Study on the loss control performance of smart adhesive lost circulation materials with Ethylene Vinyl Acetate Copolymer (EVA)

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Abstract: The conventional lost circulation materials (LCMs) particles of seal in the formation are in linear contact. Therefore, there is no cohesive force interaction, which is susceptible to pressure fluctuations, resulting in lost circulation and control failure. In response to these problems, this paper tested the high-temperature adhesion properties of EVA in the viscous flow transition zone through high-temperature adhesion experiments; then a smart adhesive LCMs is prepared using thermoplastic EVA resin with conventional LCMs; finally, through the high-temperature and high-pressure plugging experiment, the system's performance for sealing fractures was tested. The experiment results show that the smart adhesive LCMs have good plugging performance and can bond LCMs in the fracture to form a high-strength sealing with a pressure-bearing capacity of up to 9.3MPa.

1. Introduction

Lost circulation is a situation where less fluid is returned from the wellbore than is pumped into it. It has been a severe problem while drilling, leading to high financial costs in lost rig time and safety consequences[1-4]. Hence, preventing and control lost circulation immediately while drilling or control losses as soon as possible is very important for quick, safe, and economical drilling operations[5-11].

In the drilling engineering site, rigid materials are commonly used as lost circulation materials, but their compatibility with a fracture is poor, and it is easy to cause sealing out the fracture. Gel has insufficient pressure-bearing capacity and difficulty to control gel-forming time, lacking compatibility with drilling fluids, and is easy to cause sealing failure under high-temperature conditions. The expansion of water/oil-absorbing polymer is not easy to control, and it is accessible to plugging failure at high temperatures [12]. Therefore, it is essential to develop a new type of lost circulation material.

Here, we propose a new class of smart adhesion lost circulation material (LCM) to control the adhesive force and functionality of injected LCM remotely. The smart adhesive LCMs consist of plastic resin and rigid particles, which can be activated by formation temperature. First, the high-temperature adhesion properties of EVA in the viscous flow transition zone are tested through high-temperature adhesion experiments. Then, the smart adhesive LCMs of sealing performance is tested by high-temperature and high-pressure plugging experiments. The results show that the smart adhesive LCMs
can plug various fracture geometries and bond LCMs in the fracture to form a high-strength sealing with a pressure-bearing capacity of up to 9.3MPa.

2. Experiments

2.1 Materials
EVA, was purchased from Sinopec Yanshan Petrochemical company; sodium chloride (AR) was received from Budweiser Technologies Limited (Shanghai, China); Bentonite was purchased from CNPC Bohai Drilling Engineering Co., Ltd (China).

2.2 Experimental equipment
BGRL-2 roller heating furnace, Qingdao Tongchun Petroleum Instrument Co., Ltd. China; Six-speed rotating viscometer, Qingdao Haitongda Special Instrument Co., Ltd., China; ZNZ-D3 medium-pressure filtration apparatus, Qingdao Haitongda Special Instrument Co., Ltd., China; High-temperature and high-pressure plugging Apparatus, Qingdao Tongchun Petroleum Instrument Co., Ltd. China; High-Temperature and High-Pressure Visualizer, Jiangsu Haian Petroleum Scientific Research Instrument Co., Ltd China; Mastersizer 3000 laser particle size analyzer, Malvern Panalytical Ltd, United Kingdom; TGA550 thermogravimetric analyzer, American TA instrument, American.

2.3 Experimental method
(1) Particle size analysis
Put the thermoplastic resin particles into ageing furnaces at different temperatures, and measure their particle size distribution with a Mastersizer 3000 laser particle size analyzer. Then the particle size distribution of the thermoplastic resin at different temperatures was compared.

(2) Analysis of high-temperature adhesion characteristics
Put the thermoplastic resin particles into a high-temperature and high-pressure visualization device to observe the melting and adhesion characteristics of the thermoplastic resin particles in a high-temperature liquid.

(3) Evaluation of compatibility of drilling fluid
The drilling fluid containing a specific concentration of thermoplastic resin particles is put into an ageing tank, placed in a roller heating furnace for ageing, taken out at regular intervals, and the rheological properties of the drilling fluid before and after ageing are measured. Then, the apparent viscosity (AV), plastic viscosity (PV), and yield point (YP) were calculated.

(4) High-temperature and high-pressure plugging experiment
The high-temperature and high-pressure plugging apparatus were used to develop the adhesion plugging effect of the temperature-sensitive adhesive resin plugging system in the fractures.

3. Results and discussion

3.1 High temperature adhesion characteristics of EVA
The adhesive experiment of EVA resin particles in the high-temperature liquid phase is shown in Figure 1. It can be seen from Figure 1 that at room temperature, the EVA resin particles are uniformly dispersed in the liquid phase. As the temperature increases, the EVA resin particle size remains stable. However, when the temperature rises to 80°C, the surface of the EVA resin particles begins to melt and maintain a specific particle shape. The EVA resin particles have a greater viscosity and have a certain elasticity. Therefore, EVA resin particles have strong adhesion and plugging effect in high-temperature formations.
3.2 Thermogravimetric analysis

It can be seen from Fig 2 that when the temperature is less than 300°C, the weight of the EVA resin almost does not change. When the temperature is greater than 300°C, as the temperature rises, the EVA resin begins to show a significant weight loss platform and begins to decompose at this time. Therefore, EVA resin has high-temperature resistance and can adapt to high temperature and complex conditions in the well.

3.3 The influence of smart adhesive LCMs on the properties of drilling fluid

Table 1 and Figure 3 show the influence of EVA resin particles on the rheology of drilling fluids. Figure 4 shows the changes in plastic viscosity and dynamic shear force of drilling fluid before and after the ageing of EVA particles under different concentrations. It can be seen from the figure that after adding EVA particles to the bentonite-based drilling fluid, when the bottom hole temperature is lower than the resin's viscous temperature, the plastic viscosity and dynamic shear of the drilling fluid will increase. The high dynamic shear force indicates that adding EVA particles can increase the carrying cutting of the drilling fluid. After high-temperature ageing, the plastic viscosity and dynamic shear of EVA particles decrease. As the concentration increases, the dynamic shear first increases and decreases, indicating that the EVA resin with a lower concentration has less aggregation and bonding ability under high-temperature conditions. When the concentration is higher, the EVA resin has a better aggregation and bonding ability. When the concentration is 8%, the dynamic shearing force drops rapidly, and the EVA resin has the best aggregation and bonding ability at this time.
Table 1 Influence of Smart adhesive LCMs on drilling fluid performance

| Concentration of EVA/% | Test conditions | AV mPa·s | PV mPa·s | YP Pa | FL-API mL |
|-----------------------|----------------|----------|----------|-------|-----------|
| 0                     | Before aging   | 7.5      | 5.5      | 2     | 27.8      |
|                       | After aging    | 6        | 2        | 4     | 19.2      |
| 2                     | Before aging   | 15       | 10       | 5     | 20        |
|                       | After aging    | 21.5     | 15       | 6.5   | 24        |
| 4                     | Before aging   | 16.5     | 7        | 9.5   | 19.5      |
|                       | After aging    | 21.5     | 17       | 4.5   | 24        |
| 6                     | Before aging   | 16       | 7        | 9     | 19        |
|                       | After aging    | 21       | 14       | 7     | 24        |
| 8                     | Before aging   | 17.5     | 9        | 8.5   | 19        |
|                       | After aging    | 17.5     | 14       | 3.5   | 24        |

(a) The effect of EVA on the PV of drilling fluid (b) The effect of EVA on the YP of drilling fluid

Figure 3 The effect of EVA on the Rheology of drilling fluid

Figure 4 shows the change in the fluid loss of bentonite-based drilling fluid after adding different concentrations of EVA resin particles before and after ageing. It can be seen from the figure that by adding 2% of EVA resin particles, the fluid loss of the drilling fluid has decreased. As the concentration
increases, the fluid loss remains unchanged. After high-temperature ageing, the fluid loss increases due to the high-temperature adhesion of EVA resin. Therefore, the EVA resin particles can block the tiny pores of the formation at low temperatures and have a particular effect of reducing fluid loss. Under high temperatures, adhesion and aggregation can be formed to form a specific strength sealing layer in the wellbore hole or fracture.

3.4 Evaluation of plugging performance of smart adhesive LCMs

The pressure-bearing capacity of Rigid particles, EVA resin particles, and smart adhesive LCMs were tested by high-temperature and high-pressure plugging apparatus at 25°C and 80°C (as shown in Tables 2 and 3).

1) Rigid particles plugging experiment at different temperatures

| Concentration/% | Temperature/°C | Particle size/Mesh | Fracture width/mm | Pressure-bearing capacity/MPa |
|-----------------|-----------------|--------------------|--------------------|-------------------------------|
| 5               | 25              | 20-40              | 1                 | 2.2                           |
|                 | 80              | 20-40              | 1                 | 2.1                           |
| 10              | 25              | 20-40              | 1                 | 4.6                           |
|                 | 80              | 20-40              | 1                 | 4.7                           |
| 15              | 25              | 20-40              | 1                 | 7.1                           |
|                 | 80              | 20-40              | 1                 | 7.0                           |
| 20              | 25              | 20-40              | 1                 | 7.1                           |
|                 | 80              | 20-40              | 1                 | 7.2                           |

Figure 5 shows the high-temperature and high-pressure plugging experiment of rigid particles at 25°C and 80°C. It can be seen from the figure that the plugging effect of rigid particles is the same at room temperature and 80°C. When the concentration of rigid particles is less than 5%, the rigid particles cannot form an effective sealing in the fracture. When the concentration of rigid particles is equal to 5%, the rigid particles can form a sealing in the fracture. When the concentration of rigid particles is greater than 5%, as the concentration increases, the pressure-bearing capacity continues to increase. When the concentration is greater than 15%, the pressure-bearing capacity of rigid particles is unchanged. Therefore, there is an optimal LCMs concentration for the rigid particles.

2) Plugging experiment of smart adhesive LCMs at different temperatures

The ratio of rigid particles to thermoplastic resin in the smart adhesive LCMs used in the plugging experiment is 4:1.
### Table 3 Plugging experiment of smart adhesive LCMs

| Concentration/% | Temperature/°C | Particle size/Mesh | Fracture width/mm | Pressure-bearing capacity/MPa |
|-----------------|----------------|-------------------|-------------------|-------------------------------|
| 5               | 25             | 20-40             | 1mm               | 2.3                           |
| 10              | 80             | 20-40             | 1mm               | 4.6                           |
| 15              | 25             | 20-40             | 1mm               | 4.7                           |
| 15              | 80             | 20-40             | 1mm               | 6.5                           |
| 20              | 25             | 20-40             | 1mm               | 7.2                           |
| 20              | 80             | 20-40             | 1mm               | 8.7                           |

Figure 6 The plugging experiment with smart adhesive LCMs

Figure 6 shows the high-temperature and high-pressure plugging experiment of smart adhesive LCMs at 25°C and 80°C. It can be seen from figure 6 that under 25°C, the plugging law of smart adhesive LCMs is the same as that of the rigid particles. However, when the temperature rises to the viscous flow transition temperature range of EVA resin, the pressure-bearing capacity of smart adhesive LCMs is greater than that of rigid particles and EVA resin particles alone, and the maximum pressure-bearing capacity can reach 9.3MPa. The reason is the rigid particles play the role of bridging, jamming, and filling in the structure of the sealing layer. On the other hand, EVA resin particles play a crucial role in the structure of the sealing, which can bond rigid particles or fractures to form a high-strength sealing.

### 4. Conclusion

Compared with traditional LCMs, the smart adhesive LCMs have better plugging performance. In this study, High temperature adhesion characteristics of EVA showed that the smart adhesive LCMs can be partially melted with specific viscoelastic properties in the viscous flow transition temperature range in the viscous flow transition temperature. When the smart adhesive LCMs are used in the plugging fracture, the pressure-bearing capacity can be significantly improved compared with the rigid particles used separately. This is because the rigid particles play the role of bridging, jamming, and filling in the structure of the sealing layer. In addition, EVA resin particles play a crucial role in the structure of the sealing, which can bond rigid particles or missing channels to form a high-strength loss plugging layer. Therefore, the smart adhesive LCMs is recommend as an effective lost circulation materials.

Compared with traditional LCMs, the smart adhesive LCMs have better plugging performance. In this study, EVA's high-temperature adhesion characteristics showed that the smart adhesive LCMs could be partially melted with specific viscoelastic properties in the viscous flow transition temperature range
in the viscous flow transition temperature. When the smart adhesive LCMs are used in control lost circulation, the pressure-bearing capacity can be significantly improved compared with the rigid particles used separately. The reason is that the rigid particles play the role of bridging, jamming, and filling in the structure of the sealing layer. In addition, EVA resin particles play a crucial role in the sealing structure, which can bond rigid particles or missing channels to form a high-strength loss plugging layer. Therefore, the smart adhesive LCMs recommend as an effectively lost circulation material.

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