

Study on Optimum Selection Method of Additives for Slick-Water Fracturing Fluid

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Abstract: In order to clarify the research idea of fluid system optimization in slick-water fracturing, a scientific and effective single-agent optimization method was selected to study the performance optimization method and performance evaluation method of drag reducer, clay stabilizer and cleanup additive in slick-water fracturing fluid. The specific experimental steps and application examples were investigated. To select the drag reducer, the drag reduction rate rate of the drag reducer at different concentrations should be measured first, the optimal concentration of a single agent should be selected, and then the stability test of temperature, flow rate and shear time should be performed on the optimal concentration of a single agent, and finally the combination formula with high drag reduction rate rate and stable performance can be selected. To optimize the clay stabilizer, the optimal concentration of single agent should be obtained by measuring the anti-swelling rate of different single agent and different concentration, and then the anti-swelling rate of each compound formula should be determined according to the optimal concentration of single agent, and finally the anti-swelling performance of the composite combination should be evaluated according to the core flow experiment. The optimal concentration of a single agent should first be optimized according to the surface tension of the cleanup additive, and then the combined formula should be optimized according to the surface tension of the combined combination, and the cleanup additive ability should be evaluated by core spontaneous imbibition or measuring the increase rate of cleanup additive.

Keywords: Slick-water fracturing fluid, Drag reducer, Clay stabilizer, Cleanup additive.

1. Introduction

Slick water fracturing fluid is one of the most widely used fracturing fluid systems in oil and gas field development. It is mainly composed of additives such as water, drag reducer, cleanup additive and clay stabilizer. Slick-water fracturing fluid has the characteristics of low damage, low friction and easy to carry sand, which can effectively reduce the friction and surface pumping pressure of large displacement pump, and increase the displacement of pump. There are great differences in the physical properties of oil and gas reservoirs in China, so it is difficult to fracturing all reservoirs with one component formula when using slick water fracturing fluid. The key to achieve efficient fracturing is to properly adjust the composition of slick water fracturing fluid according to the physical properties of reservoirs.

2. Optimization of Drag Reducer

Drag reducer is one of the core additives in slick-water fracturing fluid. Drag drag reducer mainly includes natural macromolecules and synthetic polymers. The main synthetic polymers are polyacrylamide and its derivatives, and the natural macromolecules are mainly guanidine gum, xanthan gum, and other plant gum and its derivatives. Polyacrylamide polymers are widely used in slick water fracturing fluids because of their high drag reduction rate and low damage rate to the reservoir after gumming.

2.1. Influence of concentration on drag reduction rate

Xing Liang [1] carried out two sets of experiments to study the relationship between the concentration of drag reducer and the drag reduction rate. The first set of experiments simulated the situation of adding drag reducer to improve the

drag reduction rate when the actual construction drag reduction rate decreased: Add the drag reducer to the test fluid with a concentration of 100ppm in water to test its drag reduction rate at different flow rates, and constantly add drag reducer to the test fluid to determine the drag reduction rate at the cumulative concentration of 200ppm, 300ppm, 400ppm, 500ppm, and analyze the change law of the drag reduction rate in the low flow rate zone and high flow rate zone. The relationship between the drag reduction rate rate and the accumulated concentration in different flow velocity zones is obtained. The second group of experiments selected the optimal concentration of single agent by comparing the drag reduction rate rate of 0.01%, 0.03%, 0.05% and 0.07%.

2.2. Influence of temperature on drag reduction rate

Xing Liang [1] conducted two sets of tests to study the relationship between apparent viscosity of drag reducer and temperature and shear rate. The first set of tests measured the apparent viscosity of three different types of drag reduction agents between 25°C and 100°C, and analyzed the influence of temperature of different drag reducer on viscosity, and evaluated the stability of different drag reduction agents at high temperatures. In the second group of tests, the constant temperature was 90°C, and the viscosity of the fluid was measured at different time points from 30°C to 90°C, and the shear rate was 170S-1. In the test results, the double longitudinal curves of time-temperature and viscosity were drawn, so as to analyze the anti-shear performance of the drag reducer.

2.3. Influence of flow rate on drag reduction rate

When the concentration of drag reducer is constant, the drag reduction rate of different drag reducers is measured at

1.54-15.4m/s, and the maximum drag reduction rate and optimal flow rate range of different drag reducers are analyzed. When the flow rate is low, the drag reduction rate gradually expands with the increase of flow rate, and the drag reduction rate gradually increases until it reaches the maximum. When the flow rate further increases, the molecular bonds of the drag reducer molecules break in the state of external tension, and gradually increase until the drag reduction rate begins to decline. As a whole, the drag reduction rate was the first to increase, then stabilized, and then gradually declined.

2.4. Influence of shear time on drag reduction rate

After cyclic shear of different kinds of drag reducer for 30min under constant displacement, the drag reduction rate of each drag reducer at different time nodes was measured, time-drag reduction line diagram was drawn and the shear resistance of the drag reducer was analyzed. The overall trend showed a slow decline at first and then a steady trend.

The selection experiment of drag reducer follows that the drag reduction rate of different kinds of drag reducer with different concentrations at formation temperature is tested first, and then the stability test of temperature, flow rate and shear time is carried out according to the relative optimal concentration of different drag reducer. Finally, the drag reducer with large relative drag reduction rate and good stability is selected.

3. Optimization of Clay stabilizer

Most of the reservoirs in China contain clay minerals such as montmorillonite and illite. When the clay minerals contact with the slick-water fracturing fluid, hydration expansion and disperse migration will occur, causing water sensitive damage to the reservoir. Clay stabilizer is a key additive to inhibit the swelling of clay. Adding clay stabilizer to the slick-water fracturing fluid can effectively avoid the water-sensitive damage caused by fracturing fluid to the reservoir.

3.1. Centrifugal method was used to determine the anti-swelling rate

According to the centrifugal method in SY-T 5971-2016"Evaluation Method of clay Stabilizer Performance for Fracturing Acidification and water Injection of Oil and Gas Fields", the volume expansion of sodium bentonite powder in clay stabilizer solution and water was measured, and the anti-swelling rate B was calculated by formula (1) to evaluate the performance of clay stabilizer.

$$B = \frac{V_2 - V_1}{V_2 - V_0} \times 100\% \quad (1)$$

B -- Anti-swelling rate, %

V_0 -- volume of bentonite after centrifugation in water, ml

V_1 -- Volume of bentonite after centrifugation in a clay stabilizer solution, ml

V_2 -- volume of bentonite after centrifugation in kerosene, ml

3.2. Core flow test

According to SY-T 5971-2016 "Evaluation Method of clay Stabilizer Performance for Fracturing Acidification and water Injection of Oil and Gas Fields", core flow tests were conducted under simulated reservoir temperature conditions, and the change rate of permeability before and after injecting clay stabilizer was measured respectively, so as to evaluate the anti-swelling performance of clay stabilizer.

Experimental steps: The reservoir core was selected and injected with brine solution at the formation temperature. After the pressure stabilized, the initial permeability K_{f0} of the core was measured, and then the solution containing clay stabilizer was reversely injected and stood for 6h. Then the permeability of the core after treatment was measured again through the brine solution. The lower the permeability change rate is, the smaller the permeability change is, the better the anti-swelling performance of the clay stabilizer is

$$D_f = \frac{K_{f0} - K_f}{K_{f0}} \times 100\% \quad (2)$$

D_f -- permeability change rate, %

K_{f0} -- Core initial permeability, mD

K_f -- Permeability of treated core, mD

3.3. Clay stabilizer compounding experiment

In order to select the best clay stabilizer, the optimum combination of clay stabilizer was selected through the combination experiment of several clay stabilizers. Chen Yalian et al. [2] combined small cationic polymer clay stabilizer SM with inorganic clay stabilizer KCL and NH_4CL with a concentration of 0.25%~1% and a concentration gradient difference of 0.25% respectively, and optimized the optimal clay stabilizer formula. Shen Huibing et al. [3] obtained the optimal clay stabilizer combination by combining the clay stabilizer with aluminum sol and KCL after optimizing the single dose concentration of the clay stabilizer.

4. Optimization of Cleanup Additive

The flowback rate of slick-water fracturing fluid directly affects the effect of fracturing construction. The higher the flowback rate, the less the retention of fracturing fluid in the reservoir and the less the damage to oil and gas reservoir. The cleanup additive can effectively reduce the adsorption of fracturing fluid in the reservoir and improve the flowback performance of fracturing fluid, which has an important influence on the fracturing effect.

4.1. Wettability parameter determination

The cleanup additive is mainly composed of surfactants. Zhang Feng [4] optimized the cleanup additive by measuring the surface tension and contact Angle of surfactants such as sodium dodecyl benzene sulfonate, sodium dodecyl sulfate, span 80 and biquaternary ammonium salt composite materials. Contact Angle measurement steps: The core is sliced and dried in the oven for 12 hours, and then the core is soaked in the test solution for sealed preservation for 18 hours. After drying, the surface tension and contact Angle of different surfactants with a concentration of 0.1%~0.5% and a gradient of 0.1% are measured. The concentration with the smallest surface tension of the surfactant is used as the optimal concentration of a single agent.

Capillary force plays an important role in flowback efficiency. The higher the capillary force is, the more easily the fluid is adsorbed by the reservoir and the more difficult it is to flowback. According to formula (3), when the reservoir physical properties are determined, the capillary force is proportional to the product of interfacial tension and contact Angle. Fan Yao [5] determined the surface tension and contact Angle of four surfactants, and selected the surfactant with the smallest product of the interfacial tension value and contact Angle cosine value based on the size of the capillary force.

$$P_c = \frac{2\sigma\cos\theta}{r} \quad (3)$$

P_c -- air water interface capillary pressure, mN/m²
 σ --air-water interfacial tension, mN/m
 r -- mean curvature radius of gas-water interface in pores, m
 θ -- contact Angle of gas-liquid-solid three-phase interface, °

4.2. Spontaneous imbibition method

After entering the reservoir, fracturing fluid adsorbs in the pores, resulting in the decrease of reservoir permeability and formation of water lock damage. The spontaneous imbibition method is to evaluate the waterproof locking effect of the cleanup additive by studying the water absorption of the core before soaking in the cleanup additive treatment and the change of water absorption after the cleanup additive treatment with time. The more water absorption of the core treated by the cleanup additive under the action of capillary force, the worse the waterproof lock effect. Hu Youlin et al. [6] soaked coal and rock in surfactant solution for 4 hours and then dried it, and measured the water absorption of coal and rock before and after surfactant treatment within 4 hours. The results showed that the water absorption capacity of coal and rock after surfactant treatment was greatly reduced.

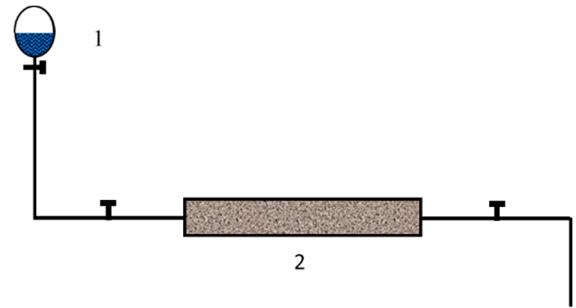
4.3. Single dose combination test

When different surfactants are mixed, there may be a synergistic effect between different molecules, which causes the surface tension to change. Zhang Feng [4] carried out four combinations of cationic-non-ionic, cationic-zwitterionic, cationic-cation, zwitterionic and non-ionic of various surfactants at the optimal concentration of a single dose. The experimental results showed that the surface tension of zwitterionic and cationic surfactants decreased and the wetting Angle increased. After the pairwise combination of cationic surfactants, the surface tension decreased significantly but the wetting Angle also decreased. The combination of cationic and non-ionic surfactants had no positive effect on the surface tension.

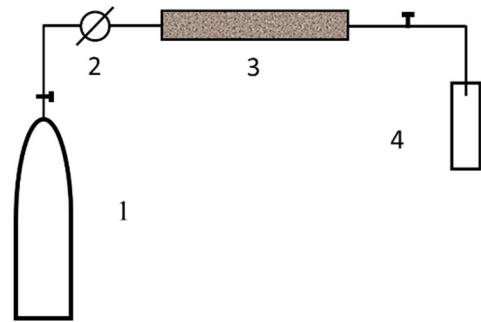
4.4. Measurement of auxiliary discharge increase rate

According to QSY 17376-2017 "Technical Specification for Acid fracturing Cleanup additive", the process of fracturing fluid backflow after entering the formation was simulated, and the auxiliary discharge increase rate of the test fluid was measured to characterize the performance of the cleanup additive macroscopic. Quartz sand of 212µm~524µm was loaded into a glass tube with an inner diameter of 15mm and a length of 500mm. The experimental fluid was saturated

according to Figure 1, and the mass m_2 of the glass tube device was measured after the liquid was discharged for 10s at the outlet end. The glass tube device was assembled according to Figure 2 and 7KPa nitrogen was injected into it. Measure the mass m_3 of the test fluid that flows out before nitrogen leaks out from the other end of the glass tube, and calculate the increase rate of the auxiliary discharge increase rate according to equation (4).



1- Separator funnel; 2- glass tube
Figure 1



1-Nitrogen cylinder; 2- manometer; 3- glass tube; 4- container
Figure 2

$$\eta_g = \frac{m_3}{m_2 - m_1} \times 100\% \quad (4)$$

η_g -- auxiliary discharge increase rate, %
 m_1 -- Mass of glass tube device before saturation, g
 m_2 -- glass tube device mass after saturation, g
 m_3 -- Mass of outflow fluid after ventilation, g

5. Summary

The main function of drag reducer in slick-water fracturing fluid is to reduce resistance and increase viscosity. The drag reducing rate of each type of drag reducer is measured first, and the optimal concentration of drag reducer is selected. Then the optimal concentration of a single agent was used to determine the drag reduction rate under different temperature, flow rate and shear time, and the highest relative drag reduction rate and stable performance were selected.

Clay stabilizer is the key to avoid water sensitive damage in reservoir. When selecting clay stabilizer, the clay stabilizer with high anti-swelling rate is selected by centrifugal method first, and then the compound combination of clay stabilizer is selected by compounding experiment. Finally, the core flow experiment is carried out on the optimized clay stabilizer combination. The anti swelling performance of clay stabilizer combination was evaluated from macroscopic point of view.

The optimal concentration of a single agent with low surface tension is selected mainly by measuring the surface tension of surfactant solutions with different concentrations,

and then the optimal concentration of a single agent combination with low surface tension is selected by compounding the optimal concentration of a single agent. Finally, the performance of the cleanup additive is evaluated macro-by spontaneous imbibition experiment or measuring the auxiliary discharge increase rate.

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