Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1147-1162
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

Preparation and Evaluation of Water-based Drilling Fluid HLR-1 Lubricant for Shale Gas Horizontal Wells

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Abstract:

Shale gas horizontal wells often face problems such as wall instability, difficult borehole cleaning and high frictional torque during the drilling process. Among them, high frictional torque can cause a series of safety problems, such as start-up and down-drilling jam, buried drilling tool and buried rotary guide. To effectively solve this problem, this paper developed a water-based drilling fluid lubricant HLR-1 for shale gas horizontal wells using environmentally friendly modified vegetable oil, compound surfactant, extreme pressure anti-wear agent and coagulant as raw materials. Indoor evaluation showed that after adding the lubricant HLR-1 to the base mud, the apparent viscosity, density, mud cake adhesion coefficient and drilling fluid lubrication coefficient variation values of the base mud were in accordance with Q/SY 1088-2012 "Technical Specification of Liquid Lubricant for Drilling Fluid". The lubricant has good low temperature fluidity, high temperature resistance and salt resistance. It shows good compatibility in both dispersion drilling fluid system and polymer drilling fluid system. Compared with the commonly used lubricants RH-220, YKZJ-1, YRH-1 and YRH-1D, HLR-1 shows excellent lubrication performance in both base mud and field well mud, and the reduction rate of lubrication coefficient is 93.5% and 19.32%, respectively.

***Keywords**: shale gas, horizontal well, water-based drilling fluid, lubricant.*

I. INTRODUCTION

The total amount of unconventional natural gas in China is about 30.7×10^{12} m^3 , ranking second in the world, after the United States, and accounting for 13.9% of the global total unconventional natural gas[1] . As a major unconventional gas, China's shale gas reserves are abundant and have a promising development prospect. The organic-rich shales of the Paleozoic marine phase are widely distributed in China, mainly in the southern part of the country and the Tarim Basin. The internal organic matter of this shale formation is rich, with good continuity and thick shale blocks. In addition, this shale is one of the most abundant recoverable resources among the three major shale types in China. In recent years, rich low-permeability

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oil reservoirs have been discovered in the Sichuan Basin in the southern part of China, and drilling fluid, as the "blood" of the drilling project, is the guarantee for the successful exploitation of this strategic energy source.

China's shale gas horizontal well were mostly drilled with oil-based drilling fluids before 2018. However, the use of oil-based drilling fluid also has its disadvantages, such as the high oil content of the drill cuttings carried up from the bottom of the well by the drilling fluid, which can be harmful to the environment, and the time and cost to handle the oil-containing drill cuttings[2-6] . In contrast, the use of water-based drilling fluids for horizontal shale gas wells has basically no impact on the environment, and the resulting rock chips are simple and convenient to dispose of at a lower cost, which can significantly reduce environmental safety hazards and development costs. However, the use of water-based drilling fluids also has its outstanding problems, such as difficulty in cleaning the borehole for well wall instability and poor lubricity (high friction torque). International well-known oil service companies such as McBar, Halliburton and Baker Hughes have developed special shale gas water-based drilling fluids for these characteristics of shale gas and put them into field applications[7-15] . Therefore, this paper develops a high-performance lubricant suitable for shale gas horizontal wells (especially for long horizontal sections) to solve the technical bottleneck of lubrication.

II. MATERIALS AND METHODS

1.1 Main drugs and instruments

SP-80, TW-80, NaCl, Na_2CO_3, chemically pure; 10# white oil, modified vegetable oil JN-300, modified vegetable oil DFL-1, alkyl naphthalene (T801), pentaerythritol ester, methyl silicone oil, polyalpha-olefin (PAO), cottonseed oil sulfide (T405), isobutylene sulfide (T321), azoborate antiwear agent (RS-569), phosphorothioic acid Triphenyl phosphorothioate (TPPT or T309), dialkyl dithiophosphate molybdenum oxide sulfide (MoDTP), polymethacrylate (T602), bentonite, industrial grade.

Fann 35A six-speed rotational viscometer, XGRL-4 high-temperature roller heating furnace, GGS42-2 high-temperature and high-pressure water loss meter, NF-2 adhesion coefficient tester, EP extreme pressure lubricator, SD6A multi-connected normal temperature and medium pressure water loss meter, high-speed frequency mixer, etc.

1.2 Formulation and preparation of lubricant HLR-1

Liquid lubricants usually consist of base oils and additives such as surfactants, extreme pressure anti-wear agents and coagulants. Therefore, the effects of various base oils and additives on the rheology and lubricity of fresh water-based mud were investigated by indoor experiments, and modified vegetable oil DFL-1 was preferably selected as the base oil for lubricant, and SP-80, TW-80, nitrogen boron ester anti-wear agent (RS-569) and alkyl naphthalene (T801) as additives for lubricant. Through orthogonal experiments, the formulation of lubricant HLR-1 was determined: 83.3% base oil (DFL-1) + 13.9%

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compound surfactant (SP-80+TW-80) + 1.7% coagulant (T801) + 1.1% extreme pressure anti-wear agent (RS-569).

The preparation process of lubricant HLR-1: take a certain amount of modified vegetable oil DFL-1 in the stirrer at 1000r/min, add surfactant SP-80 and TW-80 to the stirrer in turn and continue to stir for 30min, and finally add extreme pressure anti-wear agent RS-569 and coagulant T801 and stir for 1h to get lubricant HLR-1.

2.Lubricant HLR-1 performance evaluation

2.1 Effect of lubricant HLR-1 on the performance of the base mud

The base mud contains 6% bentonite and 0.25% sodium carbonate. The apparent viscosity, density, mudcake adhesion coefficient and the change value of lubrication coefficient of drilling fluid were measured after adding lubricant HLR-1 to the base mud with reference to the provisions in the enterprise standard Q/SY 1088-2012 "Technical Specification for Liquid Lubricants for Drilling Fluids" of China National Petroleum Corporation. The technical requirements of liquid lubricants for drilling fluids are shown in TABLE I.

TABLE I. Technical requirements for liquid lubricants for drilling fluids

Projects	Indicators
Apparent viscosity increase value (mPa·s)	≤5.0
Density change value (g/cm^3)	≤0.08
Reduction rate of sludge cake adhesion coefficient (%)	≥50.0
Lubrication factor reduction rate (%)	≥80.0
The sludge cake adhesion coefficient reduction rate or the lubrication coefficient reduction rate can be either one according to the requirement.	

Add 3% homemade lubricant HLR-1 to the base mud, stir for 20min on a high speed mixer at 12000r/min to prepare the drilling fluid for the experiment, and use the prepared drilling fluid to measure the above technical requirements index, so as to compare the effect of lubricant HLR-1 on the performance results of the base mud. The specific results are shown in TABLE II.

TABLE II. Results of the effect of lubricant HLR-1 on the performance of the base paste

Projects	Base paste	Base paste + lubricant	Change value	International Requirements
Apparent viscosity	9.0	10.0	1.0	≤5.0

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(mPa·s)				
Density (g/cm^3)	1.45	1.51	0.06	≤0.08
Mud cake adhesion coefficient	0.1521	0.0676	55.56	≥50.0
Drilling fluid lubrication factor	0.4707	0.0306	93.50	≥80.0

As can be seen from TABLE II, after adding lubricant HLR-1 to the base mud, its apparent viscosity change value is 1.0 mPa•s, density change value is 0.06 g/cm^3 , mud cake adhesion coefficient reduction rate is 55.56%, and drilling fluid lubrication coefficient reduction rate reaches 93.50%, it can be seen that all four technical requirements indexes meet the technical requirements of liquid lubricant for drilling fluid, and the lubricant for drilling fluid HLR-1 also shows excellent lubrication effect.

2.2 Effect of lubricant HLR-1 on lubricating properties of drilling fluid

Adding a small amount of lubricant to the drilling fluid can greatly reduce the frictional torque generated during the drilling process, but the amount of lubricant added is not the best, too much lubricant will reduce the lubrication effect of drilling fluid and mud cake, and affect other properties of the drilling fluid. Therefore, it is necessary to optimize the optimal amount of lubricant.

The rheological and lubricating properties were measured before and after aging (160℃,16h) by adding different amounts of lubricant HLR-1 to base mud, and the test results are shown in TABLE III.

TABLE III. Effect of different additions of HLR-1 on the lubrication performance of drilling fluids

HLR-1 (%)	Conditions	AV (mPa·s)	PV (mPa·s)	YP (Pa)	Lubrication factor	Lubrication factor reduction rate (%)
0.1	Before aging	7.5	5	2.555	0.1603	65.94
	After aging	8	7	1.022	0.1113	73.54
0.2	Before aging	7.5	5	2.555	0.1133	75.93
	After aging	7.5	6	1.533	0.0694	83.50
0.3	Before aging	7.5	5	2.555	0.0459	90.25
	After aging	10	8	2.044	0.0633	84.95
0.4	Before aging	8	6	2.044	0.0317	93.27
	After aging	11	8	3.066	0.0562	86.64
0.5	Before aging	8	6	2.044	0.0306	93.50
	After aging	11.5	8	3.577	0.0551	86.90
0.6	Before aging	8	6	2.044	0.0337	92.84
	After aging	11.5	8	3.577	0.0551	86.90

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As can be seen from TABLE III, the lubrication coefficients of drilling fluids showed an obvious decreasing trend and the reduction rate of lubrication coefficients showed an obvious increasing trend with the increase of lubricant HLR-1 addition before and after aging. When the lubricant HLR-1 dosage was 0.5%, the lubrication coefficients of drilling fluid before and after aging were 0.0306 and 0.0551, respectively, and the reduction rate of lubrication coefficient was above 85%. When the amount of lubricant HLR-1 addition gradually increased, the apparent viscosity of drilling fluid became slightly larger, but the change was very small. Therefore, the optimal amount of lubricant HLR-1 addition is 0.5%.

2.3 Evaluation of the temperature resistance of the lubricant HLR-1

The temperature resistance of lubricant HLR-1 was tested by adding 0.5% lubricant HLR-1 to the base mud and aging it at different temperatures for 16h, and the test results are shown in TABLE IV.

TABLE IV. Evaluation of temperature resistance of lubricant HLR-1 (after aging)

Temperature (°C)	AV (mPa·s)	PV (mPa·s)	YP (Pa)	ρ ($g \cdot cm^{-3}$)	Lubrication factor	Lubrication factor reduction rate(%)
Base mud	9	6	3.066	1.51	0.4707	-
120	11.5	7	4.599	1.50	0.0408	91.33
140	11	7	4.088	1.50	0.0429	90.89
160	11.5	8	3.577	1.49	0.0551	86.90
180	9.5	6	3.577	1.49	0.0541	85.51
200	9.5	6	3.577	1.49	0.0694	85.26

From the experimental data in TABLE IV, it can be seen that after adding 0.5% of lubricant HLR-1 to the base mud, with the increasing aging temperature, the density change value of drilling fluid is small, the viscosity increases slightly, and the fluidity decreases, indicating that it has basically no effect on the fluidity of drilling fluid, in addition, the lubricant HLR-1 also shows good anti-temperature lubrication performance, and at 200°C, the base mud lubrication coefficient The reduction rate was reduced, indicating that HLR-1 can resist temperature 180°C.

2.4 Evaluation of the anti-freezing performance of lubricant HLR-1

The good or bad anti-freezing performance of lubricant is closely related to its fluidity in low temperature. The lubricant with good performance should be difficult to decompose in high temperature environment and can form a solid adsorption film with the drilling tool metal surface; in low temperature condition, it should also have good low temperature fluidity to realize the contact with the drilling tool metal surface to the maximum extent.

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The anti-freezing performance of HLR-1 was examined from two aspects: fluidity at freezing temperature; lubricity at freezing temperature. A certain amount of lubricant HLR-1 was taken in a beaker and placed in the freezer for 24 hours to observe the fluidity respectively, as shown in Fig 1.

a) 0°C

b) -5°C

c) -10°C

d) -15°C

Fig 1: Flow of lubricant HLR-1 at different temperatures

At -15°C, HLR-1 still has good flowability, which shows its good anti-freezing performance.

2. 5 Evaluation of salt resistance of lubricant HLR-1

(1) Preparation of brine-based mud

Different amounts of NaCl were added to the base mud and stirred at high speed (12000 r/min) for 20 min to obtain brine drilling fluid.

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(2) Effect of salt on the lubricating properties of HLR-1

A 0.5% lubricant HLR-1 was added to the prepared brine base mud separately to test its salt resistance, and the test results are shown in TABLE V.

TABLE V. Salt resistance of lubricant HLR-1

NaCl (%)	**AV (mPa·s)**	**PV (mPa·s)**	**YP (Pa)**	**ρ ($g \cdot cm^{-3}$)**	**Lubrication factor**	**Lubrication factor reduction rate (%)**
10	7	4	3.066	1.51	0.0939	80.05
15	7.5	5	2.555	1.51	0.0970	79.39
20	8	6	2.044	1.51	0.1001	78.73
25	9	5	4.088	1.52	0.1103	76.57
30	10.5	6	4.599	1.52	0.1276	72.89

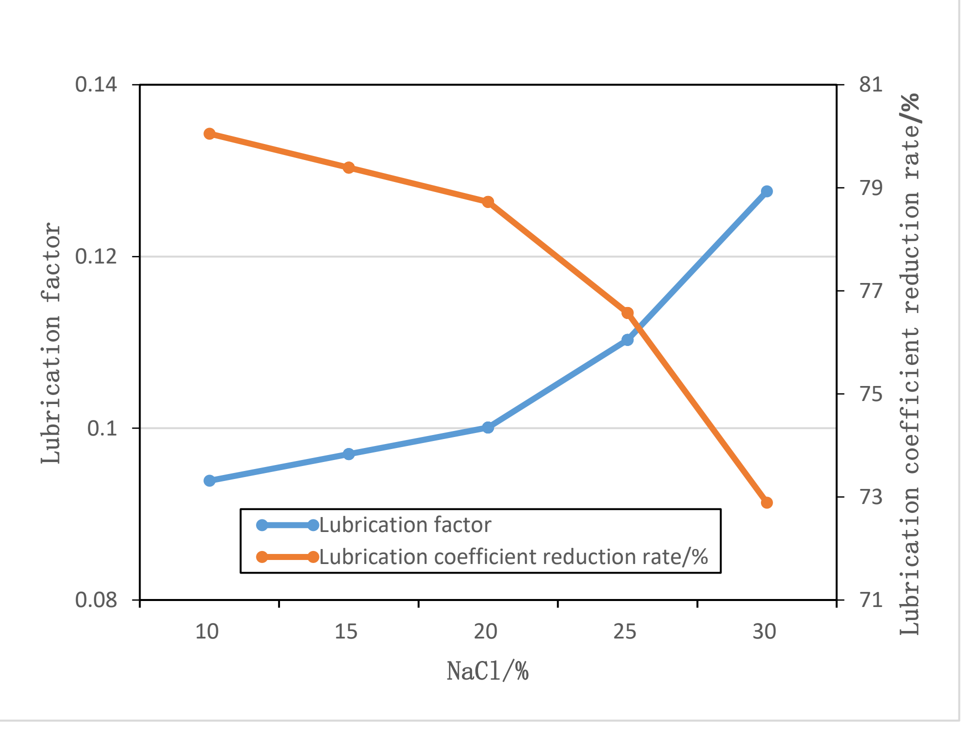

Fig 2: Salt resistance of HLR-1

From the experimental data in TABLE V, it can be seen that when NaCl is added, the apparent viscosity of the system increases, indicating that the rheological properties of the brine base mud decreases, and the density becomes slightly larger, but all within the variable range; as can be seen from Fig 2, with the increase in the mass concentration of NaCl, the base mud lubrication coefficient becomes larger, and the salt resistance of the lubricant HLR-1 can reach about 25%.

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2.6 Compatibility study of lubricant HLR-1 with drilling fluid system

2.6.1 Compatibility with dispersion drilling fluid systems

(1) Conventional dispersion drilling fluid system

Dispersion drilling fluid system formulation:5.0%bentonite +0.25%Na_2CO_3+ 0.7%FCLS+0.3%NaOH +0.3%CMC.

0.5% lubricant HLR-1 was added to the dispersion drilling fluid system to test the rheological and lubricating properties of the dispersion drilling fluid system, and the test results are shown in TABLE VI.

TABLE VI. Effect of lubricant HLR-1 on dispersion drilling fluid performance

Conditions	ρ/ $g·cm^{-3}$	AV/ mPa·s	PV/ mPa·s	YP/ Pa	FL_{API} / mL	Lubrication Coefficient	Lubrication factor reduction rate/%
BeforeAging	1.04	9	8	1.022	10	0.3839	-
After Aging	1.04	12.5	7	5.621	34	0.3543	-
BeforeAging	1.05	8	6	2.044	5.5	0.1903	50.43
After Aging	1.05	11.5	7	4.599	19	0.0939	73.50

Note: Formulation 1: Dispersion drilling fluid; Formulation 2: Dispersion drilling fluid + 0.5% HLR-1; Aging condition: 160℃/16h

From the experimental data in TABLE VI, it can be seen that after adding the lubricant HLR-1 to the dispersion drilling fluid, its density basically did not change, and the apparent viscosity, plastic viscosity and dynamic shear force slightly decreased, which improved the rheology of the experimental mud to a certain extent, and the API filtration loss of the drilling fluid before and after aging had a significant reduction, indicating that HLR-1 has good filtration loss reduction, and shows better rheology and water loss wall-building properties. After the lubricant HLR-1 was added to the dispersion drilling fluid, the lubrication coefficient was significantly reduced before and after aging, and the reduction rate of lubrication coefficient also reached 50.43% and 73.50%, indicating that HLR-1 can effectively improve the lubrication performance of the dispersion drilling fluid system and has good compatibility with the dispersion drilling fluid.

(2) Sulfonated drilling fluid system

The sulfonated drilling fluid formulation was 8.0% bentonite + 0.5% Na_2CO_3 + 3% SMC + 0.5% SMT + 3% SMP-1 + 1.0% CMC-LV + 0.3% NaOH. 0.5% lubricant HLR-1 was added to the formulated sulfonated drilling fluid system to test its rheological and lubricating properties, so as to evaluate the

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compatibility of lubricant HLR-1 with the sulfonated drilling fluid system. The test results are shown in TABLE VII.

TABLE VII. Effect of lubricant HLR-1 (0.5% addition) on the performance of sulfonated drilling fluid

Conditions	ρ/ g·cm^{-3}	AV/ mPa·s	PV/ mPa·s	YP/ Pa	FL_{API} / mL	Lubrication factor	Lubrication factor reduction rate (%)
Before aging	1.07	58.5	41	17.885	5.6	0.3491	-
After aging	1.07	60.0	22	38.836	8.0	0.3309	-
Before aging	1.07	55.5	40	15.841	3.7	0.1454	58.35
After aging	1.07	55.0	18	37.814	5.9	0.1282	61.26

Note: Formulation 1: Sulfonated drilling fluid; Formulation 2: Sulfonated drilling fluid + 0.5% HLR-1; Aging conditions: 160°C/16h

From the experimental data in TABLE VII, it can be seen that after adding the lubricant HLR-1 to the experimental mud, the drilling fluid density did not change, the apparent viscosity, plastic viscosity and dynamic shear force changed less, and the API filtration loss of the drilling fluid filtrate was slightly reduced, indicating that HLR-1 had almost no effect on the rheology of the sulfonated drilling fluid system, and the water loss wall-building property was good. In addition, the lubricant HLR-1 showed good lubrication performance in the sulfonated drilling fluid system, and the reduction of lubrication coefficient was obvious, and the reduction rate of lubrication coefficient was more than 50%, which was good compatibility with sulfonated drilling fluid.

2.6.2 Compatibility with polymeric drilling fluid systems

(1) Anionic polymer drilling fluid system

Anionic polymer drilling fluid formulation: 4.0% bentonite + 0.2% HPAM + 0.1% PHPA + 0.2% Na_2CO_3 + 0.5% CMC-LV. The performance of the drilling fluid was tested by adding HLR-1 to the anionic polymer drilling fluid, as shown in TABLE VIII.

TABLE VIII. Effect of lubricant HLR-1 on the performance of anionic polymer drilling fluid

Conditions	ρ/ g·cm^{-3}	AV/ mPa·s	PV/ mPa·s	YP/ Pa	FL_{API} / mL	Lubrication Coefficient	Lubrication factor reduction rate (%)
Before aging	1.04	21	15	6.132	16	0.3511	-

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After aging	1.04	20	13	7.154	18	0.3146	-
Before aging	1.03	22	15	7.154	11	0.1574	55.17
After aging	1.03	25	16	9.198	12	0.1358	56.83

Note: Formulation 1: Anionic polymer drilling fluid; Formulation 2: Anionic polymer drilling fluid + 0.5% HLR-1; Aging conditions: 160°C/16h

From the experimental data in TABLE VIII, it can be seen that the density did not change much after the addition of lubricant HLR-1 to the anionic polymer drilling fluid system. After aging, the apparent viscosity, plastic viscosity and dynamic shear of increased, which had a certain viscosity increasing effect, but the effect was not obvious, while the API filtration loss of the mud was reduced, indicating that the lubricant HLR-1 had good water loss reduction. In addition, the lubricant HLR-1 showed good lubrication performance, the reduction rate of lubrication coefficient reached more than 55%, and good compatibility with anionic polymer drilling fluid.

(2) Amphoteric polymer drilling fluid system

Amphoteric polymer drilling fluid formulation: 6.0% bentonite + 0.3% FA367 + 0.4% XY-27 + 0.3% JT41 + 3.0% FT-1 + 0.3% Na_2CO_3 . The performance of the drilling fluid was tested by adding HLR-1 to the amphoteric polymer drilling fluid, as shown in TABLE IX.

TABLE IX. Effect of lubricant HLR-1 on the performance of amphoteric polymer drilling fluids

Conditions	**ρ/ g·cm^{-3}**	**AV/ mPa·s**	**PV/ mPa·s**	**YP/ Pa**	**FL_{API} / mL**	**Lubrication Coefficient**	**Lubrication factor reduction rate (%)**
Before aging	1.05	23	16	7.154	10	0.3583	-
After aging	1.05	25	17	8.176	8	0.3107	-
Before aging	1.04	21	15	6.132	7	0.1574	56.07
After aging	1.04	23	16	7.154	6	0.1405	54.78

Note: Formulation 1: Amphoteric polymer drilling fluid; Formulation 2: Amphoteric polymer drilling fluid + 0.5% HLR-1; Aging conditions: 160°C/16h

From the experimental data in TABLE IX, it can be seen that after the addition of lubricant HLR-1 to the ampholytic polymer drilling fluid system, the density basically did not change, and the apparent viscosity, plastic viscosity and dynamic shear of the ampholytic polymer drilling fluid system were reduced, and the API filtration loss of drilling fluid became less, The lubricant HLR-1 has good water loss reduction property. It was also found that the lubricity coefficient of lubricant HLR-1 decreased significantly after it was added to the experimental mud, and the reduction rates of lubricity coefficient before and after aging reached 56.07% and 54.78%, respectively. HLR-1 can effectively improve the lubricity performance of ampholytic polymer drilling fluid system and has good compatibility with

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ampholytic polymer drilling fluid.

2.7 Comparison of lubricant HLR-1 with other lubricants

Lubricity performance of lubricant HLR-1 was compared with other lubricants RH-220, YKZJ-1, YRH-1 and YRH-1D in base mud and field well mud.

2.7.1 Properties in base mud Comparison

(1) The effect of lubricant on the rheology of the base mud

The variation of the effect of various lubricants on the rheological properties of the base mud is shown in TABLE X.

TABLE X. Comparative evaluation of the rheological effect of HLR-1 in the base mud

Lubricant	Experimental conditions	AV/mars	PV/mPa•s	YP/Pa
Base mud	Before aging	9	6	3.066
	After aging	10	6	4.088
0.5%RH-220	Before aging	7.5	5	2.555
	After aging	9	7	2.044
0.5%YKZJ-1	Before aging	11	7	4.088
	After aging	12.5	8	4.599
0.5%YRH-1	Before aging	7.5	5	2.555
	After aging	10	8	2.044
0.5%YRH-1D	Before aging	7.5	5	2.555
	After aging	11	8	3.066
0.5%HLR-1	Before aging	8	6	2.044
	After aging	11.5	8	3.577

Note: Aging conditions: 160℃/16h

From the experimental data in TABLE X, it can be seen that the lubricant YKZJ-1 cause the apparent viscosity of the base mud to increase, which showed a certain viscosity increasing effect on the base mud and made the flowability of the base mud slightly worse. And the lubricant HLR-1 has similar rheological properties with other lubricants and promotes the flowability of the base mud.

(2) The effect of lubricant on the lubricity of the base mud

The base mud was added with 0.5% lubricant HLR-1, RH-220, YKZJ-1, YRH-1 and YRH-1D respectively, and their effects on the lubricating properties of the base mud were tested, and the test results

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ISSN: 1520-0191
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are shown in TABLE XI.

TABLE XI. Comparative evaluation of the lubrication effect of HLR-1 in the base mud

Lubricant	Experimental conditions	Lubrication factor	Lubrication factor reduction rate (%)	Mud cake adhesion Coefficient	Reduction rate of sludge cake adhesion coefficient (%)
Base mud	Before aging	0.4707	-	0.1521	-
	After aging	0.4207	-	0.1690	-
0.5%RH-220	Before aging	0.0939	80.05	0.1099	27.74
	After aging	0.0888	78.98	0.1141	32.49
0.5%YKZJ-1	Before aging	0.0929	80.26	0.0803	47.21
	After aging	0.0643	84.72	0.0930	44.97
0.5%YRH-1	Before aging	0.0827	82.43	0.0845	44.44
	After aging	0.0429	89.80	0.0885	47.63
0.5%YRH-1D	Before aging	0.0786	83.30	0.0507	66.67
	After aging	0.0541	87.14	0.1099	34.97
0.5%HLR-1	Before aging	0.0306	93.50	0.0676	55.56
	After aging	0.0551	86.90	0.0761	54.97

Note: Aging conditions: 160℃/16h

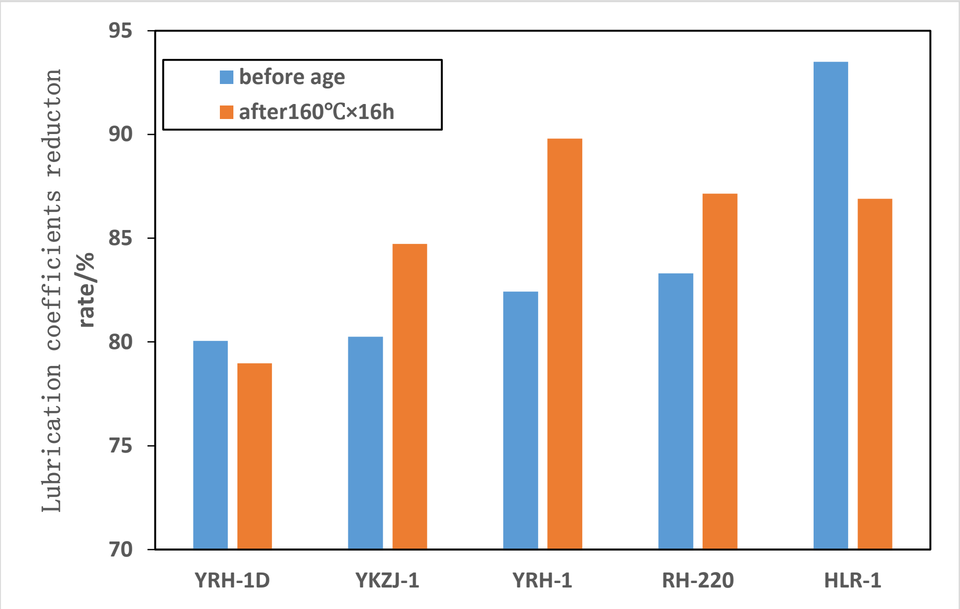

Fig 3: Effect of lubricants on the reduction rate of lubrication coefficient of base mud

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Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

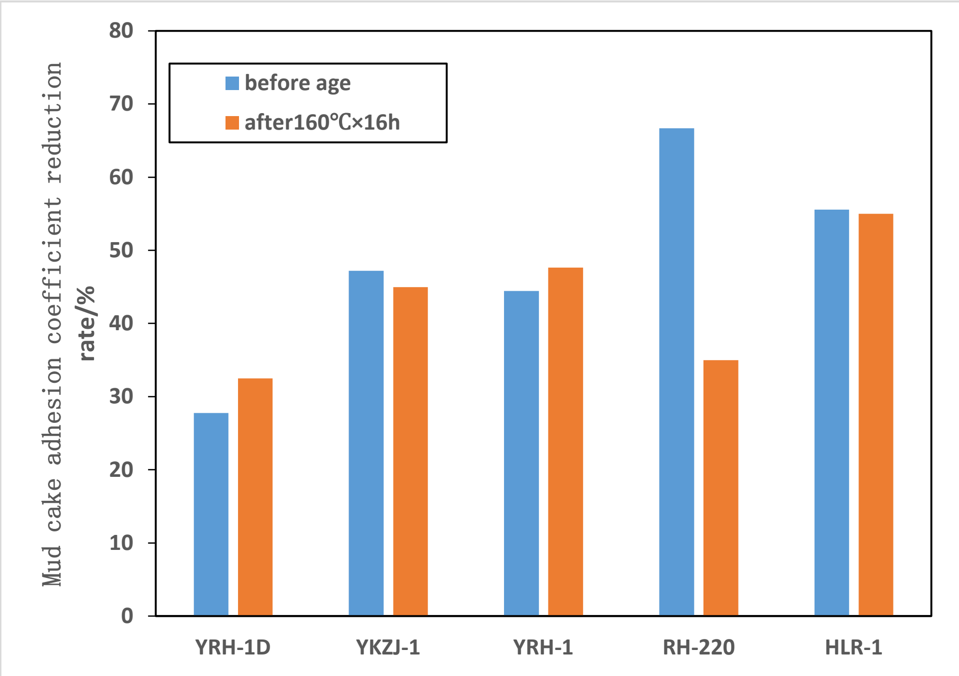

Fig 4: Effect of lubricants on the reduction rate of adhesion coefficient of mud cake

As can be seen from Fig 3, all five lubricants meet the technical requirements of liquid lubricants for drilling fluids at room temperature, i.e., the reduction rate of lubrication coefficient is greater than 80%, the lubrication coefficient reduction rate of lubricant HLR-1 is the highest, reaching 93.5%.

From Fig 4, it can be seen that the reduction rate of mud cake adhesion coefficient of lubricant RH-220 is the largest at before aging, which is 66.67%, but its lubrication effect after aging is obviously reduced. While lubricant HLR-1 shows good lubrication performance before and after hot rolling, the reduction rate of mud cake adhesion coefficient is more than 50%, which indicates that the lubricity of lubricant HLR-1 is superior to other lubricants.

2.7.2 Evaluation in the field well mud

0.5% of lubricant HLR-1, RH-220, YKZJ-1, YRH-1 and YRH-1D were added to the field well mud (3180 m well mud) of Xiangyang 102H34-3 well to test the change of field well mud rheological and lubrication properties, and the test results are shown in TABLE XII.

Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
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TABLE XII. Comparative evaluation of lubrication effect of HLR-1 in field well mud

Lubricant	Experimental conditions	AV/ mPa·s	PV/ mPa·s	YP/ Pa	Lubrication factor	Lubrication factor reduction rate/%
Base mud	Before aging	13.5	11	2.555	0.2195	-
	After aging	17	9	8.176	0.2022	-
0.5%RH-220	Before aging	11.5	8	3.577	0.2149	2.10
	After aging	8.5	5	3.577	0.1917	5.19
0.5%YKZJ-1	Before aging	11.5	8	3.577	0.2108	3.96
	After aging	12.5	9	3.577	0.1891	6.48
0.5%YRH-1	Before aging	10	8	2.044	0.2144	2.32
	After aging	15.5	14	1.533	0.1930	4.55
0.5%YRH-1D	Before aging	14.5	13	1.533	0.1838	16.26
	After aging	13	12	0.511	0.1817	10.14
0.5%HLR-1	Before aging	13	11	2.044	0.1771	19.32
	After aging	11.5	9	2.555	0.1782	11.87

Note: Aging conditions: 160℃/16h

From the experimental data in TABLE XII, it can be seen that all five lubricants can make some improvement in the rheological properties of the field well mud and promote the flowability .

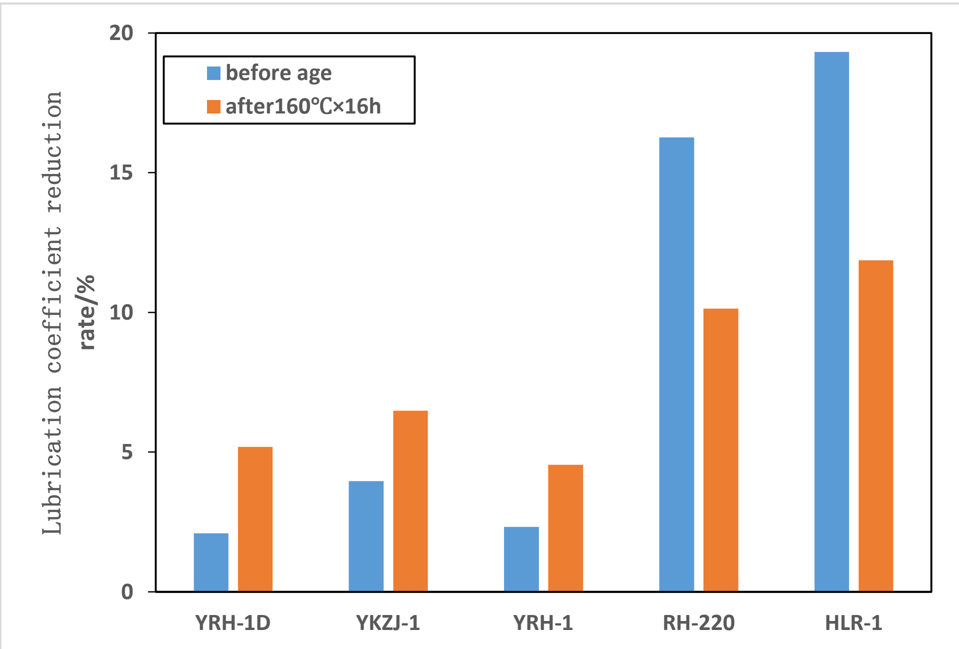

Fig 5: Evaluation of the effect of lubricants on the lubrication of field well mud

As can be seen from Fig 5, lubricants KZJ-1, YRH-1 and YRH-1D have less influence on the lubricity performance of the field well mud, while lubricants HLR-1 and RH-220 improve the lubricity performance of the field well mud to a large extent, among which the lubricant HLR-1 has a lubricity coefficient reduction rate of 19.32%, indicating that the lubricity of lubricant HLR-1 is better than others

III. CONCLUSION

(1) Through preferential experiments, modified vegetable oil DFL-1, surfactants SP-80 and TW-80, extreme pressure anti-wear agent RS-569 and coagulant T801 were selected as lubricant raw materials for the preparation of lubricant. The formulation of lubricant HLR-1 was determined by orthogonal test: 83.3% base oil (DFL-1) + 13.9% compound surfactant (SP-80+TW-80) + 1.7% coagulant (T801) + 1.1% extreme pressure anti-wear agent (RS-569).

(2) The apparent viscosity change value of lubricant HLR-1 on the base mud is 1.0mPa-s, the density change value is 0.06g/cm^3 , the mud cake adhesion coefficient reduction rate is 55.56%, and the drilling fluid lubrication coefficient reduction rate reaches 93.50%, indicating that all parameters of lubricant HLR-1 meet the Q/SY 1088-2012 Technical Specification for Liquid Lubricants for Drilling Fluids requirements.

(3) The optimum addition of this lubricant in the drilling fluid is 0.5%, which can resist temperature 180℃, and the reduction rate of lubrication coefficient can still be maintained above 70% in 25% brine base mud. It has good low temperature fluidity at -15℃, and HLR-1 shows good compatibility with both dispersion drilling fluid system and polymer drilling fluid system.

(4) Evaluation of lubricity in base mud and field well mud showed that HLR-1 exhibited superior lubricity compared to lubricants RH-220, YKZJ-1, YRH-1 and YRH-1D.

ACKNOWLEDGEMENTS

This research was supported by Major engineering technology field test project of China National Petroleum Corporation: Field test of water-based drilling fluid for shale gas long horizontal section wells (Grant No. 2018F-21).

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