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Research and Application on High Temperature Drilling Fluid in a Deepwell of China's Bohai Bay

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Abstract: *This paper introduces a special high-temperature drilling fluid for a deep well drilling in China's Bohai Bay. The special fluid (THERM) is a water-based mud and was specifically developed to drill China's first offshore research well: vertical well-depth exceeds 5 000 meters. Throughout drilling, this fluid maintained perfect performance in its rheological properties,thermal stability, contamination tolerance, inhibitive characteristics, and in filtration control.The system of THERM used all kinds of materials(include thermal stabilizer (PF-STB HT),thermal filming agent (PF-DFL HT), and thermal inhibitor(PF-JLX T)) have steadycapability in the high density and high solid drilling fluids. The laboratory evaluations and field application are describedin this paper.*

Keywords: *HPHT drilling fluid; rheological control; thermal stability; contamination tolerance; wellbore stabilization.*

INTRODUCTION

According to the latest resource assessments and evaluations, China's oil resource in shallow formation is approaching depleted. Almost 70% of the undeveloped resource is buried under depth of 5000 m (Zeng and Liu, 2005).Recently, some deep and ultra deep wells were drilled both in East and West China with depth over 5000 m and 7000 m: i.e. Moshen1 (7500 m,173 ℃), Tashen1 (8408 m,180 ℃) and Nanpu5-4 (5359 m,193 ℃), BZ-A was the first Chinese offshore well exceeding

5 000 m vertically.

BZ-A' s TVD (True Vertical Depth) was designed as5355 meters with a BHT (Bottom Hole Temperature)exceeding 170℃, and predict max pressure coefficient of 1.65. Itwas the first scientific drilling well in Bozhong Depression drilled through its complete stratigraphic sequence as well as the deepest well ever drilled in Bohai Bay. Drilling passed through Bozhong Depression's complete stratigraphic sequence. The UK Continental Shelf Operation Notice defines any well with BHT above 150 ℃ and pore pressure gradient higher than 1.80 psi/ft (0.04 MPa/m)is defined as HPHT(High Pressure High Temperature) well (Oriji and Dosunmu, 2012). Major challenges to design a HPHT drilling fluid include the controlling of rheological properties, thermal stability, shale stabilization, good lubricity, potential of barite sag and formation damage.

BACKGROUND

A key factor in maintaining a fluid's thermal stability isthe polymer used for system rheology and filtration control.Polymers are suitable for temperatures below130℃. Temperatures above 130℃ must employ syntheticpolymers to address temperature stability problems.(Tehrani, Popplestone, Guarneri, and Carminati, 2007).Several synthetic polymers were tested in a laboratoryfor not only their applicable ranges, but also for theirsynergistic behavior with other anti-high temperatureadditives. Those efforts led to the development ofTHERM, an HPHT water-based drilling fluid comprisedof sulfonated phenolic resin (PF-SMP-I), sulfonatedlignite (PF-TEMP), thermal stabilizer (PF-STB HT),thermal filming agent (PF-DFL HT), and thermal inhibitor(PF-JLX T). The formulation and properties of a new water-based fluid with density of 1.6g/cm^3 are shown as in Table 1 and Table 2.

Table 1: Formulation of THERM

Additives	Concentration (kg/m^3)
bentonite	30
NaOH	6
Na_2CO_3	4
KCl	50
PF-SMP-I	30
PF-TEMP	30
PF-STB HT	30
PF-DFL HT	20
PF-JLX T	30
barite	as required

Table 2: Properties of THERM

Testing condition	AV /mpa·s	PV /mpa·s	YP /Pa	ϕ6/ϕ3	GEL10s/10min Pa/Pa	FL /mL	HPHT /mL	pH
BR(Before Rolling)	58	38	20	6/5	2.5/7.5	2.0	--	11
AF(After Rolling)	47	32	15	4/3	1.5/6.5	2.0	8.2	9

Hot rolling: 180℃×16h; HPHT filtration test: 150℃×3.5MPa

LABORATORY EVALUATION METHOD

Clay Contamination

Contamination-tolerance of drilling cuttings was testedon various fluid formulae. Different concentration ofclay and cuttings were taken from the Dongying Group, the active shale layer to be drilled, and wereadded into various fluid-formulae. The test-contaminatedfluids were hot rolled at 180℃ and the fluid's propertieswere compared to their post-test characteristics,and no significant changes in rheological and filtrationcharacteristics were observed. The Table 3 comparisonshows that THERM can tolerate a maximum cuttings-contamination of 7%.

Table 3: Clay-cuttings Contamination

Sample	Testing condition	AV /mPa·s	PV /mPa·s	YP /Pa	ϕ6/ϕ3	GEL10s/10min Pa /Pa^{-1}	FL /mL
THERM	BR	55	38	17	23/20	10/18.5	3.2
	AR	41	33	8	4/3	1.5/6.5	1.8
THERM +3%clay	BR	61.5	43	18.5	26/24	12/21	3.0
	AR	42	33	9	5/3	2/6.5	2.4
THERM +5%clay	BR	66.5	44	22.5	28/25	12.5/22	3.4
	AR	42.5	32	10.5	4/3	1.5/7.5	2.9
THERM +3%cuttings	BR	57	39	18	25/23	11.5/21	3.8
	AR	43	35	9	4/3	1.5/6	2.7
THERM +5%cuttings	BR	63	44	19	27/24	12/22	3.9
	AR	44	34	10	5/3	2/6	2.4
THERM +7%cuttings	BR	67	46	21.5	29/26	13/23.5	3.9
	AR	45	35	10	5/3	2/6.5	2.6

Hot rolling: 180 ℃×16h

Inhibition

Tests forcuttings dispersion and swelling were carried out using cuttings from Dongying group (Table 4). After 16h hot rolling at 180℃,83.2% of cuttings were recovered, the swelling ratio was as low as 7.6%, just proving the inhibitive property of THERM was strong enough to stabilize wellbore and minimize formation damage.

Table 4: Inhibition

Fluid	Cuttings recovery /%	Swelling ratio /%
Sea water	31.4	31.9
THERM	83.2	7.6

Plugging Capacity

On-site fluids would normallybe treated with plugging agent to seal and plug the porethroats and fissures. To optimize the plugging capacity of THERM, four types of agents were tested with HPHT sand-bed filter which was conducted similar to HPHT filter but using specified sized sands as filtrate medium. It was found that Testing showedthat PF-LPF performed the best: The pressure resistance of THERM was up to 7MPa(Table 5).

Table 5: Plugging capacity

Formula	3.5MPa mL/10min	5MPa mL/10min	7MPa mL/10min
THERM	4	1	0
THERM + 1.5%PF-LPF	1.4	0	0
THERM + 1.5% PF-SZDL	3	1	0
THERM + 1.5% PF-STRH	2	1	0
THERM + 1.5% PF-ZD	2	1	0

Hot rolling: 180 ℃×16 h; HPHT filtration test: 150 ℃×(3.5,5,7) MPa

Shale Stabilization

A combination of techniques using viscosification to prevent filtrate invasion, and elevated membrane efficiencyby mud-pressure penetration, is used to controlwellbore instability in shale (Van Oort, 2003). Since KCl is less effective in viscosifying filtrates, plugging pore throats and simulating osmotic backflow of shale pore water, it wasplanned to use KCOOH to treat the THERM once drilling reached a old shale interval. The activity of treated fluid and viscosity of pure KCOOH solution were given in Table 6 and Table 7. Lower activity implied that the fluid performed better as a "leaky osmotic membrane".

Table 6: THERM Activity

Formula	Activity
THERM	0.93
THERM + 25% KCOOH	0.84
THERM + 35%KCOOH	0.72
THERM + 45%KCOOH	0.66
THERM + 55%KCOOH	0.49

Table 7: KCOOHViscosity

Solution	AV/mPa·s
Sea water	1
25% KCOOH	1.13
35%KCOOH	1.5
45%KCOOH	2
55%KCOOH	2.75

Sag Stability

Barite sag is the undesirable fluctuations in fluid density occur in any weighted drilling fluids due to the settling of weighting materials. It can lead to well control problems, lost circulation, pipe sticking, hindered running of casing. To evaluate the sag stability of THERM, fluids were hot rolled at 180℃ for 16h and monitored their sag performance at ambient temperature and 60℃ for different period of time (Table 8). The THERM fluid system provided sound sag stability that no sag were observed within 120h at both temperature.

Table 8: Sag Performance

Testing condition	Result
ambient temp, 72h	no sag
ambient temp, 120h	no sag
60℃, 72h	no sag
60℃,120h	no sag

Lubricity

Sufficient lubricity is required to eliminate excessive torque and drag. Lubricity was investigated by measuring lubricity coefficient of fluid. THERM and PEM, some kind of glycol drilling fluid widely used in China, had been tested on extreme pressure lubricity tester. From the testing results in Table 9, it is easy to find that THERM performed superior on lubricity.

Table 9: Lubricity

Drilling Fluid	Lubricity coefficient
PEM	0.1322
THERM	0.1228

FIELD APPLICATION

THERM high temperature drilling fluid was used to drill 8 1/2” section through the Tertiary Dongying group and Shahejie group, which contained thick active shale and predicted over pressure formation. Lost circulation and sloughing were also encountered in offset wells.

In the fieldapplication, several kinds of centralmaterial reflects the unique characteristics respectively,through used them to make the mud property more excellent:

The SteadyOfPF-STB HTTo High temperature

On-site fluid samples (density of 1.5 g/cm^3) and on-site fluid added 0.5%PF-STB HTwerehot-rolled at 200℃ for 16 hours and laboratory tested.Results are shown in Table 10, The stable rheologicalproperties and acceptable filtration attributes imply thatTHERM’s temperature resistance can approach 200℃. PF-STB HT reflects the good temperature resistance and high temperature glueperformance, by supplyingPF-STB HT to mud, rheological properties was better,fluid loss reduced significantly, especially in HPHT water loss decreased significantly, fully demonstrated the heat stabilizer (PF-STB HT) has a very good role of protective colloid, can improve the quality of mud cake, reduce the water loss, make the drilling fluids performance more excellent.

Table 10: Evaluation of On-site Fluid

Formula	AV /mPa.s	PV /mPa.s	YP /Pa	ϕ6/ ϕ3	GEL10s/10min Pa/Pa^{-1}	FL /mL	HPHT 150℃ /mL
On-site fluid	41.5	33	8	3/2	3/7	3.4	13.8
On-site fluid+0.5 %PF-STB HT	41	34	7	5/3	2/4	2.0	8.4

HPHT filtration test: 150 ℃×3.5MPa

Thermal Stability

Within 24 days of drilling, the fluid performed quite well in thermal stability, rheological property, lubricity and inhibitive property. Little changes in properties were observed after the second run of logging when the fluid had remained static at 170℃ for over 70h (Table 11).THERM showed highly positive characteristicsin the attributes that are listed in the following text.

Inhibition Of PF-JLX T With HCOOK And Qualified Mud Cake

PF-JLX T play a viscosity reduction, it improve the rheological properties by reducing the friction between solid - solid phase , solid-liquid phase and liquid-liquid phase. By introducing HCOOK, on the one hand, can improve the temperature resistance of drilling fluid, in addition,which can improve the inhibition of drilling fluid;PF-JLX T and HCOOK used at the same time, has a good compatibility and good inhibition for the high densityand high solid drilling fluid, can maintain better viscosity, effectively solve the water sensitivity formation of borehole wall stability.

In the 8 1/2” section tough and thin mud cake (Fig.1) was build on the borehole at bottom hole static temperature of 170℃ and circulating temperature of 123℃, which maintained the API filtration at 2mL and lowered HPHT filtration to 7.2mL.

Table 11: THERMProperties before and after logging

Sample	FV /s	MW /g.cm³	AV /mPa.s	PV /mPa.s	YP /Pa	Φ6/Φ3	GEL10s/10min (Pa /Pa⁻¹)	FL /mL	HPHT 150℃/mL
Before logging	48	1.57	42.5	35	7.5	4/3	2/4	2.2	9.0
After logging	47	1.57	36	29	7	3/2	2/4	2.0	7.2

Wellbore Stabilization

THERM fluid performed good wellbore stability and a gauged diameter hole was obtained (Fig.2). No resistance were meet while tripping in/out in active shale layer and granite apt to cave(4 402~4 410m and 4 520~4 528m).

API mud cake HPHT mud cake

Fig.1: Mud-cake Build-up

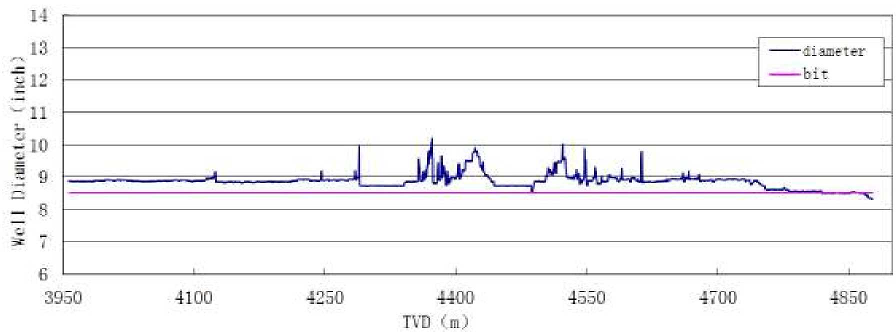

Fig.2: caliper logging of HPHT section

CONCLUSIONS

(1) THERM system used the inhibitor PF-JLX T, it has good lubrication performance, not only can significantly reduce frictional force for solid-solid phase , liquid-liquid phase and solid-liquid phaseinthe high density high solid drilling fluid, but also can be a very good adjust the rheological properties of high density drilling fluid.

(2) HCOOK togetherwithPF-JLX Tare used in the THERM, which can reduce the drilling fluid activity, improve further inhibitory and effectively solve the problem of water sensitivity formation of borehole wall stability.

(3) The system used thethermal stabilizer(PF-STB HT), it has good protective glue and water loss reduction, make drilling fluid has good filtration wall building performance, laid a solid foundationfor steadying the borehole wall.

(3) THERM water-based drilling fluid, designed for temperature to 200℃ was successfully used in a drilling at the China's first offshore research explorationwell with TVD deeper than 5 000 meters..

(4) The THERM fluid successfully met the challengeposed by drilling at the deep layers in Bohai Bay. Goodcontrol of rheological properties, filtration-minimization,and improved wellbore stability were proven.

(5) The THERM system is highly recommended for deepwell applications with BHT in the range from150℃to 200℃.

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REFERENCES

[1] A.B.Oriji, and A.Dosunmu (2012). "Design and Application of Drilling Fluids for HPHT Well- A Case Study of Maria Field," *North Africa* Technical *Conference and Exhibition*, Cairo, Egypt,SPE 151642.

[2] Eric van Oort(2003). "On the physical and chemical stability of shales,". *J.Petroleum Science and Engineering*Vol 38, pp 213-235.

[3] M. A. Tehrani, A. Popplestone, A. Guarneri, and S. Carminati, "Water-Based Drilling Fluid for HP/HT Applications," *International Symposium on Oilfield* Chemistry, Huston, Texas, USA,SPE 105485.

[4] Yijin Zeng, and Jianli Liu (2005). "Technical Status and Developmental Trend of Drilling Techniques in Deep and Ultra-Deep wells," Petroleum Drilling Techniques, Vol 33, No 5, pp 1-5.