Open Journal of Applied Sciences, 2024, 14, 2101-2111
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Research on the Performance of New Weighted Slippery Water Fracturing Fluid System

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How to cite this paper: Shi, Y.F., Yu, W.C., Zhou, D.K., Ding, F., Shu, W.M., Zhang, Y., Ju, Y.W. and Lei, Z.D. (2024) Research on the Performance of New Weighted Slippery Water Fracturing Fluid System. *Open Journal of Applied Sciences*, **14**, 2101-2111.
https://doi.org/10.4236/ojapps.2024.148138

Received: July 11, 2024
Accepted: August 10, 2024
Published: August 13, 2024

Abstract

Deep and ultra-deep reservoirs have dense matrix and high fracture pressure, which leads to high pressure and difficulty in fracturing construction. Conventional aggravated fracturing fluids have the problems of low aggravation efficiency, high friction resistance, etc., and the reduction of construction pressure cannot reach the theoretical effect. In view of the above problems, this paper adopts the weighting agent HD160 and the drag reducing agent JHFR-2 to form a new type of weighted slippery water fracturing fluid system. And the weighting performance, drag reduction performance, corrosion performance, anti-expansion performance and reservoir damage of this system were studied. The results show that the density of the system is adjustable within 1.1 - 1.6 $g \cdot cm^{-3}$, and the drag reduction rate can be up to 68% at 1.5 $g \cdot cm^{-3}$, with low corrosion rate, surface tension less than 28 $mN \cdot m^{-1}$, anti-expansion rate as high as 94.5%, and the damage rate of the reservoir permeability is less than 10%, which is of good application prospect.

Keywords

Aggravated Fracturing Fluid, Aggravator, Slickwater, Corrosive Properties, Anti-Swelling Rate

1. Introduction

The development of hydraulic fracturing technology in the field of oil and gas resource extraction, especially in the development of unconventional oil and gas resources, has made great achievements [1]. With the increase of the depth of shale gas reservoir extraction, the friction resistance of the fracturing fluid is greatly increased, and because of the high reservoir closure pressure, it brings a huge load to the ground construction equipment, and even exceeds the pressure limit range, which triggers a safety accident [2]. For deep and ultra-deep reservoir modification, the key to solving the problem is how the fracturing fluid can maximize the access to the reservoir through sand prevention and fracture modification without exceeding the limits of the surface and downhole equipment, while maintaining the stability of the well [3].

As a typical unconventional oil and gas reservoir, deep and ultra-deep reservoirs are characterized by large longitudinal depth, dense reservoir matrix, and high fracture pressure [4] [5]. Conventional slickwater fracturing fluids have excellent drag reduction performance and environmental performance [6]-[8], but their low density makes it impossible to carry out construction safely when facing high construction pressure for deep and ultra-deep reservoir modification. Weighted fracturing fluid is one of the effective ways to reduce the construction pressure due to its high density, which can provide higher fluid column pressure [9], however, after the use of weighted technology, the presence of high-quality fractional salts will greatly increase the friction resistance of the fracturing fluid during the construction pumping process, and the increase in the friction resistance will offset the additional fluid column pressure exerted by the weighted fracturing fluid to the extent that the significance of the weighting will be lost [10]. Aiming at the above problems, a new type of weighted slickwater fracturing fluid is developed in this paper, which can supply larger fluid column pressure and at the same time have lower friction resistance, which can effectively reduce the ground construction pressure.

2. Materials and Methods

2.1. Experimental Materials

Acrylamide, 2-acrylamido-2-methylpropanesulfonic acid, acrylic acid, dimethyl diallyl ammonium chloride, analytically pure, Shanghai McLean Biochemical Technology Co., Ltd; Sodium hydroxide, anhydrous ethanol, ammonium persulphate, sodium hydrogen sulfite, analytically pure, Sinopharm Chemical Reagent Co., Ltd., pH adjusting agent, multifunctional additive JHFD-2, Jingzhou Modern Petroleum Technology Development Co., Ltd.

2.2. Experimental Instruments

JBQ-10 Mechanical Stirrer, Beijing Zhongxing Weiye Century Instrument Co., Ltd; JHJZ High Temperature and High Pressure Shale Gas Well Slippery Water Reduction Resistance Tester, JHCQ Core Dynamic Damage Evaluation Device, Jingzhou Modern Petroleum Science and Technology Co., Ltd; ZNND6 Six-Speed Rotary Viscometer, Qingdao Haitongda Specialized Instrument Co., Ltd; QBZY Fully-Automatic Surface Tension Meter, Shanghai Fangrui Instrument Co., Ltd; LDZ4-1 Centrifuge, Beijing Leibel Medical Instrument Co., Ltd; DHG-9035A Blast Drying Oven, Shanghai Yiheng Scientific Instrument Co., Ltd.

2.3. Experimental Methods

2.3.1. Synthesis of Dampening Agents

In a 250 mL three-necked flask, add acrylamide, 2-acrylamido-2-methylpropanesulfonic acid, acrylic acid, dimethyl diallyl ammonium chloride, deionized water in turn, dissolve and then use dilute sodium hydroxide solution to adjust the pH to 7. Place the three-necked flask in a constant-temperature water bath under nitrogen gas; after 30 min, add ammonium peroxydisulfate and sodium bisulfite composite system of initiator, warming to 45˚C stirring for 6 h. After the reaction, wash with anhydrous ethanol and dry. At the end of the reaction, wash with anhydrous ethanol and dry to obtain a white solid. The white solid was crushed and ground and dispersed in white oil solution, added Span-80 and Twen-80 compound emulsifier, and then stirred and dispersed for 30 min with high-speed stirrer, which was obtained as drag reducing agent JHFR-2.

2.3.2. Preparation of Aggravating Agents

Separately formulate a certain amount of calcium chloride mother liquor and sodium nitrate mother liquor, mix uniformly according to a certain ratio, evaporate and concentrate the mixture to obtain the concentrated liquid, use the cooling equipment to cool down the concentrated liquid, and then put it in the crystallization kettle to add the crystal seeds, and then cool down to 20˚C - 25˚C according to a certain cooling rate; put the final reaction liquid into a centrifuge to carry on the solid-liquid separation, and obtain the solid particle size of 2 - 4 mm particle crystals.

2.3.3. Formulation of Weighted Slickwater Fracturing Fluids

According to the density requirements of different fracturing fluids, a certain mass fraction of HD160 brine is prepared, and when HD160 is fully dissolved, its pH is adjusted to 7.5 with a pH adjuster, and then the drag reducing agent JHFR-2 is added while stirring, and when the drag reducing agent is fully dissolved, the polyether multifunctional additive JHFD-2 is added and stirred and mixed well, then it will be obtained as aggravated slippery water fracturing fluid.

2.3.4. Weighted Performance Evaluation

Tap water and aggravating agent HD160 were added to the high stirring cup according to a certain ratio, and dissolved by stirring at 10,000 r/min, observing the dissolution situation every 1 min, and recording the dissolution time and density of different dosage of HD160.

2.3.5. Evaluation of Drag Reduction and Dissolution Performance

The experiment referred to China's oil and gas industry standard SY/T 5107-2016 "Evaluation Methods of Water-Based Fracturing Fluid Performance", and JHJZ high-temperature and high-pressure shale gas well skidding water drag reduction rate tester was used to evaluate the drag reduction and dissolution performance of the drag reducer in the aggravator solution.

2.3.6. Corrosion Performance Evaluation

According to the Chinese machinery industry standard JB/T 7901-1999 "Laboratory Uniform Corrosion Full Immersion Test Method for Metallic Materials", oilfield drilling tool steel N80 steel sheet was used to conduct corrosion weightlessness test in a high temperature oven. Due to the short contact time between the slickwater fracturing fluid and the oil pipe, the 4h corrosion test time is more in line with the reality.

2.3.7. Aid in Drainage and Anti-Swelling Performance

According to China's oil and gas industry standard SY/T 5107-2016 "Evaluation Methods for the Performance of Water-based Fracturing Fluid", the surface tension and anti-expansion rate of the weighted slippery water fracturing fluid were tested.

2.3.8. Reservoir Damage Assessment

Referring to China's oil and gas industry standard SY/T 5107-2016 "Evaluation Method of Water-Based Fracturing Fluid Performance", the effect of weighted slippery water fracturing fluid on the permeability of artificial core matrix was evaluated.

3. Results and Discussion

3.1. Aggravating Agent Properties

Traditional fracturing fluid weighting agents mainly include NaBr, NaCl, formate, etc. [11]-[15]. NaBr weighting agent can be weighted up to 1.5 g·cm^{-3}, but due to the pollution of NaBr to the environment and the expensive price, it is less used now; NaCl or KCl is more friendly to the environment, but the weighting efficiency is low, and the density of the weighted fracturing fluid is only 1.18 g·cm^{-3} at the most, and the pressure of fluid column is limited; formate is the weighting agent, but there are problems such as the difficulty of dispensing sodium formate and the high cost of potassium formate. The density of fracturing fluid is only 1.18 g·cm^{-3} at the most, and the pressure of fluid column is limited; formate is an aggravating agent, but there are problems such as the difficulty of dispensing sodium formate and the high cost of potassium formate. In view of the shortcomings of the existing aggravating agents, this paper selects the aggravating agent HD160 with high aggravating density and good solubility, and the densities of aqueous solutions corresponding to different mass fractions of HD160 at room temperature are shown in **Figure 1**.

As can be seen from **Figure 1**, when the mass fraction of HD160 is 75%, the solution density can reach 1.6 g/cm^3, and still has the potential to dissolve, which can effectively increase the net column pressure of fracturing fluid and reduce the construction pressure. The relationship equation between the density and mass fraction of HD160 solution is obtained as follows:

$$\rho = 0.0094\omega + 0.8947 \tag{1}$$

where: ρ is the solution density, ω is the HD160 mass fraction.

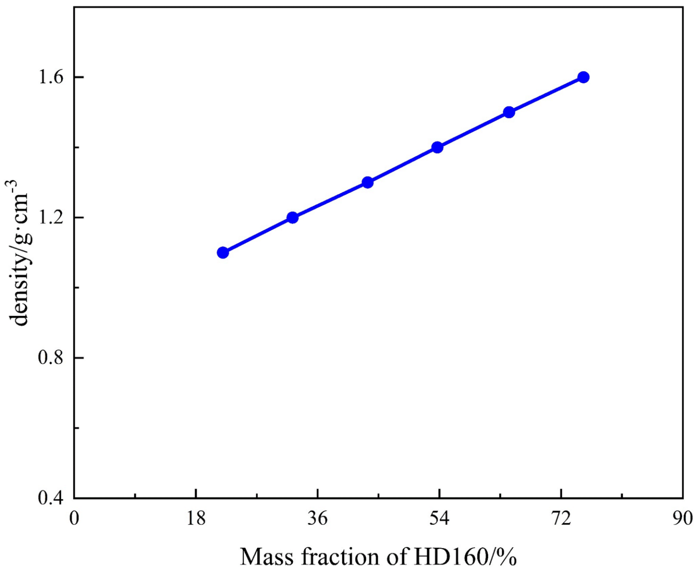

Figure 1. Variation of solution density with mass fraction of HD160.

The above formula responds to the dissolution law of HD160 brine, according to which different densities of HD160 brine can be prepared, and the configuration time is proportional to the density.

3.2. Properties of a New Weighted Slickwater Fracturing Fluid System

3.2.1. Dissolution Properties of Drag Reducing Agents

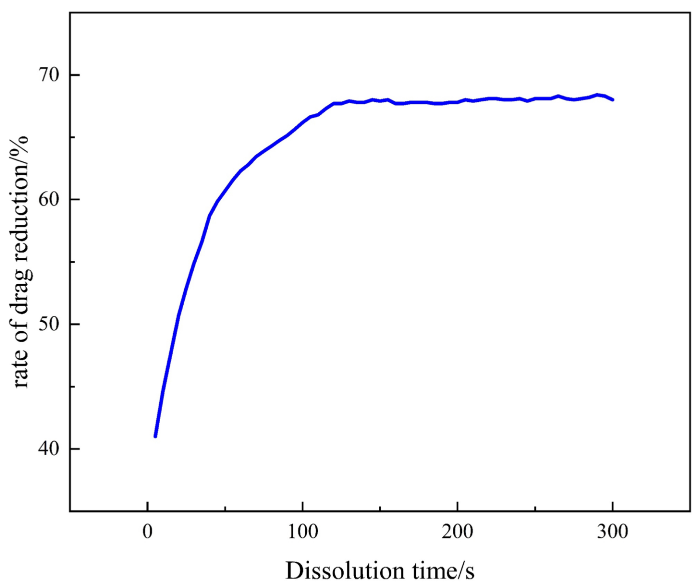

Figure 2. Variation of 0.2% JHFR-2 resistance reduction with dissolution time.

The construction displacement of fracturing is high, and the slip water usually reaches the well low in a short time, so there is a requirement for the dissolution onset time of the drag reducing agent, and the experiment was conducted to determine the effect of the dissolution of the JHFR-2 drag reducing agent in the 1.5 g·cm^{-3} HD160 weighted fluid. The test procedure refers to SY/T 5107-2016 "Evaluation Method of Water-based Fracturing Fluid Performance", and the experimental instrument is JHJZ high-temperature and high-pressure dynamic drag reduction evaluation system, the experimental pipe diameter is 10 mm, the experimental flow rate is 50 L/min, the test system records the data every 5 s, and the experimental duration is 5 min. From **Figure 2**, it can be seen that the drag reducing agent has a drag reduction rate of 60.7% at 50s, and at 120s, the drag reduction rate reaches the maximum value of 68%, which remains stable until the end of the experiment. It shows that the drag reducing agent has the ability of quick dissolving, and in the high-density and high-concentration brine solution can still maintain a better effect of reducing the friction resistance, and effectively reduce the construction pressure.

3.2.2. Resistance Reduction Performance

The presence of salts after the use of weighted technology will cause the fracturing fluid's molar resistance to rise sharply during the construction pumping process, and the additional increase in molar resistance will offset the static pressure exerted by the weighted fracturing fluid, or even lead to the loss of the significance of weighting. In this paper, the use of homemade JHFR-2 drag reducing agent can effectively reduce the flow drag of the weighted fracturing fluid in the casing or tubing, and play the actual role of weighted slickwater fracturing fluid.

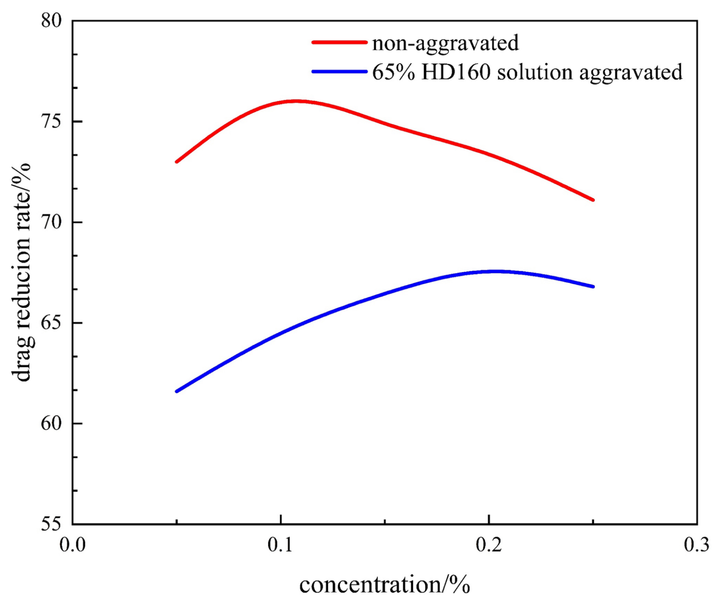

Figure 3. Variation of drag reduction rate with drag reducer concentration.

The change of drag reduction rate with the amount of drag reducing agent before and after weighting was tested, see **Figure 3**. When not weighted, the drag reduction rate reached the maximum value of 74.7% when the amount of

JHFR-2 drag reducing agent was added at 0.1%, and the drag reduction rate gradually decreased with the larger concentration; when 65% of HD160 weighting liquid was used for testing, the maximum value reached 68% when the amount was added at 0.2%, which had a significant effect on drag reduction. The mechanism of drag reduction is as follows: within a certain range of mass fraction, the linear structure of the drag reducing agent molecule can be fully elastic deformation to store energy. With the increase of the mass fraction, the molecular chains of the drag reducing agent begin to entangle with each other and form spatial aggregates, which impede the fluid flow, leading to an increase in viscosity and a decrease in drag reduction performance [16] [17].

3.2.3. Corrosion Performance

Due to the introduction of a large number of salts, the aggravated slickwater fracturing fluid has stronger corrosive properties compared with conventional fracturing fluid, and in the downhole high-temperature environment, the corrosive behavior of the metal casing is further increased, which may lead to the fracture of tubing and affect the normal fracturing operation. In this paper, the weightlessness method is used to test the corrosive performance of the aggravated slickwater fracturing fluid, and the experimental material is N80 steel sheet of oilfield drilling tool steel, and its main components are listed in **Table 1** below:

Table 1. Main components of N80 steel.

component	C	Si	Mn	Cu	P	Mo	Cr	S
Content/%	0.30	0.40	1.10	0.20	0.02	1.10	1.00	0.01

Take N80 steel piece sequentially with acetone and anhydrous ethanol cleaning, remove surface oil and water, after the cold air blow-dry and weighing (m_1), with vernier calipers to measure its length, width and height; will be put into the aggravation of the steel piece of slippery water fracking fluid, static 4 h after the removal of the washing clean and cold air blow-dry and weighing (m_2); before and after corrosion of the specimen according to the difference in the quality of the corrosion rate is calculated, the calculation formula is as follows:

$$V_c = \frac{m_1 - m_2}{S \cdot t} \tag{2}$$

where: V_c, average corrosion rate of steel sheet, $g \cdot (m^2 \cdot h)^{-1}$, m_1, mass of steel sheet before corrosion, g, m_2, mass of steel sheet after corrosion, g, S, surface area of steel sheet, m^2, t, immersion time of steel sheet in weighted slip water fracturing fluid, h.

As can be seen from **Figure 4**, at the same temperature, the higher the density of the aggravated slickwater fracturing fluid, *i.e.*, the higher the mass fraction of salt, the slower the corrosion rate. The reason for this phenomenon: N80 steel sheet is mainly oxygen absorbing corrosion in the aggravated slickwater fracturing fluid, when the mass fraction of aggravating agent HD160 increases, the dissolved oxygen content in the fracturing fluid gradually decreases, resulting in a decrease in the depolarizing ability of oxygen, and the corrosion effect is weakened [18]; in the aggravated slickwater fracturing fluid density is the same, the higher the temperature is, the faster the rate of corrosion of the N80 steel sheet, which is mainly due to the following reasons high temperature accelerates the generation of active oxidizing substances in the solution, which accelerates the corrosion rate of N80 steel sheet by aggravated slick water fracturing fluid.

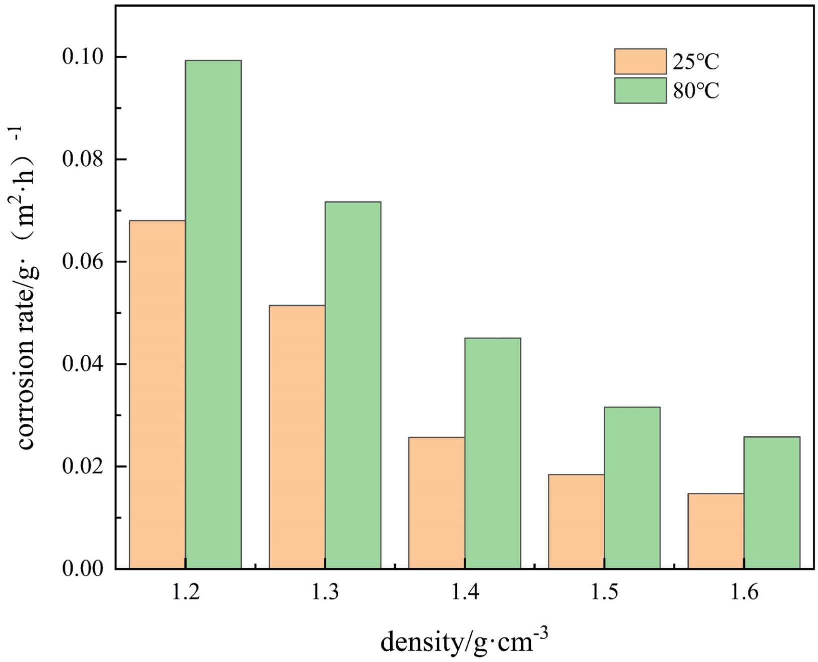

Figure 4. Corrosion rate of N80 steel sheet in aggravated slickwater fracturing fluid.

3.2.4. Anti-Discharge and Anti-Expansion Properties

After the fracturing construction, in order to make the fracturing fluid return smoothly, the fracturing fluid is required to have low surface tension and good ability to inhibit clay swelling. The surface tension and anti-expansion rate of conventional slickenside fracturing fluid and 1.5 $g \cdot cm^{-3}$ weighted slickenside fracturing fluid were tested. As shown in **Table 2**, compared with the conventional slickwater fracturing fluid, the weighted slickwater fracturing fluid has a better ability to inhibit clay swelling, which is because the inorganic salt has an inhibitory effect on the hydration of the clay, and with the increase of the concentration of the inorganic salt, the spacing of the crystal layers of the minerals in the clay is gradually reduced, and the inhibition of the hydration of clay is more obvious [19]; and the surface tension increases, which is due to the higher content of inorganic salt and the increase of the surface tension in the weighted slickwater fracturing fluid. The surface tension increased because of the higher content of inorganic salts in the aggravated slickwater fracturing fluid, the attraction of ions in the aggravated slickwater fracturing fluid to water molecules tends to drag water molecules into the interior of the solution, and the work done per unit of surface area increases, and the surface tension also becomes larger [20]. The results show that the aggravated slickwater fracturing fluid has good performance of aiding drainage and preventing expansion.

Table 2. Properties of different fracturing fluids in aiding drainage and preventing swelling.

item	surface tension/mN·m^{-1}	deflation rate/%
unweighted fracturing fluid	25.45	85.0
weighted fracturing fluid	26.80	94.5

3.2.5. Reservoir Damage Testing

When the fracturing fluid is retained in the reservoir, it will affect the structure and plasticity of the rock and cause damage to the reservoir, leading to the reduction of single-well production. In this paper, with reference to SY/T 5107-2016 "Performance Evaluation Method of Water-Based Fracturing Fluid", the effect of weighted slippery water fracturing fluid on the permeability of man-made core was tested, and the results are shown in **Table 3**. As can be seen in **Table 3**, the permeability damage rate of weighted slippery water fracturing fluid is lower than 10%, which is much lower than the permeability damage rate of water-based fracturing fluid as specified in SY/T 6376-2008 "General Technical Conditions for Fracturing Fluid". **Table 3** shows that the permeability damage rate of the water-based fracturing fluid is less than 10%, which is far lower than the requirement of less than 30% in SY/T 6376-2008 General Technical Conditions for Fracturing Fluid, proving that the damage of weighted slippery water fracturing fluid to the reservoir is extremely small in the process of simmering the well after fracturing.

Table 3. Weighted slip water fracturing fluid on core permeability damage rate results.

Core number	Pre-injury penetration rate/10^{-3} μm^2	Post-injury penetration rate/10^{-3} μm^2	Penetration damage rate/%
1	199.5	183.9	7.82
2	186.3	171.2	8.11

4. Conclusions

1) A weighting agent HD160 and a drag reducing agent JHFR-2 have been synthesized, using HD160 as the weighting agent and JFHR-2 as the drag reducing agent, and the density of the new type of slickwater fracturing fluid can be adjusted within 1.1 - 1.6 g·cm^{-3}, which can effectively increase the pressure of the fracturing fluid column and reduce the construction pressure, and the weighted slickwater fracturing fluid with suitable density can be selected according to the on-site fracturing construction parameters and cost control to carry out the construction.

2) The new aggravated slickwater fracturing fluid can reduce the resistance rate up to 68%, the surface tension is less than 28 mN/m, the anti-expansion rate is 94.5%, which is much more than that of the conventional slickwater fracturing fluids, and the damage rate to the permeability of the core is less than 10%, and it has low corrosive property, which is less damaging to the reservoir as well as the working equipment, and it has a good prospect of application.

Conflicts of Interest

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

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