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Research on Emulsion Stability and Solubility of Polymer Drag Reducer

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Abstract

In oilfield fracturing construction, to solve the technical problems such as poor dissolution effect and long dissolution time of polymer drag reducer powder, the rheological regulator, phase transfer agent, organic solvent, and drag reducer powder were compounded to prepare a drag reducer emulsion that was soluble in water. The stability of the drag reducer emulsion was observed at room temperature for 90 days. The effects of the rheological regulator, phase transfer agent, and organic solvent on the stability and solubility of the drag reducer emulsion were studied. The dissolution time, dissolution effect, viscosity of the aqueous solution, and drag reduction performance of the drag reducer emulsion were evaluated. The results show the stability rate of the drag reducer emulsion prepared by MOST-1 rheological regulator, BHJ-8 and BHJ-6 compound phase inversion agent, ethylene glycol ether and 120 - 140 mesh powder can reach 97% at room temperature for 90 days. Compared with the drag reducer powder, when the aqueous solution concentration is 0.1%, the dissolution time is only 28 s, the viscosity can be increased by 30%, and the drag reduction rate can be increased by up to 8%.

Keywords

Drag Reducing Agent, Dissolution Effect, Dissolution Time, Stability Rate, Drag Reduction Rate

1. Introduction

Currently, the commonly used drag reduction agents in the oilfield fracturing production site are divided into natural and synthetic polymers. The amide-based polymer drag reduction agent is the most widely used water-soluble drag reduction agent in the slippery water fracturing operation because of its mature manufacturing process and high drag reduction efficiency [1] [2] [3] [4]. However, after the synthesis of some amide-based polymers, it is necessary to use ethanol or petroleum ether to remove the unreacted impurities [5] [6] [7] [8], dry, and grind into powder for use. The polymer powder has poor solubility in use, so it is particularly important to prepare such an amide polymer powder into a water-soluble emulsion. The survey found that most of the drag-reducer emulsions on the market have poor stability. Generally, there will be obvious stratification from half a month to one month, and the solubility is general. This leads to the difficulty of rapid hydration of polymer powder in the emulsion and the inability to completely dissolve in a short time, resulting in too long liquid preparation time and affecting the construction progress. The polymer that fails to dissolve in time will also form agglomeration and block the pipeline [9].

Emulsion stability, solubility as the core index of drag reducer emulsion, mainly depends on the drag reducer powder, rheological regulator, phase change agent and organic solvent four aspects [10] [11] [12] [13], in order to solve the poor stability, poor dissolution effect and other technical problems, this paper from the polymer powder particle size, rheological regulator compatibility, HLB value of phase change agent and organic solvent, at room temperature about 25˚C to carry out stability and solubility research, by evaluating the viscosity of the aqueous solution, drag reduction rate and other technical indicators to optimize the best drag reducer emulsion compound system, the results show that compared with drag reducer powder. The prepared drag reducer emulsion has a long stability time, short dissolution time, and better dissolution effect, significantly reducing construction time and improving operation efficiency.

2. Experimental Section

2.1. Experimental Materials

Drag reducer powder (polyacrylamide, industrial grade); phase inversion agent: BHJ-8, BHJ-6, BHJ-2, (surfactant, industrial grade); rheological regulator: MOST-1, JSPZ (bentonite, industrial grade); aluminum stearate, magnesium stearate, (analytically pure); organic solvent: cyclohexane, ethylene glycol ether, (analytically pure); kerosene, No. 3 white oil, (industrial grade).

2.2. Experimental Method

2.2.1. Preparation of Drag Reducer Emulsion

The phase inversion agent and organic solvent with a mass fraction ratio of phase inversion agent: organic solvent = 1:9 were placed in a high-speed stirrer, stirred for 30 min at 10,000 r/min, and then transferred to a reaction kettle at 1000 r/min. The rheological regulator with a mass fraction ratio of rheological regulator: organic solvent = 1:9 was added and stirred for 30 min in the reactor. Finally, the drag reducer powder with a mass fraction ratio of drag reducer powder: organic solvent = 1:1 was added and stirred in the reactor for 1 h to obtain the drag reducer emulsion.

2.2.2. Stability Rate Evaluation

According to the preparation method of drag-reducing agent lotion in 1.2.1, put 250 ml of the prepared drag-reducing agent lotion into a 250 ml plug cylinder, and record the total height of the lotion at that time. At room temperature of 25˚C, record the height of the supernatant every ten days, and its stability rate is

$$Y = (H - H1)/H \times 100\%$$

where Y—stability rate, %; H—the height of drag reducing agent lotion, cm; $H1$—Supernatant height, cm.

2.2.3. Gelling Rate Evaluation

Put the rheological regulator and solvent with the mass fraction ratio of the rheological regulator: organic solvent = 1:20 in a high-speed mixer, mix at 10,000 r/min for 30 min, put 250 ml of prepared lotion into a 250 ml measuring cylinder with a stopper, and record the total height of lotion at that time. After standing at 25˚C for 90 min, record the height of the supernatant, and the gel-forming rate is

$$F = (T - T1)/T \times 100\%$$

where: F—gelling rate, %; T—liquid height, cm; $T1$—Supernatant height, cm.

2.2.4. Dissolution Effect and Dissolution Time Evaluation

Concerning the People's Republic of China oil and gas industry standard SY/T 7627-2021 "water-based fracturing fluid performance evaluation method", con Figure the fracturing fluid aqueous solution and evaluate the dissolution effect when the aqueous solution is uniformly dispersed, with no particles, no floccules record the time required for dissolution.

2.2.5. Viscosity Performance Evaluation

Concerning the People's Republic of China oil and gas industry standard SY/T 7627-2021 "water-based fracturing fluid performance evaluation method", evaluation of drag reducer emulsion aqueous solution and drag reducer powder aqueous solution viscosity properties.

2.2.6. Drag Reduction Performance Evaluation

Concerning the People's Republic of China oil and gas industry standard SY/T 7627-2021 "water-based fracturing fluid performance evaluation method", evaluation of drag reduction performance of drag reducer emulsion aqueous solution and drag reducer powder aqueous solution.

3. Experimental Results and Analysis

3.1. Influence Analysis of Emulsion Stability

3.1.1. Effect of Particle Size on Emulsion Stability

The effect of different drag reducer powder particle sizes on the stability of drag reducer emulsion was investigated under the condition that the inversion agent was BHJ-8 + BHJ-6, the rheology modifier was MOST-1 and the organic solvent was ethylene glycol ether. The stability rate of drag reducer emulsion prepared by different particle sizes of drag reducer powder is shown in Figure 1. The stability rate of drag reducer emulsion prepared by drag reducer powder with a particle size of 120 - 140 mesh is the highest, and the initial stability rate can reach 99%. As the particle size of the powder increases, when the particle size of the drag reducer powder is 40 - 60 mesh, the initial stability rate of the drag reducer emulsion is only 90%. It can be seen that the stability rate of the drag reducer emulsion has a large difference in the early stage, and the stability rate gradually tends to be gentle over time. It can be seen that the stability rate of the drag reducer emulsion prepared by the drag reducer powder with a smaller particle size is better than that of the drag reducer emulsion prepared by the drag reducer powder with a larger particle size in both the initial and later stages. The principle can be understood as the smaller the particle size of the particles, the larger the surface area, the unit area carried by the more potential ions, the electric double layer is thicker, the greater the electrostatic repulsion between the particles, the powder in the emulsion sinking rate is smaller, the solution stability is higher; the larger the particle size, the smaller the electrostatic force between the particles, the greater the rate at which the powder sinks in the solution, and the worse its stability in the solvent [14]. At the same time, the critical value of the solution formed by particles with smaller particle sizes is higher than that of particles with larger particle sizes [15], so the lotion prepared by powders with smaller particle sizes has better stability.

3.1.2. Effect of Rheological Modifier on Emulsion Stability

The effects of different rheological modifiers on the drag reducer emulsion stability were investigated under the compound phase inversion agent of BHJ-8 +

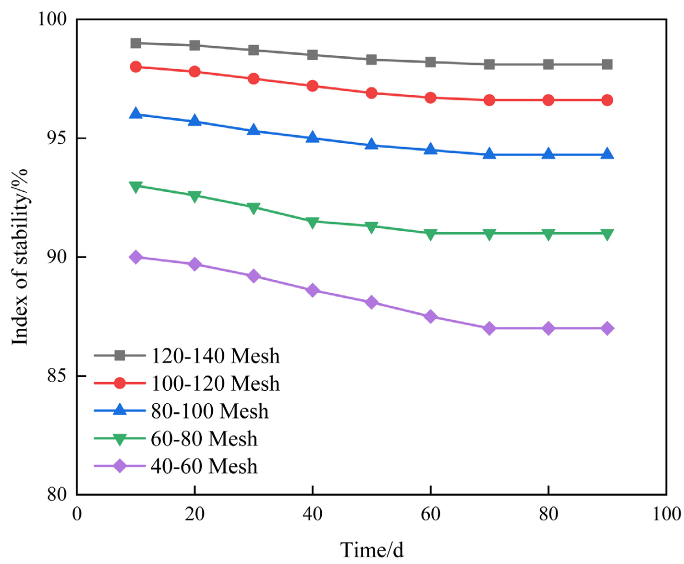

Figure 1. Effect of powder particle size on emulsion stability.

BHJ-6, the particle size of the drag reducer powder was 120 - 140 mesh, and the organic solvent was ethylene glycol ether. As shown in **Figure 2**, the gelling rate of different rheological regulators is shown in **Figure 3**. The highest gelling rate of MOST-1 can reach 90%, and the corresponding emulsion stability rate is the best. After 90 days, it still maintains 97% of the stability rate, while the gelling rates of aluminum stearate, magnesium stearate, and JSPZ are 73%, 65%, and 83%, respectively. The stability rates of the prepared drag reducer emulsion are 43%, 36%, and 38% after 90 days, respectively. The stability rate of the emulsion is far less than that of the emulsion prepared by MOST-1. Further analysis shows that the stability rate of the drag reducer emulsion is mainly determined by the

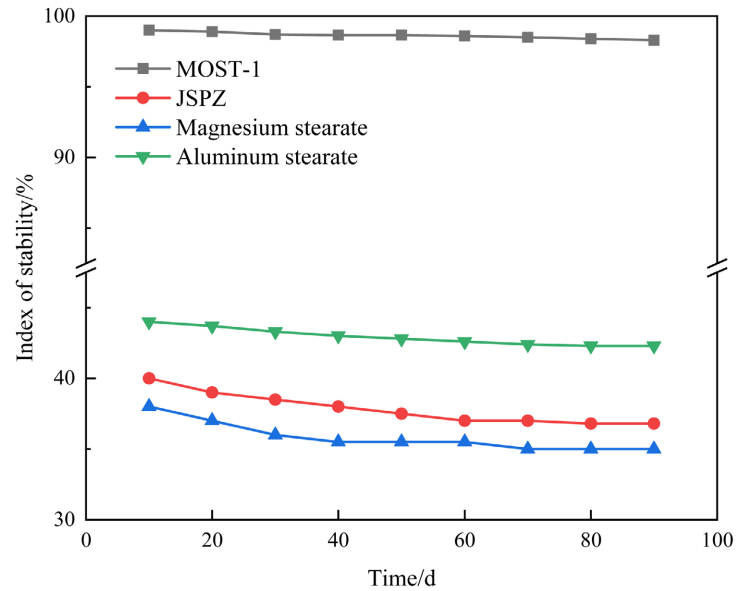

Figure 2. Effect of rheological modifier on emulsion stability.

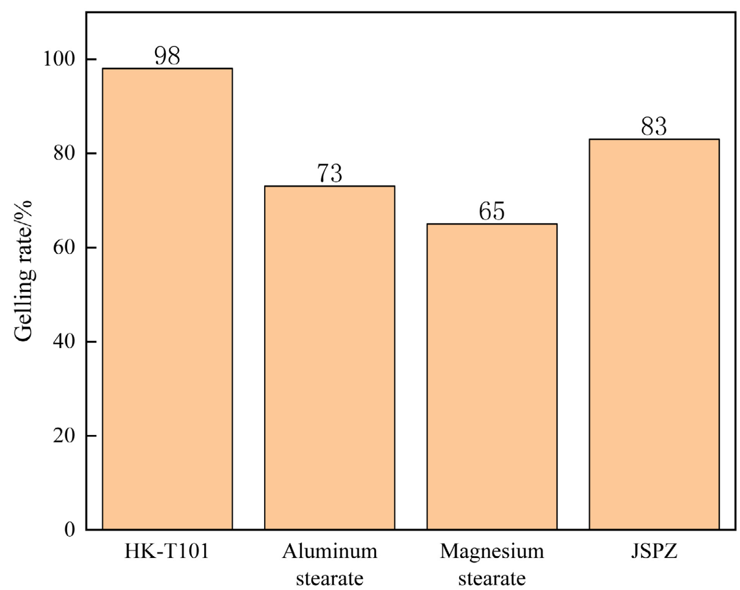

Figure 3. Relationship between rheological modifier and gelation rate.

compatibility and gelation rate of the rheological regulator. The principle is that the rheological regulator is combined with the end-end and end-surface in the solvent to form a pseudoplastic "Z"-type three-dimensional structure that can encapsulate the dispersed particles. The gelation rate is the proportion of the formed three-dimensional structure in the overall emulsion, which maintains the stability of the particles in the emulsion [16], while different types of rheological regulators have different gelation rates [17]. Comparative analysis shows that the MOST-1 type rheological regulator is better.

3.2. Analysis of Dissolution Effect of Emulsion

3.2.1. Effect of Powder Particle Size on Dissolution of Emulsion

The effect of different particle sizes of drag reducer powder on the solubility of drag reducer emulsion was investigated under the condition that the inversion agent was BHJ-8 + BHJ-6, the rheological modifier was MOST-1 and the organic solvent was ethylene glycol ether. The dissolution parameters of drag reducer emulsion prepared by different powder particle sizes are shown in **Table 1**, and the dissolution effect of drag reducer emulsion prepared by different powder particle sizes is shown in **Figure 4**. It can be seen that after the drag reducer emulsion prepared by the drag reducer powder with a particle size of 40 - 60 mesh is dissolved, a large number of floccules float on the upper layer of the solution, and the stratification is obvious. The emulsion prepared by drag reducer powder with a particle size of 120 - 140 mesh is uniformly dispersed in an aqueous solution without undissolved particles and floccules. The single drag reducer powder has a long dissolution time. After ten minutes, there are still a large number of undissolved complete powders floating on the upper layer of the solution, and the aqueous solution is layered. Further analysis of its causes shows that due to the water absorption and gelation of the drag reducer powder, when it comes into contact with water molecules, it will immediately form a layer of gel layer on the surface of the molecule. The larger the particle size of the powder, the thicker the gel layer, and the powder center is difficult to contact with

Table 1. Dissolution parameters of emulsion with different powder particle sizes.

The particle size of the drag reducer powder, Mesh number	Concentration, %	Dissolved State
120 - 140	0.1	Solution uniform, no particles and flocs
100 - 120	0.1	The solution has a small number of undissolved powder particles
80 - 100	0.1	The solution has a small number of floccules
60 - 80	0.1	Uneven solution with a large amount of floc
40 - 60	0.1	The aqueous solution is uneven with the "fish eye" formation

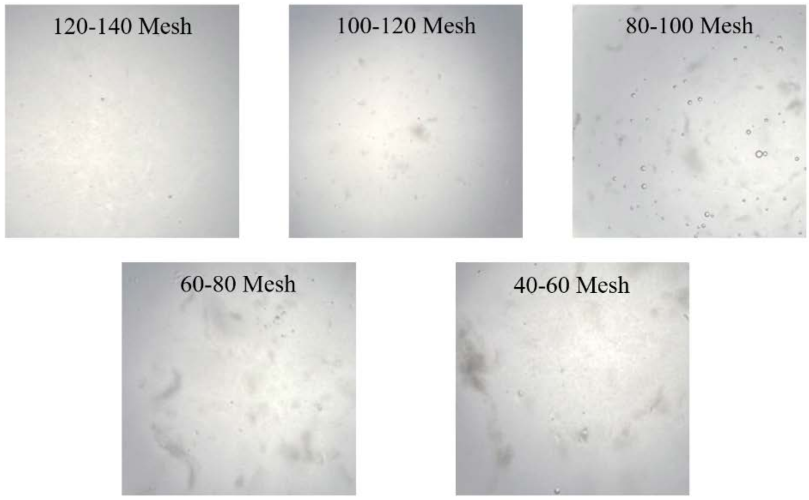

Figure 4. Effect of powder particle size on emulsion dissolution.

water molecules, which makes it difficult to dissolve. When such molecules that fail to dissolve in time are slowly adsorbed together, a "fish eye" will be formed. The smaller the particle size of the drag reducer molecule, the larger the surface area, the larger the area of contact with water, and the better the dissolution effect, Therefore, it is better to choose 120 - 140 mesh friction reducer powder.

3.2.2. Effect of Phase Inversion Agent on Emulsion Dissolution

The effects of different inversion agents on the solubility of drag reducer emulsion were investigated under the conditions of powder particle size of 120 - 140 mesh, a rheological modifier of MOST-1, and an organic solvent of ethylene glycol ether. The dissolution parameters of the drag reducer emulsion prepared by single and compound phase inversion agents are shown in **Table 2**. The dissolution effect of the drag reducer emulsion con Figured with a single phase change agent is shown in **Figure 5**. When the HLB value of the phase change agent is 4.3 or 15.0, there are still a large number of undissolved particles in the aqueous solution. When the HLB value is 8.6, the undissolved particles in the aqueous solution are significantly reduced, and there is a small number of flocs. It can be seen that the HLB value is around 8.6. The dissolution effect is better.

The phase change agent is compounded, and the HLB value of the phase change agent is proportional. The calculation method of the HLB value of the compound phase change agent is HLB = HLB (A)·A% + HLB (B)·B%. When the HLB value of the compound phase change agent is 8.0 or 9.0, the drag reducer emulsion dissolves as shown in **Figure 6**. Compared with the single phase change agent, the aqueous solution of the drag reducer emulsion prepared by the compound phase change agent does not have undissolved particles, and the flocculent molecules in the solution are dissolved completely. When the HLB value of the compound phase change agent is controlled at 8.6, the dissolution effect of the drag reducer emulsion is shown in **Figure 6**. The aqueous solution is uniformly dispersed without particles and floccules. Therefore, when the HLB

Figure 5. Effect of a single inversion agent on an aqueous solution of drag reducer emulsion.

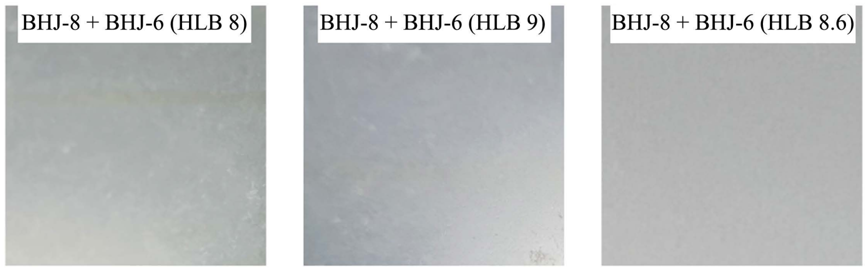

Figure 6. Effect of compound inversion agent on an aqueous solution of drag reducer emulsion.

Table 2. Dissolution parameters of different inversion emulsions.

Phase transfer agent	HLB Value	Concentration, %	Dissolved State
BHJ-8	4.3	0.1	A large number of insoluble particles
BHJ-6	15.0	0.1	A large number of insoluble particles
BHJ-2	8.6	0.1	Part of particles, flocs
BHJ-8 + BHJ-6	8.0	0.1	A small number of particles, flocs
BHJ-8 + BHJ-6	9.0	0.1	A small number of particles, flocs
BHJ-8 + BHJ-6	8.6	0.1	No particles, no floccules

value of the compound phase change agent is 8.6, the dissolution effect of the drag reducer emulsion of the compound phase change agent is the best.

Further studies show that the dispersion solution formed by the drag reducer emulsion in water is emulsion [18]. When the emulsion is dispersed in water, the drag reducer powder is originally wrapped by an organic solvent and forms fine suspended microspheres after entering the water. Under the emulsification of the phase inversion agent, by changing the interfacial tension between the organic solvent and water [19], the suspended microspheres wrapped with the drag reducer powder are gradually dispersed and dissolved under the action of the phase inversion agent. When the HLB value is higher than 9 or lower than 8, the dissolution rate of the suspended microspheres is slow, resulting in the drag reducer powder in the suspended microspheres cannot be hydrated at a constant speed [20], resulting in a large number of "fish eyes". It is difficult to meet the construction needs resulting in uneven liquid distribution. Controlling the HLB value of the compound phase inversion agent at 8 - 9 ensures that the suspension microspheres maintain a suitable dissolution rate. The suspension microspheres in the solution can dissolve at the specified time and avoid the emergence of "fisheye".

3.2.3. Effect of Organic Solvent on Emulsion Dissolution

The effect of different organic solvents on the solubility of drag reducer emulsion was investigated under the condition that the inversion agent was BHJ-8 + BHJ-6, the rheological modifier was MOST-1, and the particle size of drag reducer powder was 120 - 140 mesh. The drag reducer emulsion prepared by different organic solvents was prepared at an aqueous solution concentration of 0.1%. The time required for the aqueous solution to form a uniformly dispersed, particle-free, and floc-free state is shown in Figure 7. It can be seen from the graph that the viscosity of ethylene glycol ether, cyclohexane, kerosene, and No.3 white oil is small, but the dissolution time is quite different. The time required for the dissolution of ethylene glycol ether is the shortest, and 28 s can form a uniformly dispersed, particle-free, and floc-free aqueous solution, while the No.3 white oil takes the longest time, 40 s to dissolve into a uniformly dispersed aqueous solution. Further analysis shows that cyclohexane, No. 3 white oil, and kerosene are oily organic solvents, difficult to dissolve in water. Although ethylene glycol ether is an oily organic solvent, it can be dissolved in water and can be mixed with water in any proportion, so the dissolution rate is improved. Ethylene glycol ether is better as an organic solvent.

3.3. Viscosity Performance Evaluation

Through the above experimental results, 120 - 140 mesh drag reducer powder,

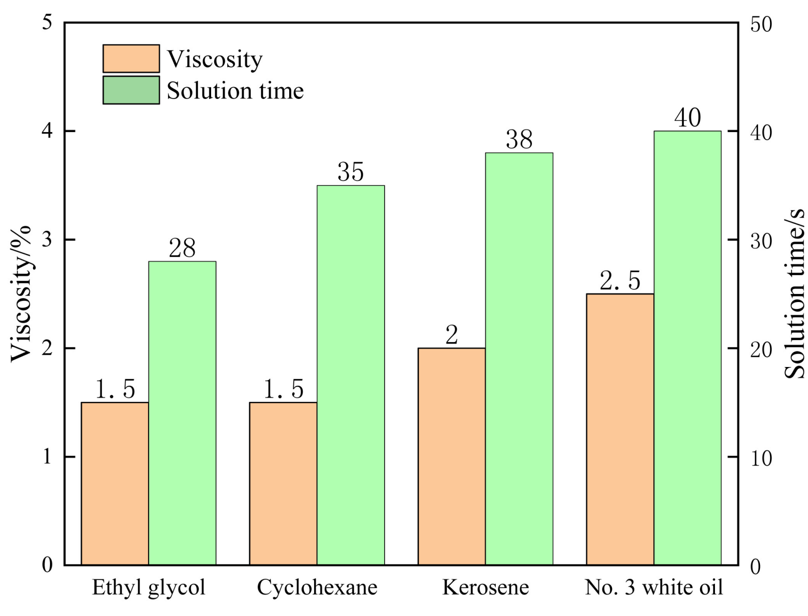

Figure 7. Effect of organic solvents on emulsion dissolution.

BHJ-8 + BHJ-6 compound phase inversion agent, ethylene glycol ether, and MOST-1 rheological regulator system were selected to prepare drag reducer emulsion. The drag reducer emulsion under this system cannot be easily stratified at room temperature for 90 days and has good solubility. Under the same effective content of drag reducer powder, the corresponding viscosity of drag reducer emulsion and drag reducer powder at different concentrations was investigated. The viscosity data of the aqueous solution of the drag reducer emulsion and the aqueous solution of the drag reducer powder were recorded when the drag reducer emulsion formed a uniformly dispersed, particle-free, and floc-free solution. The viscosity is shown in **Figure 8**. At the same concentration, the viscosity of the drag reducer emulsion aqueous solution is higher than that of the drag reducer powder aqueous solution. When the aqueous solution concentration is 0.1%, the viscosity of the drag reducer emulsion aqueous solution is 25 mPa·s, and the viscosity of the drag reducer powder aqueous solution is 17.5 mPa·s. At this time, the viscosity increase rate is up to 30%.

3.4. Drag Reduction Performance Evaluation

Under the most suitable drag reducer emulsion system, when the effective content of drag reducer powder is the same, the drag reduction rate of drag reducer emulsion and drag reducer powder at the same concentration is investigated. As shown in **Figure 9**, when the concentration is 0.1% and the flow rate is 50 L/min, the drag reduction rate of the drag reducer emulsion aqueous solution is 62.1%, the drag reduction rate of the drag reducer powder aqueous solution is 58.8%, and the drag reduction rate is increased by 3.5%. As the concentration of the drag reducer gradually increases, the drag reduction rate gap between the drag reducer emulsion and the drag reducer powder gradually increases. When

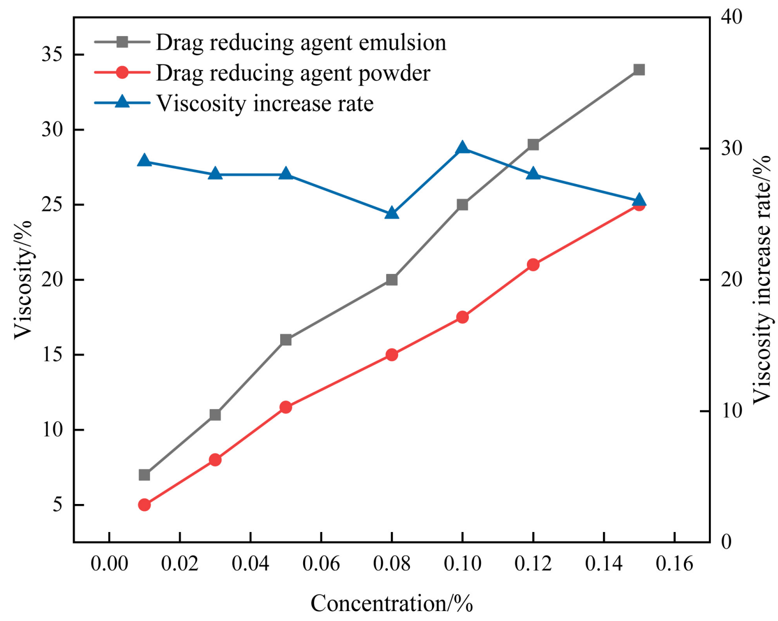

Figure 8. Effect of drag reducer concentration on viscosity.

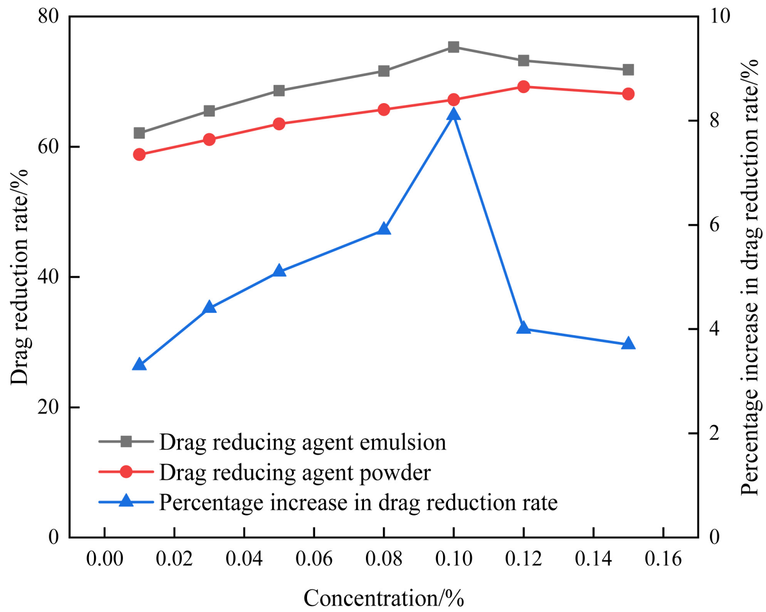

Figure 9. Effect of drag reducer concentration on the drag reduction rate.

the drag reducer concentration is 0.1%, the drag reduction rate corresponding to the drag reducer emulsion is 75.0%, and the drag reduction rate corresponding to the drag reducer powder is 67.1%. At this time, the drag reduction rate is the largest, and the drag reduction rate can be increased by up to 8%.

4. Conclusions

1) Through the study of stability and solubility, a drag-reducing agent lotion system composed of MOST-1 rheological regulator, BHJ-8 + BHJ-6 compound phase inversion agent, ethylene glycol ether, and drag-reducing agent powder was selected, which did not delaminate at room temperature for 90 days, and had the best stability and solubility.

2) The comparison of the research results shows that the rheological regulator is the main factor to ensure the stability of the drag reducer emulsion. On the premise of the same other conditions, the smaller the particle size of the drag reducer powder, the better the compatibility of the rheological regulator with the organic solvent, the higher the gelation rate, and the better the stability of the prepared drag reducer emulsion.

3) By controlling the HLB value of the compound phase inversion agent at 8 - 9 and using ethylene glycol ether as the solvent, the dissolution effect of the drag reducer emulsion in water can be effectively improved, and the time required for dissolution can be reduced. The shortest time is 28 s to form a uniformly dispersed, particle-free, and floc-free aqueous solution.

4) At the same concentration of the effective content of the drag reducer, compared with the drag reducer powder aqueous solution, the viscosity of the drag reducer emulsion aqueous solution can be increased by up to 30%, and the drag reduction rate can be increased by up to 8%, which reduces the time re-

quired for the preparation of the construction and improves the operation efficiency.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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