Selective Water Shutoff Mechanism of Double-Crosslinked Gel-Type Selective Plugging Agent (Org)

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Abstract. In this paper, the selective plugging capacity of ORG plugging agent under different temperatures, different permeabilities and the same injection pressure was studied by using a self-made selective plugging simulation device. With the increase of core permeability, the water plugging rate and oil plugging rate increased, while the water plugging rate and oil plugging rate were low due to the low permeability core, but all showed good selective water plugging capacity. And the theory of molecular action of cationic polymer adsorption on rock surface was studied in the ORG plugging agent. The plugging mechanism of ORG plugging agent in the rock pore was studied.

1. Introduction

The double cross-linked gel-type plugging agent had dense grid porosity, full-scale structure which outer network was filled with inner network and the water retention and viscoelasticity of gels was pretty good [1-3]. Also, double cross-linked gel can selectively enter the fracture according to the size of the permeability of the fracture, mainly blocking the large fractures, the water plugging rate of the system was far greater than the oil plugging rate [4-5]. Then the high blocking property of the gel system came from physical plugging and surface adsorption [6]. The wettability of the rock surface mainly affected the surface adsorption of the gel system. The double cross-linked gel had a high degree of swelling in the simulated formation water, and the hydrogel-expanded gel had a high shrinkage in the crude oil [7]. So in this paper the selective water shutoff experiment and the plugging mechanism of ORG plugging agent in the rock pore were studied for providing theoretical support for the application of double cross-linked gel-type plugging agent, and providing technical support for the high and stable output of the oilfield.

2. Experimental section

2.1. Material

4 different permeability cores, 2% KCl solution, kerosene, ORG plugging agent, 14-hydroxystearic acid and crude oil A.

2.2. Selective water shut-off simulation device

The entire selective water shut-off simulation device consisted of five parts:
(1) Injection system: high-pressure with constant speed and constant pressure pump (HBS-04, rated pressure: 25MPa, rated displacement: 0.01-6ml/min) and manual pump (HDS-1, rated pressure: 50MPa).

(2) Liquid storage system: four high-pressure containers and filters. Three common high-pressure containers (ZR-1, rated pressure: 32MPa, volume: 1000ml) were stored selective plugging agent, water and kerosene respectively. An acid-resistant high-pressure container (ZR-6, rated pressure: 32MPa, volume: 500ml) was stored plugging removal acid. Four filters (G-1, rated pressure: 50MPa).

(3) Oil layer simulation system: inner tube (simulated tubing), outer tube (simulated slotted tubing) and four core holders. Four oil layers with different properties were simulated by four different positions of the core holder.

(4) Measurement system: pressure gauges, collectors and stopwatches.

(5) Constant-temperature system: control temperature ~ 90°C

2.3. Device function

(1) Simulation of selective water shutoff test, plugging rate, breakthrough pressure, water and oil plugging rate of the plugging agent were measured.

(2) When injected the same plugging agent, the plugging rate of different layers were stimulated.

(3) The selective water shutoff and oil shutoff of the plugging agent was evaluated.

3. Result and discussion

3.1. Indoor simulation experiment of selective water shutoff

3.1.1. Effect of experimental temperature on selectivity. Four core samples with different permeability were selected. The experimental temperature was 40°C and 60°C, experiment with four cores respectively, injecting plugging agent. When the end of one of the cores had the plugging agent exudation, the experiment was stopped. Maintenance at the experimental temperature for 48h, making the ORG plugging agent become a gel and the water plugging rate of the plugging agent was measured. The experimental data was shown in Table 1.

| Experiment number | Permeability×10⁻³μm² | Water plugging rate % |
|-------------------|----------------------|-----------------------|
|                   |                      | 40°C | 60°C   |
| 1                 | 59.8                 | 53.2 | 58.7   |
| 2                 | 269.7                | 69.8 | 70.9   |
| 3                 | 689.1                | 80.1 | 85.9   |
| 4                 | 2351.7               | 93.5 | 95.6   |

It can be seen from Table 1 that the greater the core permeability, the higher the blockage rate. During the two experiments, the cores with high permeability and the plugging agent preferentially exuded, which proved that the plugging agent had completely filled the fourth core pores. However, in low permeability cores, less plugging agent went into the pores and the water plugging rate was significantly lower.

Comparing with the two experimental temperature points, the temperature had little effect on the plugging rate of the plugging agent. According to the evaluation experiment of the plugging agent, the temperature had a strong influence on the gel forming time of the plugging agent, but had little effect on the gel strength. Maintenance at 40°C and 60°C for 48h, the plugging agent had been basically gel, the gel strength no longer changed. Therefore, temperature had little effect on gel strength. In the subsequent simulation test, the general choice of 60°C as the maintenance temperature.
3.1.2. Under the same injection pressure, the effect of water and oil shutoff rate of the ORG plugging agent. At 60°C, four different permeability cores were chosen and injected ORG plugging agent, when the end of one of the cores had the plugging agent exudation, the experiment was stopped. Maintenance at the experimental temperature for 48h, making the ORG plugging agent become a gel in the core. The plugging rate was measured with 2% KCl solution. Another four different permeability cores were selected, repeating the above experimental process and oil plugging rate of the ORG plugging agent was measured by kerosene. The experimental data was shown in Table 2.

Table 2. The water and oil plugging rate of the ORG plugging agent

| Experiment number | Water plugging experiment | Oil plugging experiment |
|-------------------|---------------------------|-------------------------|
|                   | Permeability×10⁻³μm²      | Water plugging rate     |                         |
| 1                 | 58.7                      | 55.2                    | 78.4                    |
| 2                 | 271.4                     | 68.7                    | 310.7                   |
| 3                 | 687.9                     | 80.5                    | 756.8                   |
| 4                 | 2157.1                    | 91.0                    | 2223.6                  |

It can be seen from Table 2 that with the increase of core permeability, the water plugging rate and oil plugging rate increased. Mainly due to the influence of experimental conditions, when the experiment was carried out, when the plugging agent appeared in the fourth high-permeability core, the injection was stopped, the injection pump was closed and maintenance started. At this point, the plugging rate was low due to the low injection pressure and the access of low-permeability cores with very few plugging agents. After the experiment, the core cut open, which can prove this phenomenon that the lower the permeability of the core, the less access to the plugging agent. When the fourth core had been fully filled, the first core just entered the end of 1~2cm.

3.2. Selective water shutoff mechanism of the ORG plugging agent

The ORG plugging agent for indoor research mainly consisted of cationic polyacrylamide and cross-linking agent. In the range of 40°C ~80°C the gel-forming, the gelling time can be adjusted between 4h and 50h, the gel strength was more than 5000mPa·s, the gel body was very stable after being gelled, and was not influenced by acidity and salinity. ORG plugging agent mainly played a role in selective water shutoff in the following two aspects:

3.2.1. Adsorption properties on the rock surfaces of the ORG plugging agent. Adsorption was an intrinsic property of adsorbate, when the cationic polymer solution and mineral surface contacted, it produced adsorption. Detention was a dynamic adsorption. In practice, it was impossible to separate the adsorption and retention quantitatively. For ORG plugging agent, due to its complex composition, it was almost impossible to determine the adsorption and retention of ORG plugging agent by chemical analysis. In this experiment proposed an ideal model: the synthetic quartz sand in the core was treated by silicone oil, making quartz sand surface cover with a layer of oil film and the choice of cement was lipophilic unsaturated resin so that the entire core surface covered with a layer of oil film, to prevent the cationic polymer molecules and mineral surfaces in direct contact. In this case, it was considered that the blocking of the cationic polymer was caused by retention. Similarly, the surface of the selected quartz sand was not treated, then considering the core permeability reduction was due to adsorption and retention results. Different cores were choseed, surface of core A was treated and surface of core B was untreated. The change of the permeability of two cores before and after the plugging was measured and calculated the blocking rate. The result was shown in Table 3.
It can be seen from Table 3 that after the plugging of the core, the decrease in permeability was mainly due to the retention of the gel. In the surface-treated core, the plugging rate was 87.2%, and it can be considered that the plugging rate was caused by the retention of the gel. In the surface-untreated core, the plugging rate was 99.7%, the plugging rate was the result of gel retention and adsorption and the difference between them was 12.5%. It was believed that the difference of the plugging rate was due to the adsorption of the gel on the surface of the core. And the increase of the adsorption capacity can improve the scouring resistance of the plugging agent. An excellent ORG plugging agent must have the role of adsorption and retention on the rock surface, it not only had good plugging rate, but also had good erosion resistance.

3.2.2. Blocking ability of selective plugging agent gels on rock cores. In order to investigate this theory, 14-hydroxystearic acid and crude oil A were used as oil-based gels. Low-temperature catalytic cross-linking reacted above 60°C and 14-hydroxystearic acid dissolved in crude oil A. The formation of opaque gel, this reaction can be heated by the reaction in the opposite direction of transfer. For oil-based gels, two different gels were used for core experiments. In each experiment, the colloid with a plastic viscosity of 10 mPa·s was injected into the highly permeable core at 60°C and after injection into the gel, maintance at 60°C for 3 days. For 2% of 14-hydroxystearic acid of oil-based colloids, the residual drag coefficient Fr was measured at different flow rates. The data was shown in Table 4.

| Gelling agent                  | First oil drive Fro | First water drive Frw | Second oil drive Fro |
|--------------------------------|---------------------|-----------------------|----------------------|
| 2% 14-hydroxystearic acid, Crude Oil A | 26                  | 1                     | 3                    |
| 4% 14-hydroxystearic acid, Crude Oil A | 36                  | 2                     | 18                   |

4. Conclusion  
(1) The selective plugging capacity of ORG plugging agent under different temperatures, different permeabilities and the same injection pressure was evaluated using a self-made selective plugging simulation device. With the increase of core permeability, the water plugging rate and oil plugging rate increased, while the water plugging rate and oil plugging rate were low due to the low permeability core, but all showed good selective water plugging capacity.

(2) The selective water shutoff mechanism of the ORG plugging agent mainly consisted of the adsorption of cationic polymer and selective gel plugging agent. ORG plugging agent preferentially entered the aqueous channel to form a gel that reduced the core's water phase permeability.

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