Evaluation of Deep Migration Performance of Large Size Elastic Profile Control Particles

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Abstract. In this paper, aiming at a millimeter scale large size elastic profile control particle used in field application, an evaluation experiment on the performance of deep migration was designed, the corresponding fracture model and replacement device were made and the relevant data solution method was proposed. The effects of the fracture width, particle mass fraction and particle injection velocity on the deep migration ability of the particles were evaluated respectively. At the same time, the plugging ability of the fractured filling particles for the water flow was evaluated. The fracture width has a great influence on the pressure threshold of the particle through the fracture, while the particle mass fraction and displacement injection velocity have a certain influence on the pressure threshold, but it is not very obvious. The particle plugging system is very poor in the ability of plugging and diversion. The water film bridge is formed in the interval between fractures and has great permeability to water flow. Compared with rigid particles, elastic particles increase the deep migration ability, but the pressure capacity of plugging is weakened, so it needs to be combined with other profile control systems in practical application.

Introduction

At present, most of the oil fields in China belong to the development of water injection. The biggest problem in the process of water injection development is the short period of oil production without water. With the increase of developing time, the water content is constantly improved and the production of the oil field is affected. In view of the high water cut problem [1], oil researchers have put forward various kinds of profile control methods successively. In recent years, deep profile control technology has been developed greatly. Oil researchers have developed a variety of deep profile control agents, including expansion grains, delaying cross linked particles and pre-crosslinked particles, there are also many kinds of laboratory evaluation methods for these particles. At present, there are few laboratory evaluation experiments related to large size elastic particles in the literature [2]. This paper is based on a kind of elastic profile control particle with millimeter diameter. In this paper related models and equipments are made to evaluate the ability of the particle passing through the fracture. Through the evaluation of ability of passing through the fracture, it is also the evaluation of the deep migration ability of particles [3].

The experimental object is a large particle size particle used in field oil field, with a particle diameter of about 3mm, with high elasticity and shear resistance, which ensures that it can pass through pores and fractures which are smaller than itself, thus entering the deep part of the stratum to realize the steering effect on the fluid flow [4]. The elastic particles are widely used in the field because of its low cost, but the field effect is not obviously good. At present, the laboratory evaluation experiment on this kind of particles is limited to its millimeter size. The commonly used evaluation...
methods of transport and plugging capability of particles cannot be conducted. Therefore, in this paper, relevant experiments are designed to analyze the influence of the different mass fraction of particles. The different width of the fracture and the different injection velocity of particles on the pressure threshold of the particle deformation through the crack. The plugging capacity of the particle system for the water flow is also evaluated\[^5\].

**Experimental Method and Equipment**

Because the diameter of the elastic particle is 3 millimeter, the size of the conventional device in the laboratory can not meet its experimental requirements, and the conventional core displacement experiment can not be conducted. According to the innovative design of the existing equipment in the laboratory, the particle displacement device is designed, and the fracture models with different widths are customized (The width of the fracture is 1mm, 3mm, 5mm, and the thickness of the model is 10mm). The particle solution is loaded into the piston container, and the bottom piston power is input through the ISCO pump to replace the particles to the top crack. The pressure sensor is used to record the pressure change at the displacement piston in real time, and the corresponding relation curves are observed to analyze the process of the particle deformation through the fracture. The specific experimental device is shown in Fig.1.

![Figure 1. Schematic diagram of the experimental device.](image)

The principle of the experimental analysis method is to use pressure sensors to record the data on the computer and draw the injection pressure—time curve to analyze the migration performance of particles. The pressure diagram can be divided into the following stages: the untouched stage, the plugging stage, the plateau stage and the rushing stage.

The untouched stage: Because the position of the particle system has a certain distance from the top of the crack model, the pre-stage pressure is only the driving force of the piston, and the value is very small and will not change.

The plugging stage: The particles began to contact the crack model and the pressure increased. During this stage, the particles gradually blocked up the fracture model and prevented the upward movement of the subsequent particles.

The plateau stage: As the particle system continuously blocking the fracture, the pressure rises until the pressure value reaches the threshold, forcing the top particles to deform and pass through the cracks. In this stage, the phenomenon of the deformation of the front particles—displacement particles enter into cracks—the deformation of displacement particles continues to happen. The pressure fluctuates on a certain base value. This average pressure is defined as the particle deformation through pressure, that is, the maximum plugging pressure of particles to the fracture.

The rushing stage: After most of the particles are replaced out of the fracture, the piston gradually rises to contact with the top crack model, and the pressure will rise sharply at this time. This stage has not much analysis for the particles.
The plugging stage and the platform stage are key points of researching. These two stages directly represent the plugging ability and migration ability of particles.

**Related Experiments and Data**

Using the above replacement device, fracture models and analysis method, the experiment of different particle mass fraction, the experiment of different injection velocity and the experiment of particle plugging ability have been conducted.

(1) Comparison experiment of different mass fraction of particles

A contrast experiment was carried out with 20ml distilled water as the base fluid, and the mass fraction of profile control particle solution was 20%, 35% and 50% respectively. The ISCO pump displacement velocity is set to constant speed 5ml/min. According to three different fracture models, 9 experiments were carried out to investigate the plugging ability of the particles with different mass fraction. The nine sets of experimental results are shown in Table 1.

<table>
<thead>
<tr>
<th>Particle Mass Fraction (%)</th>
<th>Fracture Width (mm)</th>
<th>Deformation Pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1</td>
<td>0</td>
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<tr>
<td></td>
<td>3</td>
<td>0</td>
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<td></td>
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(2) Contrast experiment of different injection velocity

Using 20ml distilled water as the base fluid, the profile control particle solution is disposed. According to the contrast experiment of different particle mass fraction, it is considered that the particle solution of 50% mass fraction has the most continuous and the most obvious changing through the fracture, so 50% mass fraction of the particle solution is selected for the experiment under the condition of changing the flow rate.

The displacement velocity of ISCO pump is changed to 10mL/min, 15mL/min and 20mL/min respectively, and the pressure threshold of the particle system passing through the fracture at different injection speeds is investigated, and the effect of flow velocity on the particle deformation through pressure is evaluated. The three sets of experimental results are shown in Fig. 2, and the specific values are shown in Table 2.
Figure 2. Comparison results of three fracture models at different injection speeds (From left to right, the injection speed is 10ml/min, 15ml/min and 20ml/min; Blue line means 1mm fracture, red line means 3mm fracture, green line means 5mm fracture.)

Table 2. Experimental results of different mass fraction of three fracture width models.

<table>
<thead>
<tr>
<th>Injection Velocity (ml/min)</th>
<th>Fracture Width (mm)</th>
<th>Deformation Pressure (MPa)</th>
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<tbody>
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<td>10</td>
<td>1</td>
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<tr>
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</tbody>
</table>

(3) Experiment on the capacity of water flow blocking by particles

The pre-blocked cracks were made by the particle mass matching experiment (experiment 1). The pre-blocked fracture model is loaded into the replacement device which is equipped with distilled water. ISCO pump is used to conduct the displacement experiment. In order to achieve the maximum theoretical blocking effect, the 1mm crack is selected as the pre-blocking model. Three groups of experiments were conducted in a constant flow velocity displacement of 10ml/min, 15ml/min and 20ml/min to explore the ability to block the water flow of elastic particles after the fracture was filled. The result is shown in Fig. 3.

Figure 3. Plugging performance of particles to 1mm fracture width model at different injection rates (From left to right, the injection speed is 10ml/min, 15ml/min and 20ml/min).

Experimental Analysis Results

(1) Comparison experiment of different mass fraction of particles
The fracture width affects the deformation through pressure and deformation through time. Under the same mass fraction, the smaller the width of the fracture is, the higher the deformation through pressure of the elastic particles is, the longer the deformation through time is. The deformation of the elastic particles is associated with the mass fraction of the particles. Under the condition of low mass fraction, the particles will not block the fracture, but flow out of the fracture. 20% mass fraction particles cannot produce effective blocking on three kinds of width fracture model. 35% mass fraction and 50% mass fraction of particle plugging system can observe plugging stage and platform stage with blocking effect. After reaching the plugging mass fraction, the particle mass fraction is different, but the deformation through pressure has little difference.

(2) Contrast experiment of different injection velocity

The injection velocity has no obvious influence on the deformation pressure of the elastic particles through different sizes of fractures, and the deformation pressure of the elastic particles is mainly dependent on the width of the fracture. No matter how much the injection speed is set, after the particles are blocked at the end surface of the fracture, the subsequent particles and solutions will keep pressing the particles in the fracture. When the pressure reaches the threshold of the corresponding particle to the fracture, the particles will be deformed through the fracture.

(3) Experiment on the capacity of water flow blocking by particles

The results of the experiment are true but not ideal. Due to the large size of the elastic particles, even if the elastic particles are filled fully, the fracture cannot be completely sealed. The flow will flow down the tiny pores between the particles. In the experiment, it is intuitively observed that the particles are blocked very closely and has only some small gaps, but the actual permeability to the flow is higher. There is no resistance to the flow of water. This phenomenon is due to the formation of a water film bridge between the wetting particles, which leads to the flow of water around the particles and flow out of the crack model through the water film-liquid bridge.

Summary

(1) In this paper, three fracture models with different width are designed and made for the elastic particles with millimeter diameter, and the existing experimental instruments in the laboratory are reformed. Finally, the displacement device of the particle fracture model is designed to record and analyze the pressure changes of the particles passing through the fracture under different conditions. An analytical method for injection pressure-time curve is presented.

(2) The effect of the fracture width, particle mass fraction and displacement injection velocity on deformation pressure threshold of particle through the fracture is evaluated, and the plugging capacity of the elastic particle system for the water flow is evaluated. The result is that the fracture width has a great influence on the pressure threshold of the particle deformation through the crack, the particle mass fraction and displacement injection velocity have a certain influence on the pressure threshold, but it is not very obvious. The plugging ability of particle system is very poor for water flow. The water film bridge which is formed in the gap between particles has great permeability to water flow.

(3) The purpose of elastic particles is deep migration and plugging, therefore, it has no strong plugging ability and strong bearing capacity which rigid particles have. Its elastic deformation capacity is improved, which means that the capacity of plugging is weakened. The elastic particles need to be used in conjunction with other profile control systems in the process of profile control.

Acknowledgement

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References


