Preparation and Performance Evaluation of an Environmentally Friendly Lubricant for Water-based Drilling fluid

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Abstract. With the increasing difficulty of exploration and development of oil and gas resources, the problems of high friction torque in long horizontal well section and high temperature in deep well are increasingly prominent, which put forward higher technical requirements for the lubricity, temperature resistance and environmental protection of drilling fluid lubricant. Traditional drilling fluid lubricants are difficult to meet the above technical requirements. Based on the optimization of modified vegetable oil, extreme pressure agent, surfactant, antioxidant and preparation conditions, an environmentally friendly drilling fluid lubricant SDGL-2 was developed. The evaluation results show that the lubricant SDGL-2 has fluorescence grade of 1~2, temperature resistance of 160 ℃, good biodegradability and no toxicity. Its lubricity is better than that of common drilling fluid lubricants, and it is compatible with several common drilling fluids.

1. Introduction
Drilling fluid is known as “the blood of drilling engineering”, which plays an important role in drilling operation. With the increasing difficulty of oil and gas exploration, the number of special process wells such as extended reach wells, horizontal wells and high temperature wells is increasing. The resulting harsh drilling conditions such as high friction torque and high temperature put forward higher technical requirements for the lubrication performance of drilling fluid. [1-3] At present, the commonly used drilling fluid lubricants generally have the problems of high foaming rate, poor temperature resistance, and have a great impact on the environment, seriously threaten the ecological environment, and cannot meet the increasingly stringent requirements of environmental protection.[4-7] The conventional drilling fluid lubricant base oils are usually ordinary mineral oil or vegetable oil, which generally has the problems of high fluorescence level or poor temperature resistance, and most of the commonly used lubricant additives contain phosphorus, sulfur and other elements, which has a great impact on the environment and limits its popularization and application to a large extent.[8-9]
In view of the poor temperature resistance and environmental protection performance of drilling fluid lubricants, this paper selects environment-friendly modified vegetable oil MOV-1 as lubricant base oil through a lot of investigation and experiments, and develops an environmentally friendly high-efficiency drilling fluid lubricant SDGL-2 by adding environment-friendly extreme pressure agent GEP-1, environment-friendly antioxidant GANT-1, complex surfactant GH-1, etc.

2. Experiments

2.1. Materials
Non-ionic surfactant NP-1, NP-2, chemical purity; modified vegetable oil MVO-1, MVO-2, MVO-3, MVO-4, anionic surfactant GAS-1, organic borate extreme pressure agent GEP-2, composite antioxidant GANT-1, industrial grade.

2.2. Preparation of lubricant

2.2.1. Optimization of base oil. Although mineral oil has good temperature resistance, it has high fluorescence level and cannot meet the requirements of environmental protection. Therefore, the modified vegetable oil is selected as the lubricant base oil in this experiment. Several kinds of vegetable oils were selected in the laboratory, and their basic parameters were tested. The experimental results are shown in table 1.

| Base oil | Kinematic viscosity /mm²·s⁻¹ | Flash point/℃ | Aromatics content/% | Reduction rate of lubrication coefficient/% | Fluorescence level |
|----------|-----------------------------|---------------|---------------------|-------------------------------------------|-------------------|
| MOV-1    | 5.02                        | 191           | 3.5                 | 63.21                                     | 1~2               |
| MOV-2    | 6.38                        | 132           | 2.0                 | 55.63                                     | 2~3               |
| MOV-3    | 7.72                        | 155           | 4.0                 | 60.33                                     | 3~5               |
| MOV-4    | 4.33                        | 179           | 8.0                 | 56.68                                     | 2~3               |

The experimental results show that MOV-1 has good lubricity, fluidity, low fluorescence level, high flash point and good comprehensive performance. Therefore, modified vegetable oil MOV-1 was selected as lubricant base oil.

2.2.2. Optimization of lubricant formulation and preparation conditions. Single base oil cannot meet the technical requirements of drilling engineering effectively. Therefore, the compatibility of different surfactants, extreme pressure agents and antioxidants with modified vegetable oil MOV-1 and the improvement of its lubricity were investigated. The composite surfactant GH-1 (composed of anion surfactant GAS-1, non-ionic surfactant NP-1 and NP-2 in a certain proportion), the organic borate GEP-1 and antioxidant GANT-1 were optimized. Through orthogonal experiment, the formulation and preparation conditions of lubricant were optimized, and environmentally friendly lubricant SDGL-2 for drilling fluid was prepared.

The formulation and preparation conditions of lubricant SDGL-2 are as follows:

92%~95% MOV-1 + 2.0%~3.0% GH-1 + 2.0%~3.0% GEP-1 + 1.0%~2.0% GANT-1. The reaction temperature is 35~40 ℃ and the reaction time is 3 h.

2.3. Preparation of experimental mud

Fresh water based bentonite mud (FWM): 400 mL Fresh water + 0.8 g Na₂CO₃ + 20.0 g drilling fluid bentonite. Then the mud was sealed and kept incubation for at least 24 h to reach thorough hydration.

Brine water based bentonite mud (BWM): 400 mL FWM + 16.0 g NaCl.
2.4. Performance test of drilling fluid

2.4.1. Rheological property test. ZNN-D6 six-speed rotating viscometer is used to measure the apparent viscosity (AV), plastic viscosity (PV) and yield point (YP) of drilling fluid. AV, PV and YP are calculated as follows:

\[ AV = \Phi_{600}/2 \text{(mPa.s)} \]  
\[ PV = \Phi_{600} - \Phi_{300} \text{(mPa.s)} \]  
\[ YP = (\Phi_{300} - PV)/2 \text{(Pa)} \]

Where \( \Phi_{600} \) and \( \Phi_{300} \) are the dial readings at 600 and 300 rpm, respectively.

2.4.2. API filtration (FL API) test. According to API standard, the API filtration of drilling fluid at 0.7MPa pressure for 30min is measured by SD4-type medium-pressure filtration apparatus (Qingdao Chuangmeng Special Instrument Co., Ltd., China).

2.4.3. Lubrication performance test. According to the test method of drilling fluid lubrication performance, EP-C extreme pressure lubricator (Qingdao Senxin Special Instrument Co., Ltd., China) and NZ-2 filter cake stuck factor tester (Qingdao Haitongda Special Instrument Co., Ltd., China) are used to measure the extreme pressure lubrication coefficient and filter cake stuck factor of drilling fluid respectively.

3. Results and discussion

3.1. Routine physical and chemical properties test
Referring to the technical specification for liquid lubricants for drilling fluids, the main physical and chemical properties of SDGL-2 are evaluated. The results are shown in table 2. The results show that the fluorescence level of SDGL-2 is low and its physical and chemical properties can meet the basic requirements of field lubricant.

| Performance Index       | Test result                          |
|-------------------------|--------------------------------------|
| Appearance              | Homogeneous liquid                   |
| \( \rho/\text{(g/cm}^3) \) | 0.90±0.10                            |
| Density change of FWM/(g/cm³) | ≤0.08                                   |
| AV of FWM/mPa.s         | ≤20.0                                 |
| Filtrate value of FWM/mL| ≤25.0                                 |
| Reduction rate of lubrication coefficient/% | ≥70.0                                   |
| Fluorescence level      | <5                                    |

3.2. The influence on the properties of FWM and BWM
Different amounts of lubricant SDGL-2 were added to FWM and BWM respectively. The effects of lubricant SDGL-2 on the properties of mud were investigated by testing the density, rheological properties, filtrate value and lubricating properties of the experimental mud. The results are shown in table 3.
Table 3. Effect of lubricant SDGL-2 on properties of FWM and BWM

| Type of drilling fluid | Dosage of SDGL-2 | AV /mPa.s | PV /mPa.s | YP/Pa | FLAPI /mL | ρ/(g/cm³) | Reduction rate of lubrication coefficient/% |
|------------------------|------------------|-----------|-----------|-------|-----------|----------|-----------------------------------------|
| FWM                    | 0.0              | 11.0      | 6.0       | 5.0   | 20.0      | 1.028    | —                                       |
|                        | 0.5              | 15.0      | 9.5       | 5.5   | 15.6      | 0.998    | 80.25                                   |
|                        | 1.0              | 16.5      | 11.0      | 5.5   | 15.0      | 0.986    | 85.33                                   |
| BWM                    | 0.0              | 9.5       | 5.0       | 3.0   | 52.6      | 0.998    | —                                       |
|                        | 0.5              | 12.0      | 7.0       | 5.0   | 32.2      | 0.986    | 75.65                                   |
|                        | 1.0              | 13.0      | 7.5       | 5.5   | 24.2      | 0.986    | 77.51                                   |

It can be seen from table 3 that after adding lubricant SDGL-2, the density and rheological parameters of FWM and BWM change little. With the increase of lubricant SDGL-2 dosage, the filtrate value of FWM and BWM decreased gradually. Under different lubricant SDGL-2 dosage, the reduction rate of lubrication coefficient of FWM was more than 80%, and that of BWM was more than 70%. It shows that the lubricant SDGL-2 has little effect on the properties of FWM and BWM, and has good lubrication performance.

3.3. Evaluation of temperature resistance

When the dosage of SDGL-2 is 0.5%, the rheological and filtration properties of FWM before and after hot rolling for 16 h at different temperatures are tested to evaluate the temperature resistance of the lubricant. The results are shown in table 4.

Table 4. Evaluation of high temperature resistance of lubricant SDGL-2

| SDGL-2/% | T/℃ | AV /mPa.s | PV /mPa.s | YP/Pa | FLAPI /mL | ρ/(g/cm³) | Reduction rate of lubrication coefficient/% |
|----------|-----|-----------|-----------|-------|-----------|----------|-----------------------------------------|
| 0.0      | Room temperature 11.0 6.0 5.0 20.0 1.028 — |
|          | 120 12.5 8.0 4.5 21.2 1.025 — |
|          | 140 13.0 9.0 4.0 23.8 1.025 — |
|          | 160 13.0 9.5 3.5 24.0 1.025 — |
| 0.5      | Room temperature 15.0 9.5 5.5 15.6 0.996 80.25 |
|          | 120 15.5 10.0 5.5 16.0 0.987 81.66 |
|          | 140 17.0 10.0 7.0 16.8 0.985 83.25 |
|          | 160 18.5 10.5 8.0 17.2 0.979 82.54 |

It can be seen from table 4 that the lubricant SDGL-2 has little effect on the density and rheological properties of FWM, and can reduce its filtration value to a certain extent. After aging at 160℃/16h, the reduction rate of the lubrication coefficient of the experimental mud is still as high as 82.54%. The results show that the temperature resistance of SDGL-2 can reach 160℃. With the increase of aging temperature, the reduction rate of the lubrication coefficient of the experimental mud, first increases and then decreases. This is mainly because with the increase of temperature, the extreme pressure agent can form a semi-solid film with strong adhesion on the metal surface, which plays a synergistic role with the oil-based lubricating components. However, when the temperature is too high, the effect of the oil-based lubricating components in the lubricant is weakened, then the lubricity of the lubricant will decrease.

3.4. Evaluation of biological toxicity

According to the biological toxicity classification and detection method of oilfield chemicals and drilling fluids, the biological toxicity of lubricant SDGL-2 was evaluated by using the luminescent
bacteria method. The results show that the EC50 of SDGL-2 is $17.2 \times 10^4$ mg/L, which is higher than the standard requirement of $2.5 \times 10^4$ mg/L. Therefore, it can be considered that SDGL-2 has no biological toxicity.

3.5. Evaluation of biodegradability

According to the national environmental protection standard, the biochemical oxygen demand (BOD5) and chemical oxygen demand (CODCr) of lubricant SDGL-2 were tested respectively, and the BOD5/CODCr was calculated to judge the biodegradability of lubricant. The results show that the ratio of BOD5/CODCr of SDGL-2 is 5.62%, indicating that it has good biodegradability, which can meet the requirements of drilling fluid treatment agent.

3.6. Comparison with common drilling fluid lubricants

Four lubricants HLUB-1, HLUB-2, HLUB-3, HLUB-4 with good temperature resistance were collected and compared with SDGL-2. When the lubricant dosage is 0.5%, the reduction rate of lubrication coefficient of FWM and BWM after hot rolling at 160 °C/16 h is shown in figure 1. It can be seen from figure 1 that the reduction rates of lubrication coefficient of SDGL-2 in FWM and BWM are better than those of the other four lubricants.

![Figure 1. Comparative evaluation experiment of common lubricants](image)

3.7. Compatibility test of lubricant SDGL-2 and common drilling fluids

Different types of drilling fluids with density of 1.25 g/cm³ were selected to investigate the effect of SDGL-2 dosage on their performance. The experimental results are shown in table 5.

| Drilling fluid       | SDGL-2/% | AV/mPa.s | PV/mPa.s | FLAPI/mL | ρ/(g/cm³) | Reduction rate of filter cake stuck factor/% |
|----------------------|----------|----------|----------|----------|-----------|------------------------------------------|
|Polymer-sulfonate     | 0.0      | 43       | 27       | 3.2      | 1.250     | —                                        |
|Polymer drilling fluid| 0.5      | 36       | 21       | 3.6      | 1.250     | 63.75                                    |
|Solid free drilling fluid| 0.5  | 37.5     | 22       | 3.0      | 1.230     | 67.50                                    |
|                      | 1.0      | 40       | 25       | 2.8      | 1.200     | 75.17                                    |
|                      | 0.0      | 35       | 15       | 6.2      | 1.250     | —                                        |
|                      | 0.5      | 40       | 20       | 5.6      | 1.250     | 63.75                                    |
|                      | 1.0      | 44       | 20       | 5.6      | 1.250     | 70.50                                    |
The experimental results show that when the lubricant dosage is 1.0%, the lubricant SDGL-2 has good lubrication performance and good compatibility with several commonly used water-based drilling fluids.

4. Conclusions
The environmentally friendly drilling fluid lubricant SDGL-2 was developed by optimizing the modified vegetable oil, extreme pressure agent, surfactant and antioxidant. The lubricant SDGL-2 has fluorescence level of 1~2, good biodegradability and no toxicity, which can meet the environmental protection requirements of drilling fluid lubricant.

The lubricant SDGL-2 can resist the temperature of 160 °C. When the dosage of SDGL-2 is 1.0%, the reduction rates of lubrication coefficient of fresh water based bentonite mud and brine water based bentonite mud after hot rolling at 160 °C/16 h are 85.33% and 77.51%, respectively. The lubricant SDGL-2 has better lubrication performance than the traditional drilling fluid lubricants, and has good compatibility with several commonly used water-based drilling fluids.

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References
[1] Xie B, Qiu Z, Huang W and Shen Z 2012 Summary on key technical issues of drilling fluid for extended reach well Drilling Fluid & Completion Fluid 29(2):76-82
[2] Jin J 2017 Research advances of the lubricants for drilling fluid Applied Chemical Industry 46(4) 770-774
[3] Sonmez A, Kok M V and Ozel R 2013 Performance analysis of drilling fluid liquid lubricants. Journal of Petroleum Science and Engineering 108
[4] Liu Y, Qiu Z, Yang P, Chen Z, Zhong H and Zhao X 2018 Preparation and evaluation of an environment-friendly and extreme pressure lubricant used in drilling fluid Applied Chemical Industry 47(12) 2590-94
[5] Kania D, Yunus R, Omar R, Rashid S A and Jan B M 2015 A review of biolubricants in drilling fluids: Recent research, performance, and applications. Journal of Petroleum Science and Engineering, 135.
[6] Zheng Y, Amiri A and Polycarpou A A 2020 Enhancements in the tribological performance of environmentally friendly water-based drilling fluids using additives Applied Surface Science 527
[7] Liu Y, Qiu Z, Yang P, Zhong H, Huang W and Zhao X 2018 A high-performance drilling fluid anti-wear lubricant Drilling Fluid & Completion Fluid 35(5) 8-13
[8] Qiu Z, Wang W Huang W, Zhong H and Zhang S 2013 Research and evaluation of novel anti-wear extreme-pressure lubricant SDR used for drilling fluid Drilling Fluid & Completion Fluid, 31(2) 18-21
[9] Saffari H R M, Soltani R, Alaei M and Soleymani M 2018 Tribological properties of water-based drilling fluids with borate nanoparticles as lubricant additives. Journal of Petroleum Science and Engineering 171