Open Journal of Yangtze Gas and Oil, 2020, 5, 176-187
https://www.scirp.org/journal/ojogas
ISSN Online: 2473-1900
ISSN Print: 2473-1889

Laboratory Research on the Performance of Fracturing Fluid System for Unconventional Oil and Gas Reservoir Transformation

Jizhao Xing[1], Aibin Wu[1], Wenming Shu[1], Ying Zhang[1], Yaolu Li[1], Weichu Yu[1,2*]

[1]College of Chemistry and Environmental Engineering, Yangtze University, Jingzhou, China
[2]Hubei Collaborative Innovation Center for Unconventional Oil and Gas, Wuhan, China
Email: 857426117@qq.com, *yuweichu@126.com

How to cite this paper: Xing, J.Z., Wu, A.B., Shu, W.M., Zhang, Y., Li, Y.L. and Yu, W.C. (2020) Laboratory Research on the Performance of Fracturing Fluid System for Unconventional Oil and Gas Reservoir Transformation. *Open Journal of Yangtze Gas and Oil*, **5**, 176-187.
https://doi.org/10.4236/ojogas.2020.54014

Received: July 22, 2020
Accepted: August 29, 2020
Published: September 2, 2020

Abstract

Fracturing fluid is the blood of fracturing construction, which is very important for fracturing, which requires that fracturing fluid needs to have good performance. The three commonly used fracturing fluids for unconventional oil and gas reservoir transformation are: 1) Guar gum fracturing fluid; 2) Water-based emulsion slippery water fracturing fluid; 3) Oil-based emulsion slippery water fracturing fluid. In this paper, water samples and other experimental data provided by Mahu Oilfield are used to evaluate three different fracturing fluid systems in laboratory. The formulas of the three different fracturing fluid systems are: 1) Water-based emulsion slippery water fracturing fluid is clean slippery water fracturing fluid 0.1% JHFR-2D drag reducer + 0.2% JHFD-2 multifunctional additive; 2) Oil-based emulsion slippery water fracturing fluid 0.1% A agent + 0.2% B agent; 3) Guar gum fracturing fluid 0.1% guanidine gum + 0.5% drainage aid + 0.3% demulsifier. The compatibility, drag reduction performance, reservoir damage, residue content, anti-swelling performance, surface interfacial tension, viscosity and other properties of three different slippery water fracturing fluid systems were studied. Through laboratory experiments, the comprehensive indicators show that clean slippery water fracturing fluid has obvious advantages.

Keywords

Fracturing Fluid System, Drag Reduction Performance, Reservoir Damage, Biological Toxicity, Compatibility

1. Introduction

With the continuous deepening of unconventional oil and gas development, large-scale volume fracturing has gradually become a key technology for economic development of unconventional oil and gas reservoirs with low and ultra-low permeability [1]. The most widely used fracturing fluid system for large volume fracturing is slippery water fracturing fluid. Fracturing fluid is the blood of fracturing construction; its performance not only directly affects the success rate of fracturing, but also has a great impact on the effect of oil and gas layer transformation after fracturing [2]. In addition, large fluid volume and large displacement are the most prominent characteristics of volume fracturing, which also requires its fracturing fluid to have good performance, which can effectively reduce friction, cause little damage to reservoirs, good compatibility, and be green, clean and pollution-free [3] [4] [5]. The three commonly used fracturing fluids for unconventional oil and gas reservoir transformation are: 1) Guar gum fracturing fluid; 2) Water-based emulsion slippery water fracturing fluid; 3) Oil-based emulsion slippery water fracturing fluid. At present, guanidine gum fracturing fluid and oil-based emulsion slickwater fracturing fluid have some shortcomings, such as high viscosity, poor drag reduction effect, high residue content, difficult oilfield sewage treatment, serious damage to tight reservoir caused by easily plugging pores, slow swelling speed of thickener, etc., which make them unable to better meet the requirements of large displacement construction. After fracturing with these two kinds of fracturing fluids, problems such as soft formation and rapid production decline often occur, so it is urgent to develop a slickwater fracturing fluid system with good drag reduction effect, quick dissolution and low damage. The compatibility, drag reduction performance, reservoir damage, residue content, anti-swelling performance, surface tension, viscosity and other properties of three different fracturing fluid systems were evaluated in laboratory with water samples and other experimental materials provided by Mahu Oilfield. A qualified slickwater fracturing fluid system is selected.

2. Experimental Part

2.1. Experimental Drugs and Instruments

1) Drug. a) Drag reducer JHFR-2D, composed of water-soluble monomers (acrylics, acrylic phthalimides, acrylic vinegars, acrylic salts, sulfonates), fluorine-containing acrylic vinegar, mutual solvent (alcohol), surface activity Agent/dispersant (polypropylene ammonium salt) and inorganic ammonium salt are obtained by free radical initiated dispersion polymerization in water; b) Multifunctional additive JHFD-2D, which has both anti-swelling and drainage aid effects; c) Oil-based emulsion drag reducer A; d) Agent B; e) Guar gum; f) Drainage aid; g) Demulsifier

2) Instrument. a) #Z-I Drag reduction performance test device (Jingzhou Modern Petroleum Technology Co., Ltd.); b) Intelligent biological toxicity tester (manufactured by Nanjing Institute of Soil Science, Chinese Academy of Sciences); c) LDZ4-1.8 Balanced centrifuge (Beijing Leiboer Centrifuge Co., Ltd.); d) Multifunctional core displacement device (Jingzhou Modern Petroleum Technology Co., Ltd.); e) Pinz Viscometer (Shanghai Huichuang Chemical Instrument Co., Ltd.).

2.2. Experimental Method

1) Resistance reduction test method. The drag reduction rate test system is composed of a test device and a data acquisition and processing device. The core of the test device is a test pipeline, which has 2 pipes with a length of 2 m and an internal diameter of 6.8 mm and 10 mm respectively. Made of pressure-resistant material, it can withstand the impact of liquid on the pipeline at high flow rates. The data acquisition system includes differential pressure sensors, pressure sensors, and flow meters.

First, pour the prepared liquid to be tested into the batch tank of the drag reduction rate test system; open the computer operation interface, open the corresponding valve through the software control system, and let the liquid to be tested enter the heating tank, if high temperature test is required, then turn on the temperature control system for heating; after reaching the preset conditions, turn on the circulation pump to make the liquid to be tested run normally in the test pipeline; set the flow rate and test time through the computer control interface. After the flow rate is stable, begin to collect the data of the differential pressure sensor of the corresponding test pipeline is collected and automatically processed by the software system to calculate the drag reduction rate, combined with the flow rate, temperature and pressure difference recorded by the system, so as to evaluate the drag reduction effect of the liquid to be tested.

The formula for calculating the drag reduction rate is as follows:

$$\eta = \frac{p_0 - p}{p_0} \times 100$$

where: η *is the drag reduction rate*, %; p_0 *is the friction pressure drop of fresh water before adding the liquid to be tested*, *kPa*; p *is the friction pressure drop after adding the liquid to be tested*, *kPa*.

2) Biological toxicity test method. According to the standard Q/SY 111—2007 "Oilfield chemicals, drilling fluid biological toxicity classification and detection method luminous bacteria method" [6] and SY/T6788—2010 "Evaluation method for environmental protection of water-soluble oil field chemicals" [7] determination of biological toxicity.

3) Expansion volume test method. According to the standard Q/SH 0053—2010 "Clay stabilizer technical requirements" [8] determination of the expansion volume of the fracturing fluid system.

4) Test method for residue content. According to the standard NB/T 14003.3-2017 "Shale gas fracturing fluid Part 3: Performance index and evaluation method of continuous mixing fracturing fluid" [9] test residue content. Measure 50 mL of fracturing fluid and put it into a closed container to break gel at constant temperature of reservoir, then pour it into a dried centrifuge tube and put it into a centrifuge, centrifuge it for 30 min at a rotating speed of 3000 r/min, then slowly pour out the supernatant, add distilled water to 50 mL, stir and wash the residue sample with a glass rod, then put it into a centrifuge for 20 min, then pour out the supernatant and put the centrifuge tube into a blast dry-

ing oven for baking, after drying to a constant weight at a temperature of 105˚C ± 1˚C, take its value.

5) Test viscosity according to the standard NB/T 14003.3-2017 "Shale Gas Fracturing Fluid Part 3: Performance Index and Evaluation Method of Continuous Mixing Fracturing Fluid" [9]. Measuring principle: Measure the time required for a certain volume of fluid to flow through Pinter viscometer at a uniform laminar flow under the action of gravity to obtain kinematic viscosity.

2.3. Three Slippery Water Fracturing Fluid Systems

The formulas of the three fracturing fluids are shown in **Table 1**. The solution prepared according to the formula is shown in **Figures 1-3**.

Table 1. Formulation of three fracturing fluids.

Numbering	Fracturing fluid type	Formula
1	Clean slippery water fracturing fluid	0.1% JHFR-2D drag reducer + 0.2% JHFD-2 multifunctional additive
2	Oil-based emulsion slippery water fracturing fluid	0.1% A agent + 0.2% B agent
3	Guar gum fracturing fluid	0.1% guar gum + 0.5% drainage aid + 0.3% demulsifier

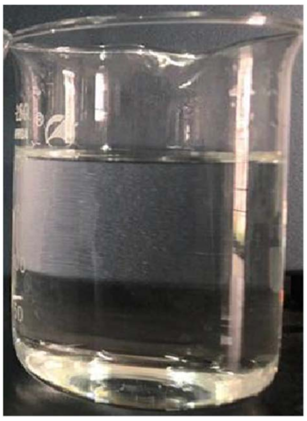

Figure 1. Slippery water fracturing fluid prepared by JHFR-2D and JHFD-2.

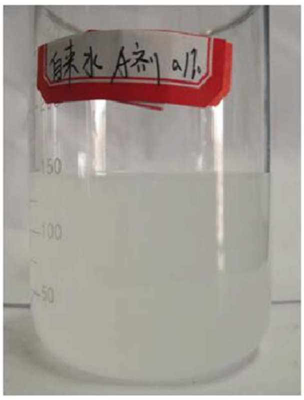

Figure 2. Slippery water fracturing fluid prepared by agent A and agent B.

Figure 3. Slippery water fracturing fluid formulated with guar gum, drainage aid and demulsifier.

3. Experimental Results and Discussion

3.1. Compatibility

The compatibility of the fracturing fluid itself affects whether it will cause damage to the formation. If the fracturing fluid is produced during its preparation, it will affect the permeability of the reservoir and sand-filled fractures [10]. Therefore, the compatibility test of the three slippery water fracturing fluids was conducted. The clean slippery water fracturing fluid prepared by JHFR-2D and JHFD-2 had no flocculent and sedimentation phenomena (see **Figure 1**), indicating that the two are well compatible.; The Oil-based emulsion slippery water fracturing fluid formulated with agent A and agent B produces a small amount of insoluble matter in suspended particles (see **Figure 2**), indicating that the compatibility between the two is not good; the guanidine gum prepared with guar gum, drainage aid and demulsifier. The split fluid is slightly turbid and produces a small amount of flocculent insolubles (see **Figure 3**), indicating that the three are not compatible.

3.2. Drag Reduction Performance

3.2.1. Drag Reduction Performance in Clean Water

The drag reduction rate of three slippery water fracturing fluids in clear water was measured using its own drag reduction rate test system. The diameter of the test tube was 10 mm.

1) According to the fracturing fluid system prepared according to formula in **Table 1**, the fracturing fluid system with displacement of 30 L/min was selected and the concentration of the three kinds of drag reducing agents was increased under the same other conditions. The test results are shown in **Figure 4**. It can be seen that almost all of the three fracturing fluid systems reached the maximum drag reduction rate when the additive concentration was 0.1%, and then the drag reduction rate declined with the increase of the concentration. Thus, the amount of drag reducing agent is determined to be 0.1%. The drag reduction rate of Oil-based emulsion slippery water fracturing fluid and clean slippery wa-

ter fracturing fluid is significantly higher than that of guar gum fracturing fluid. The highest drag reduction rate is Oil-based emulsion slippery water fracturing fluid, but with the increase of dosage, its drag reduction. The stability gradually decreases, so the clean slippery water fracturing fluid has a high drag reduction rate and stability.

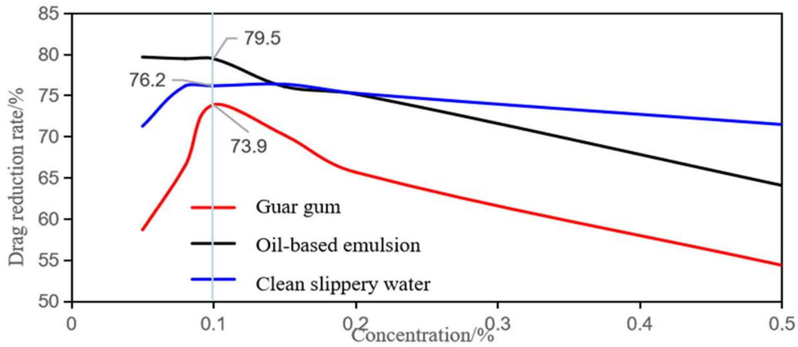

Figure 4. The relationship between the concentration of three fracturing fluids and the drag reduction rate.

2) Large fluid volume and large displacement are the characteristics of volume fracturing, so it is particularly important to test the drag reduction performance at different displacements. The fracturing fluid system formulated according to the formula in **Table 1** is selected under the condition that the concentration of the drag reducer is added at 0.1%, and other conditions are kept the same. The test results are shown in **Figure 5**. It can be seen from this that when the amount of drag reducing agent in the three fracturing fluid systems is 0.1%, the higher the displacement, the greater the drag reduction rate. And the clean and slippery water drag reducer also has a good drag reduction rate at a small displacement. Taken together, the medium drag reduction performance of clean slippery water fracturing fluid is close to that of Oil-based emulsion slippery water fracturing fluid, both of which are higher than that of guar gum fracturing fluid.

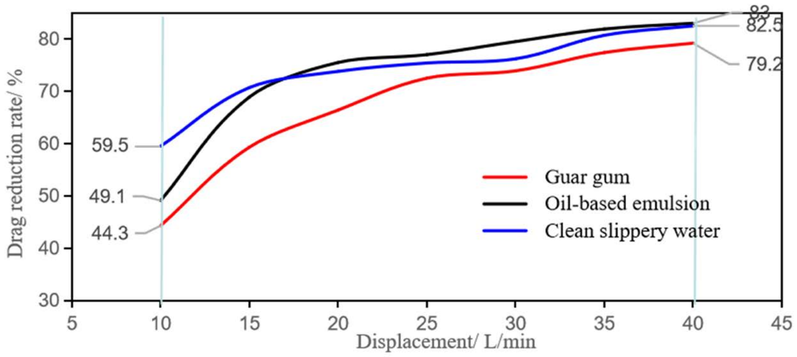

Figure 5. The relationship between the displacement of three fracturing fluids and the drag reduction rate.

3.2.2. Resistance to Salt and Drag Reduction

In the field fracturing construction, in order to save costs and protect the environment, the backflow is usually used to prepare slick water, but there will be dissolved salts in the backflow, and the metal ions in the liquid may have a certain effect on the fracturing fluid system. The influence of [11], so testing the fracturing fluid drag reduction rate in brine is of great practical significance for the development and application of oil and gas fields. By analyzing the water quality of a well in Mahu Oilfield (see **Table 2**), it can be seen that the main metal ions are Na^+, K^+, Mg^{2+} and Ca^{2+}. The fracturing fluid system formulated according to the formula in **Table 1** was tested for drag reduction in different ionic solutions. The results are shown in **Figure 6**. It can be seen that the drag reduction rates of the three fracturing fluid systems in different ionic solutions all show a downward trend, but the clean slip water fracturing fluid has the smallest decline, and it can be clearly seen that the Oil-based emulsion slippery water fracturing fluid and clean slip water fracturing. The drag reduction rate of the fluid is higher than that of guar gum fracturing fluid.

Table 2. Water quality analysis of a well in Mahu Oilfield.

Water sample	pH value	Na^+	K^+	Mg^{2+}	Ca^{2+}	Total salinity
Formation water	6	97.018	8.614	13.584	45.87	800.00
Back drainage	6	1707.254	394.7	13.49	1548.54	11933.33

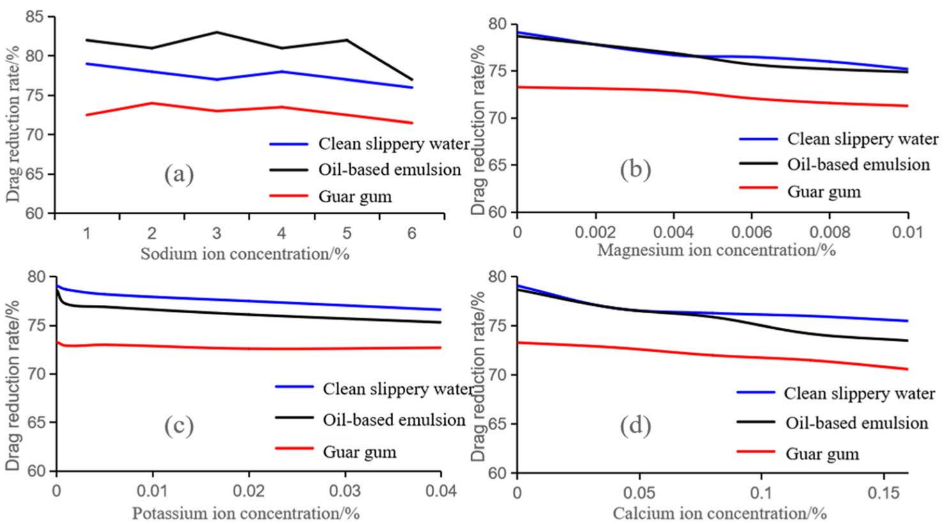

Figure 6. Drag reduction rate of three kinds of fracturing in different ions.

3.3. Reservoir Damage

During the fracturing process, the solid particles carried by the foreign liquid enter the reservoir, which is incompatible with the formation fluid and produces precipitation or expansion or migration of clay minerals, which blocks the pore channels, reduces the permeability, and damages the reservoir to varying degrees [12]. There are many factors that cause fracture damage to the reservoir, including the expansion of the surrounding clay minerals after fracturing fluid enters the well and the amount of fracturing fluid residue.

1) The change of reservoir permeability can be used to characterize the degree of reservoir damage. The greater the decrease in permeability, the more severe the reservoir damage. Using a multi-functional core displacement device at a temperature of 25˚C, using natural core feed to conduct core displacement experiments on three fracturing fluid systems, respectively measuring the permeability values of the three fracturing fluid systems before and after displacement. Characterize the degree of reservoir damage. The results are shown in **Table 3**. According to the change of permeability, the damage of clean slippery water fracturing fluid to the reservoir is much smaller than that of Oil-based emulsion slippery water fracturing fluid and guar gum fracturing fluid, which is more conducive to protecting the reservoir.

Table 3. Permeability damage rate data table.

Numbering	Fracturing fluid type	Original permeability/um^2	Penetration after injury/um^2	Penetration rate Damage rate /%
1	Clean slippery water fracturing fluid	7.87×10^{-3}	6.43×10^{-3}	18.34
2	Oil-based emulsion slippery water fracturing fluid	2.16×10^{-4}	5.00×10^{-4}	76.84
3	Guar gum fracturing fluid	6.3×10^{-3}	6.70×10^{-4}	89.36

2) The residue of the fracturing fluid may block the pores in the fracture, resulting in reduced flow capacity. The higher the residue content, the greater the damage to the reservoir [13]. The test results of three different fracturing fluid systems are shown in **Table 4**. The residue content of 0.1% JHFR-2D and clean slippery water fracturing fluid is zero, that of 0.1% A drag reducer is 60.00 mg/L, and that of oil-based emulsion slickwater fracturing fluid is 12.99 mg/L, which is lower than that of agent A single agent. This is mainly due to the addition of agent B (a surfactant) to Oil-based emulsion slippery water fracturing fluid, which can solubilize agent A. The residue content of guar gum fracturing fluid is the largest at 99.42 mg/L. The results show that the clean slippery water fracturing fluid has the least damage to the reservoir and meets the current requirements of the reservoir for environmental protection.

Table 4. Experimental results of residue content.

Numbering	Sample name	Residue content, mg/L
1	0.1% JHFR-2D	0
2	Clean slippery water fracturing fluid	0
3	0.1% A agent	60.00
4	Oil-based emulsion slippery water fracturing fluid	12.99
5	Guar gum fracturing fluid	99.42

3.4. Biological Toxicity

There are various chemicals in the fracturing fluid system added during the fracturing process. Once the water enters the reservoir, it may cause problems such as pollution of the formation water. Therefore, it is necessary to analyze the biological toxicity of various chemicals in the well fluid to minimize pollution. See **Table 5** for the results of biological toxicity experiments on the three fracturing fluid systems. The EC_{50} value of clean slippery water fracturing fluid is similar to that of clean water. The greater the EC_{50} value, the lower the toxicity. When $EC_{50} > 20{,}000$, it is non-toxic, indicating that the clean slippery water fracturing fluid and guar gum fracturing fluid are safe, non-toxic and environmentally friendly. However, the Oil-based emulsion slippery water fracturing fluid has certain biological toxicity, which does not meet the requirements of the current green environmental protection fracturing fluid.

Table 5. Results of biological toxicity testing of three fracturing fluid systems.

Fracturing fluid system	EC_{50}, mg·L^{-1}	Toxicity level
Shimizu	1.0×10^6	Non-toxic
Clean slippery water fracturing fluid	1.89×10^6	Non-toxic
Oil-based emulsion slippery water fracturing fluid	1.06×10^6	Non-toxic
Guar gum fracturing fluid	1.13×10^3	Slightly toxic

3.5. Other Properties

For fracturing fluid system, priority should be given to its drag reduction performance, reservoir damage, biotoxicity and compatibility, etc., but other performances should also be considered, including kinematic viscosity, surface tension, anti-swelling rate, etc. The test results are shown in **Table 6**. It can be seen from the test results that the viscosity of clean slickwater fracturing fluid is low, which may lead to its sand carrying effect being inferior to that of the other two fracturing fluid systems, but this shortcoming can be well compensated by combining the fracturing method with large displacement and large liquid volume [14]. The surface tension of clean slippery water fracturing fluid is 23.42 mN/m, which is smaller than that of guar gum fracturing fluid and Oil-based emulsion slippery water fracturing fluid, which is beneficial to the exploitation of crude oil. The anti-swelling rate of clean slickwater fracturing fluid is as high as 81.12%, which is about twice as high as that of guanidine gum fracturing fluid and Oil-based emulsion slippery water fracturing fluid, which shows that it has strong ability to inhibit the hydration expansion of clay minerals and is not easy to block pores and damage reservoirs.

Table 6. Other performance test results of three fracturing fluid systems.

Fracturing fluid system	Kinematic viscosity/mm^2/s	Surface Tension/mN/m	Anti-swelling rate/%
Clean slippery water fracturing fluid	1.37	23.42	81.12
Oil-based emulsion slippery water fracturing fluid	3.30	29.92	40.00
Guar gum fracturing fluid	3.21	27.41	46.88

3.6. Summary of the Performance of Three Fracturing Fluid Systems

The performance evaluation results of the three fracturing fluid systems are shown in Table 7. Comprehensive indicators show that compared with the other two fracturing fluids, the clean slick water fracturing fluid has good compatibility, higher drag reduction rate, ultra-low core permeability damage rate, non-toxic, low viscosity, low surface tension and high anti-swelling rate.

Table 7. Performance comparison results of three fracturing fluid systems.

Fracturing fluid type performance	Clean slippery water fracturing fluid	Oil-based emulsion slippery water fracturing fluid	Guar gum fracturing fluid
Fracturing fluid formula	0.1% JHFR-2D drag reducer + 0.2% JHFD-2 multifunctional additive	0.1% A agent + 0.2% B agent	0.1% guar gum + 0.5% drainage aid + 0.3% demulsifier
Compatibility	good	not good	not good
Drag reduction rate, %	76.2	79.5	73.9
Core permeability damage rate, %	18.34	76.84	89.36
Biological toxicity, EC_{50}, mg/L	1.89×10^6 (Non-toxic)	1.13×10^3 (Slightly poisonous)	1.06×10^6 (Non-toxic)
Kinematic viscosity, mm^2/s	1.37	3.30	3.21
Surface tension, mN/m	23.42	29.92	27.41
Anti-swelling rate, %	81.12	40.00	46.88

4. Conclusions

1) The clean slippery water fracturing fluid shows good drag reduction performance in clear water or in different metal ions and its drag reduction effect is stable, which can reduce the pressure of fracturing construction and help to ensure the smooth progress of fracturing construction.

2) Compared with guar gum fracturing fluid and Oil-based emulsion slippery water fracturing fluid, the clean and smooth water fracturing liquid has the advantages of non-toxic and environmental protection, and is environmentally friendly, and the clean and smooth water fracturing fluid is less harmful to the reservoir and is beneficial to protect the reservoir. It meets the requirements of the current green development of oil reservoirs, and provides certain basic support for the selection of fracturing fluids for oil and gas field development.

3) Clean slickwater fracturing fluid has the characteristics of good compatibility, low viscosity, green cleaning and little damage to reservoir. Combined with large volume fracturing, it has the characteristics of large displacement and large fluid volume, which can increase mechanical kinetic energy, make up for the disadvantage of low sand-carrying strength of water-based fracturing fluid, thus forming longer and more complex fractures, improving oil recovery efficiency and having good development prospects.

Acknowledgements

This article was completed under the careful guidance of Professor Yu Weichu. The article relies on the National Science and Technology Major Project "Research on Flow Mechanism and Key Technology of Continental Shale Oil Development" (No. 2017ZX05049003-007). Thank you Professor Yu Weichu and all members of the research team, thank Xinjiang Oilfield for your support, and thank Yangtze University for training me.

Conflicts of Interest

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

References

[1] Fan, Y., Xiao, Y., Guo, X. and Yu, W. (2018) Application of Clean Slippery Water Fracturing Fluid in Changning H26 Platform. *Drilling Fluid and Completion Fluid*, **35**, 122-125.

[2] Li, Y., Yang, G., Zhu, C. and Yang, H. (2014) Progress in Fracturing Fluid Technology for Shale Gas Production. E*xploration Engineering* (*Rock and Soil Drilling and Engineering*), **41**, 13-16.

[3] Tang, Y., Tang, X., Wang, G. and Zhang, Q. (2011) Summary of Shale Gas Development Hydraulic Fracturing Technology. *Geological Bulletin*, **30**, 393-399.

[4] Yu, W., Wu, J. and Han, B. (2015) Synthesis and Application of Green Clean Nanocomposite Drag Reducer for Shale Gas Development. *Journal of Yangtze University* (*Self-Edition*), **12**, 78-82+7.

[5] Jiang, G., Xu, W., Li, Y. and Li, L. (2013) Technology and Research Progress of Drag Reduction Water Fracturing Fluids Abroad. *Special Oil and Gas Reservoirs*, **20**, 1-6+151.

[6] Q/SY 111-2007 "Oilfield Bacterial Agents, Drilling Fluid Biological Toxicity Classification and Detection Methods Luminescent Bacteria Method".

[7] SY/T6788-2010 "Environmental Protection Evaluation Method for Water-soluble Oilfield Chemical Agents".

[8] Q/SH 0053-2010 "Technical Requirements for Clay Stabilizer".

[9] NB/T 14003. 3-2017 "Shale Gas Fracturing Fluid Part 3: Performance Index and Evaluation Method of Continuous Mixing Fracturing Fluid".

[10] Wang, S. (2010) Evaluation and Protection Technology of Oil and Gas Reservoir Damage. *Neijiang Science and Technology*, **31**, 61+118.

[11] Yuan, X., Xu, D., Chen, S., He, X., Cheng, N. and Chen, J. (2020) Fracture Fluid Intrusion Damages the Shale Reservoir Conductivity. *Science Technology and Engineering*, **20**, 3591-3597.

[12] Zhou, D., Li, X., Xiao, Y., Guo, X., Ding, F. and Yu, W. (2018) A New Type of Slippery Water Fracturing Fluid System Based on Return Drainage. *Petroleum Drilling and Production Technology*, **40**, 503-508.

[13] Wang, T. (2020) Fracturing Fluid Damage to the Reservoir and Its Protection Technology. *Chemical Engineering and Equipment*, No. 4, 104-105.

[14] Li, P., Fan, P., Hao, S., Zheng, Z. and Yu, W. (2019) Application Practice of

Large-Volume, Large-Displacement, Low-Sand-Ratio Slipping Water Staged Fracturing Technology. *Petroleum Drilling and Production Technology*, **41**, 534-540.