptability. The resistance factor, residual resistance factor and plugging percentage of KL-1 corresponding different fractures are listed in Tab. 5.

It can be founded that pre-linked gel particles are not suitable to fracture, whose permeability is less than 100D. Also, we can see that the particle, whose particle diameter is 2-4mm, matches with the porous medium, whose permeability is 150D.



(a) (b)

Figure 1: Injection pressure and water flooding pressure curve (50D).



(a) (b)

Figure 2: Injection pressure and water flooding pressure curve (100D).

4.2.2 Continuous chromium gel dynamic performance evaluation

Two formulations were selected to study the continuous chromium gel, and the polymer concentration was 0.3% and 0.5% respectively. The plugging percentage and breakthrough pressure gradient of continuous chromium gel under different conditions are listed in Tab. 6 and Tab. 7. It can be founded that, for the continuous chromium with different viscosity, the added polymer concentration higher, the viscosity is higher, with higher plugging strength.

4.2.3 Emulsion microsphere dynamic performance evaluation

After 1-day swelling at 64°, the microsphere dispersion system was injected into the model, whose permeability is 10D. The pressure of three different positions in

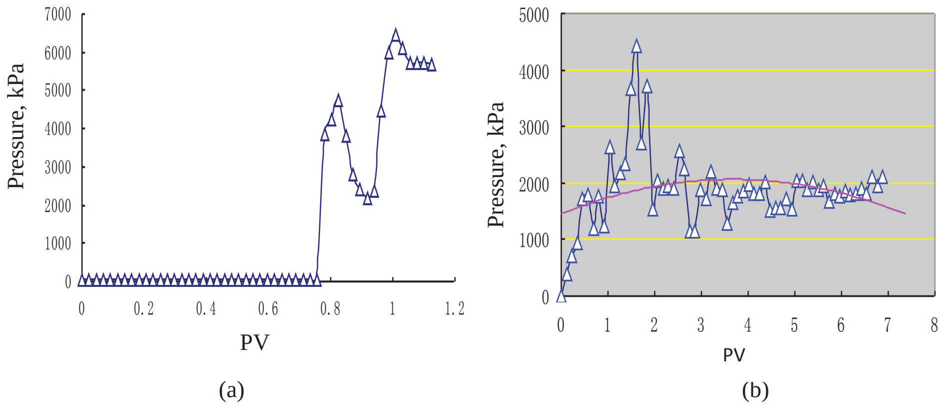


Figure 3: Injection pressure and water flooding pressure curve (150D).

Table 5: Plugging property of KL-1.

Particle size (mm)	Permeability of Fracture (D)	Resistance factor	Residual resistance factor	Plugging percentage (%)
2∼4	51.6	1	3.95	74.7
	98.6	1	1.88	46.9
	150	15	5.68	82.4

Table 6: Plugging percentage of chromium gel with different injection volume.

Polymer concentration (mg/L)	Permeability of Fracture (D)	Injection volume (PV)	Plugging percentage (%)
3000	10	0.1	88.10
		0.3	95.88
	100	0.1	77.78
		0.3	93.42
5000	10	0.1	93.29
		0.3	97.54
	100	0.1	81.48
		0.3	94.29

Table 7: Breakthrough pressure gradient of chromium gel.

Polymer concentration (mg/L)	Permeability of Fracture (D)	Breakthrough Pressure Gradient (MPa/m)		
		0.1PV	0.5PV	1PV
3000	10	0.075	0.95	1.32
	100	0	0.075	0.105
5000	10	0.16	0.985	1.73
	100	0.031	0.17	0.28

the model during the entire experimental process is shown in Fig. 4. It can be seen that the pressure has not been changed from the microsphere injection process until subsequent water flooding. That illustrates emulsion microspheres system has been completely unable to form plugging in the pores when the permeability is 10D. Also, the resistance factor and residual resistance factor both are 1.0. So, emulsion microspheres system is not suitable to the formation, whose permeability is 10D or more.

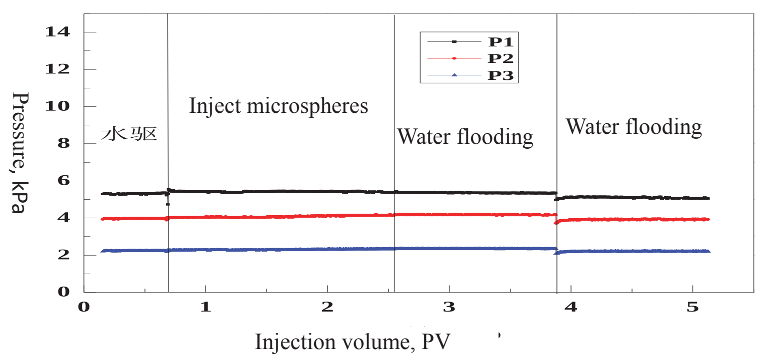


Figure 4: Displacement pressure of different positions of 10D model.

4.2.4 Underground starch graft copolymer gel dynamic performance evaluation

The starch system was injected into different permeability models to test its resistance factor and residual resistance factor. The results are listed in Tab. 8 and the high residual resistance factor and high plugging percentage prove that the system has high plugging strength.

Table 8: Resistance characteristics of underground starch graft copolymer gel.

Number	1	2	3
Permeability of Fracture (D)	213	196	88
Breakthrough pressure (MPa)	7.06	28.28	30.77
Resistance factor, Fr	2.2	13.8	14.4
Residual resistance factor, Frr	54.3	73.4	106.3
Plugging percentage (%)	98.16	99.03	97.22

5 Conclusion

1. For the particle type water control agent (pre-linked gel particles and emulsion microspheres), emulsion microspheres are not suitable to fractures, whose permeability is 10D or more; pre-linked gel particle KL-1(2$\sim$4mm) has good plugging adaptability to fractures of 150D, while not suit to fractures of permeability less than 100D. So, the particle size of and distribution are crucial characters for the plugging property. The particle size should be must be adaptable with the fracture width, not be too big or small, which is very difficult to control.

2. For the continuous chromium, the plugging percentage and breakthrough pressure gradient when polymer concentration is 5000mg/L are both higher than those when polymer concentration is 3000mg/L. That indicates the added polymer concentration is higher, the viscosity is higher, with higher plugging strength. Meantime, high polymer concentration will lead to poor injectivity (high viscosity on ground) and high cost. Therefore the plugging and strength should be coordinated.

3. For the starch graft copolymer gel, its viscosity (56mPas) is very low before gelation, and the resistance factor in different fractures is low. The high residual resistance factor and high plugging percentage indicates that the starch has high plugging strength. So it is easy to be injected into formation and has good plugging property.

4. Through feasibility evaluation, underground starch graft copolymer gel is more suitable to be used for water control in low permeability formation than the other three water control agents.

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