Research on Performance of High-temperature High-density Oil-based Drilling Fluids

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***Abstract*—The oil-gas exploitation techniques of super-deep formations in West China are facing a great challenge. Due to the super-high temperature, high pressure, salt formation, it brings enormous challenge to drilling engineering. To meet the need of drilling operation in the super-deep formations, a new kind of high-temperature high-density oil-based drilling fluid system is developed. This oil-based drilling fluid system has excellent comprehensive properties, and it could resolve the contradiction between safety drilling of complicated deep wells and formation complexity.**

Keywords-high temperature; high pressure; high density; oil-based drilling fluid; performance

I. INTRODUCTION

The super-deep formations in West China is characterized by high temperature hydrocarbon zone, abnormal high pressure formation, salt formation, and high collapse stress formation is widely distributed, which brings great challenge to drilling operation[1-3].

Traditionally the oil and gas wells in this area are drilled with high-density water-based mud (WBM). But when the salt formations is drilled using WBM, kicks, downhole losses and stuck pipe will be often encountered, resulting in a high pressured brine influx, so higher mud weight is needed to kill the well. This is normally followed by downhole losses and stuck pipe event [4-6]. In addition, since the mud weight required in drilling the salt formation is much higher than the mud weight required in drilling the target zones, heavy losses and stuck pipe will be caused in drilling the salt formation when the target zones is inadvertently penetrated. Moreover, the water-base drilling fluids would become unstable when they are heavily contaminated by divalent salts or brine influx.

Drilling fluid stability under high temperature and high pressure, and the mud ability to tolerate the salt contamination are two of the key factors that affect the drilling efficiency in this area. The stability of the existing WBM system under high temperature, high pressure and high salinity conditions is difficult to maintain and fluid rheology is often not controllable. It is understood that the existing WBM system is not tolerant to the brine and salt contamination [7-9].

In order to meet the requirement of drilling operation in the super-deep formations, a new kind of high-temperature high-density oil-based drilling fluid system (HDOBM) is developed. The properties of HDOBM are tested in details. The results indicate that HDOBM has excellent thermal stability, and superior filtrate reducing performance. HDOBM is recommended to drill the super-deep target zones to maintain wellbore instability under HTHP conditions.

II. EXPERIMENT

A. *Synthesis of high temperature resisting primary emulsifier*

Using aliphatic acid and polyamine compound as starting material, a new type of oleamide compound is synthesized. The amount of active groups of this compound is very low, so it has good stability at high temperature. Moreover, due to its multiple amide groups, this high temperature resisting primary emulsifier could provide enough emulsion breaking voltage. This compound could maintain modest acid value and low amine value, and it has stable performance under high temperature and high-pressure conditions.

B. *Synthesis of high temperature resisting auxiliary emulsifier*

Using aliphatic acid and alkylol amine as starting material, a new kind of alkanolamide compound is prepared by two-step method to reduce side reaction, and it has excellent control effect on the rheological property of high density mud. Moreover, the molecular structure of this compound has two hydroxyl groups and one amide group, so it has both emulsifying and wetting function.

C. *Basic formulation and properties of HDOBM*

Based on the development of high temperature resisting primary emulsifiers, auxiliary emulsifiers, organophilic clay, oil-soluble filtrate loss control additive and so on, a new kind of high-temperature high density oil-based drilling fluid (HDOBM) formulation is developed, and the rheological properties of drilling fluid formulation is tested. Its anti-temperature capability is as high as above 200ºC, and its maximum density is 2.60 g/cm^3. The basic formulation and properties of HDOBM formulation are shown in table I and table II.

TABLE I. BASIC FORMULATIONS OF HDOBM

Composition	I	II	III
Diesel oil, mL	219.6	219.6	212.6
Primary emulsifier, mL	17.9	17.9	21.2
Auxiliary emulsifier, mL	10.6	10.6	14.3
Fluid loss additive, g	17.9	17.9	17.9
Lime, g	14.3	14.3	14.3
Water, mL	13.5	13.5	13.5
Viscosifier, g	3.6	3	4.3
Lime chloride, g	7.6	7.6	7.6
Wetting agent, mL	2.17	2.17	2.8
Rheology conditioning agent, mL	1.53	1.53	1.53
Deflocculating agent, g	1.45	1.45	3
Barite, g	890	870	870

TABLE II. THE PROPERTIES OF BASIC FORMULATIONS OF HDOBM

Formulation	I		II		III	
Aging condition	before roll	after roll	before roll	after roll	before roll	after roll
ρ, g/cm^3	2.39	2.37	2.36	2.36	2.36	2.41
AV, mPa·s	80.5	81.5	71.5	69.5	100.5	91
PV, mPa·s	71	81	65	72	84	86
YP, Pa	9.5	0.5	6.5	-3.5	16.5	5
Φ6/Φ3	5.5/5	1.5/1	4.5/4	1/0.5	8.5/7.5	2.3/1.5
GEL, Pa/Pa	5.5/8	1.5/4	5.5/7	0.5/1	9/12.5	2.5/11
ES, V	958	1006	902	982	2047	1293

Note: The rolling condition is 180 ºC×16.

Compared with Formulation I and Formulation II, Formulation III has better thermal stability and rheological properties before and after rolling at 180 ºC. In addition, Formulation III has appropriate dynamic shear force for hole cleaning, and it has good suspension ability for barite at high temperature. As a result, Formulation III is chosen as basic formulation of HDOBM for field application.

D. The formulation and properties of HDOBM

Based on the laboratory tests, the on-site formulation and properties of HDOBM is recommended, as shown in Table III and Table IV. The experimental results indicate that HDOBM system has good rheological properties and sedimentation stability at high-density condition, so it can withstand high solids loadings, and provide lower HTHP fluid-loss values at high temperature and high pressure conditions.

TABLE III. THE FORMULATION OF HDOBM

Composition	Concentration (g/m^3)
Diesel oil, mL	400-430
Primary emulsifier, mL	30-40
Auxiliary emulsifier, mL	20-30
Fluid loss additive, g	50-60
Lime, g	25-35
Viscosifier, g	30-45
Water, mL	5-15
Lime chloride, g	15-20
Wetting agent, mL	5-8
Rheology conditioning agent, mL	1-3
Deflocculating agent, g	1-3
Barite, g	1900-2200

TABLE IV. THE PROPERTIES OF HDOBM FORMULATION

Performance	Parameter
Density	1.80-2.40 g/cm^3
Oil-water ratio	90/10-95/5
Electrical stability	>600 V
Funnel viscosity	60-85 s
API fluid-loss value	0 mL
HTHP fluid-loss value	<6.0 mL
Plastic viscosity	60-90 MPa·s
Yield value	7-15 Pa
Initial gel/final gel	2-6/5-10 Pa
pH value	7-8

Note: The rolling condition is 180 ºC×16 h, HTHP filtration condition is 180 ºC×3.5 MPa.

III. RESULTS AND DISCUSSION

A. The evaluation of ageing resistance of HDOBM formulation

The performance parameters of HDOBM before and after rolling at 180ºC are shown in Table V. After drilling fluid formulation is rolled after various times at high temperature, the plastic viscosity of HDOBM has increased only marginally, the yield value and shear force of HDOBM have change very little, and it still has good suspension performance.

Meanwhile, the emulsion-breaking voltage of drilling fluids increases gradually as the rolling time rises, so the stability of drilling fluids become better and better. As a result, HDOBM has strong ageing resistance and good rheology under high temperature.

TABLE V. THE ANTI-AGING PROPERTIES OF HDOBM FORMULATION

Aging condition		PV (mPa.s)	YP (Pa)	GEL (Pa/Pa)	ES (V)	FL_{HTHP} (mL)	Note
before roll		72	3.0	5.5/6	407	1.9	-
after roll	16 h	87	11.5	5.5/6.0	720	4.3	no precipitation
	24 h	90	9.0	5.0/8.0	923	4.1	no precipitation
	72 h	97	7.5	3.0/5.5	1047	3.8	no precipitation

Note: The rolling condition is 180 ºC×16~72 h, HTHP filtration condition is 180 ºC×3.5 MPa.

B. The evaluation of inhibiting properties of HDOBM. Formulation

The rolling recovery rate of mudstone cuttings in WBM and HDOBM is shown in Table VI. The results demonstrate that the average recovery rate of cuttings in WBM is 96.6%, but the average recovery rate of cuttings in HDOBM is 99.0%, so HDOBM has stronger inhibiting property.

TABLE VI. THE ROLLING RECOVERY RATE OF CUTTINGS IN VARIOUS DRILLING FLUIDS

Drilling fluid system	The recovery rate of cuttings	The average recovery rate of cuttings
WBM	95.8%	96.6%
	97.8%	
	96.2%	
HDOBM	99.6%	99.0%
	98.8%	
	98.6%	

Note: The rolling condition is 180 ºC×16 h.

TABLE VII. THE EXPERIMENT RESULTS OF EXPANSION RATIO OF VARIOUS SAMPLES

Base fluid types	The average expansion ratio of core samples	The average expansion ratio of standard bentonite
Water	11.35%	40.35%
WBM	6.86%	8.73%
HDOBM	1.84%	3.38%

The expansion ratio of various samples in various drilling fluid system is shown in Table VII. The average expansion ratio of core samples in HDOBM is only 1.84%, which is much less than that in water or WBM. The average expansion ratio of standard bentonite in HDOBM is much less than that in water or WBM, too. So HDOBM system has good inhibitive ability for the dispersion and hydrate expansion of clay particles of target zones, improving the wellbore stability.

C. The evaluation of anti-pollution ability of HDOBM. formulation

The HDOBM formulation with the oil-water ratio of 90:10 is contaminated by 10% $CaSO_4$ and 10% NaCl, respectively, and the properties of mud is tested, as shown in Table VIII.

When HDOBM formulation is contaminated by 10% $CaSO_4$ and rolled after 16 h at 180 ºC, the viscosity of mud increases only marginally, and the yield value of mud decreases slightly, but the emulsion breaking voltage of mud increases slightly. As HDOBM formulation is contaminated by 10% NaCl, the rheological characteristics of mud before and after rolling change very little, but the emulsion breaking voltage of mud reduces slightly. As a result, the rheological properties of HDOBM have not changed very much after $CaSO_4$ or NaCl is added to mud, so HDOBM has good anti-gypsum and anti-salt ability.

TABLE VIII. THE ANTI-GYPSUM AND ANTI-SALT OF HDOBM FORMULATION

Aging condition	PV (mPa.s)	YP (Pa)	GEL (Pa/Pa)	ES (V)	FL_{HTHP} (mL)
before roll	72	3.0	5.5/6	407	1.9
after roll	87	11.5	5.5/6.0	720	4.3
10% $CaSO_4$	112	7	4.5/5	853	1.2
10% NaCl	102	6.5	4/4.5	630	3.4

Note: The rolling condition is 180 ºC×16.

The HDOBM formulation with the oil-water ratio of 90:10 is added by different proportions of saturated brines, and the anti-saturated brine properties of HDOBM formulation is tested, as shown in Table IX. The experimental results show that HDOBM formulation has stable performance when the dosage of saturated brine is less than 10%. However, when the dosage is more than 15%, the emulsion breaking voltage of mud before rolling can reduce remarkably, and the mud thickening becomes very serious after rolling at high temperature.

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TABLE IX. THE ANTI-SATURATED BRINE ABILITY OF HDOBM FORMULATION WITH A DENSITY OF 2.50 G/CM^3

NaCl (V/V%)		AV (mPa.s)	PV (mPa.s)	YP (Pa)	GEL (Pa/Pa)	ES (V)
0	before roll	102.5	88	14.5	6.5/7.5	2000
	after roll	106	95	11	6/6.5	1300
5%(17.5 mL/350 mL)	before roll	116.5	95	21.5	10/11	1202
	after roll	140.5	117	23.5	11/12.5	1500
10%(35 mL/350 mL)	before roll	137.5	102	35.5	16.5/18	1206
	after roll	156	130	26	20/21.5	750
15%(52.5 mL/350 mL)	before roll	133	92	41	19/21	1020
	after roll	/	/	/	20/26	790

Note: The rolling condition is 180 $^oC\times16$.

IV. CONCLUSIONS

1) HDOBM has good rheological properties, good filtrate control capacity, strong mud anti-aging properties and anti-pollution ability under high temperature and high pressure conditions.

2) HDOBM can withstand high solids loadings, and provide lower HTHP fluid-loss values at high temperature and high pressure conditions.

3) HDOBM is a type of oil-based drilling fluids with superior comprehensive properties, and it can meet the need of drilling technology of super-deep formations in West China.

ACKNOWLEDGMENT

This study is supported by the National High Technology Research and Development Program of China (863 Program) (No. 2012AA091502) and CNPC Project (No. 2013E-3802).

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