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Study on Strong Inhibition Compound-salt Plugging Drilling Fluid and Its Application in Offshore Drilling Practices

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Abstract

Well-bore instability problems often occurred when drilling in the formations of Dongying Group and Shahejie Group in Block Chengbei of Shengli Offshore in the past, which led to various down-hole complex problems and seriously affected the comprehensive benefits. In view of this situation, a seawater compound-salt plugging drilling fluid system is developed. The system is obviously superior to the traditional polysulfonate system in rheology, inhibition, high temperature resistance, bentonite contamination resistance and lubricity, and the temperature resistance can reach more than 180°C. The application results of more than ten wells on several platforms in Shengli offshore show that the drilling fluid system has stable performance, convenient maintenance, strong clay inhibition, plugging and collapse prevention, the average well diameter swelling rate of all wells is less than 8.0%, and the cementing quality qualification rate is 100%. It can effectively control the formation mud making, and the waste drilling fluid is only 1/3~1/4 of the conventional water-based drilling fluid. After well completion, the plug can be removed by acidizing, which has achieved good formation damage controlling effect.

Key words: Compound-salt; Inhibition; Plugging and collapse prevention; Rheology; High temperature resistance

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1. INTRODUCTION

Compound-salt plugging drilling fluid is a strong inhibition drilling fluid system that adapts to the drilling with small flow rate, effectively makes the wellbore regular and controls formation damage [1-3]. This system is mainly composed of water, bentonite, inorganic salt and inhibitor, which is convenient to use and maintain. The system can realize the safety of drilling process with small flow rate through calcium chloride drilling fluid in the upper section, and inorganic salts such as sodium chloride and potassium chloride are added in front of the target layer to further enhance the inhibition of the drilling fluid in the deeper section. This system has strong inhibition, good wellbore stability, large solid capacity limit, low submicron particle content, low filtrate-loss, good lubricity, wide adaptability, easy adjustment and low comprehensive cost [3]. It can effectively ensure the cementing quality and effectively control the formation damage in the reservoir.

2. LABORATORY PERFORMANCE EVALUATION

The wellbores of Dongying Group, Shahejie Group and Mesozoic in Shengli offshore have poor stability, and the inhibition of traditional polysulfonate system is insufficient, which is easy to cause wellbore instability and difficulties in tripping out and electrical logging. Therefore, based on the experience of compound-salt plugging drilling fluid system, the matching test of seawater drilling fluid system is carried out (the sea water is taken from Yellow River Harbor of Zhuangxi).

2.1 Evaluation for Rheology and Filtration of Drilling Fluids

Sample 1: Base mud is taken from 2670m of well CB306-3 +10%Sea water (the sea water is taken from Yellow River Harbor); Performance of base mud: ρ= 1.15g/cm^3, FV=40s, AV=17mPa·s, PV=12mPa·s, YP=5Pa, pH= 7.5, FL_{API}=15mL.

Sample 2: Seawater polysulfonate drilling fluid: Base mud+ 0.3% Coating agent +2% High temperature and salt resistant filtrate reducer +1% Sulfonate copolymer filtrate reducer +3%SMP-I+2% Solid polyol +2% White asphalt +3% Superfine calcium carbonate (50% with 2000 mesh, 50% with 4000 mesh) +Appropriate amount of caustic soda.

Sample 3: Seawater compound-salt plugging drilling fluid：Base mud +0.3% Coating agent +10% NaCl+5% KCl +2% High temperature and salt resistant filtrate reducer +1% Sulfonate copolymer filtrate reducer +3% SMP-I+0.5% Amino polyol +2%SF-4+2%Emulsion wax+3% Superfine calcium carbonate (50% with 2000 mesh, 50% with 4000 mesh) +Appropriate amount of caustic soda.

Table 1
Rheology and filtration loss of three samples under different conditions

No.	Experimental Condition	AV / mPa·s	PV/ mPa·s	YP/ Pa	pH	FL_{API}/ mL
Sample 1	Room Temperature	17	12	5	7.5	15
	100℃/16h aging Static aging	22	13	4	7	20.6
Sample 2	Room Temperature	26	18	7.5	7.5	4.6
	100℃/16h aging Static Aging	22.5	15	6	7	4.4
Sample 3	Room Temperature	23.5	16.5	7	7.5	4.4
	100℃/16h aging Static aging	21.5	15	6.5	7	2.8

It can be seen from Table 1 that the filtrate-loss of the last systems is less than 5ml at room temperature, indicating that the filtration effect of the two drilling fluid systems is similar at room temperature. After aging under 100℃/16h, the filtrate-loss decreases to different degrees, and their apparent viscosity, plastic viscosity and dynamic shear force have a certain change. Generally speaking, the rheology change of the compound-salt plugging drilling fluid system is relatively small, and the filtrate-loss does not rise but fall at this temperature. Basic performance of sample 3 under different temperatures in Table 2.

Table 2
Temperature resistance of compound-salt plugging drilling fluid with seawater

ρ /g/cm^3	AV / mPa·s	PV / mPa·s	YP / Pa	FL_{API} / mL	Testing condition
1.15	23.5	16.5	7	4.4	Room temperature
1.15	21.5	15	6.5	4.0	90℃/16h
1.15	21.5	15	6.5	2.8	100℃/16h
1.15	20.5	14	6.5	3.2	110℃/16h
1.15	19	13.5	6	3.6	120℃/16h
1.15	19	13.5	6	3.6	130℃/16h
1.15	18.5	13	5.5	4.2	140℃/16h
1.15	19	13.5	5.5	4.4	150℃/16h
1.15	18	13	5	4.4	160℃/16h
1.15	17	12.5	4.5	4.8	170℃/16h
1.15	15	12	4	5.0	180℃/16h

It can be seen from Table 2 that, the performance of drilling fluid system has little change in the temperature limit room temperature to 180°C, which indicates the high temperature resistance of the drilling fluid. Table 3 shows the filtrate-loss of the system under different temperature.

Table 3
High temperature water loss test

ρ /g/cm^3	Tempera-ture	FL_{HTHP} /mL		
		3#	4#	5#
1.15	150℃	9	7.6	6.0
1.15	160℃	10.4	8.6	8.0
1.15	170℃	11.0	10.2	9.6
1.15	180℃	17.6	14	11.4

It can be seen from Table 2 and 3 that the viscosity and shearing force of drilling fluid decrease with the increase of temperature, and the filtration loss decreases. However, when the temperature exceeds 120 ℃, the viscosity decreases with the increase of temperature, and the filtrate-loss increases, but it can still meet drilling needs under the downhole condition. When the temperature exceeds 180℃, shearing force is low, and the filtrate-loss is 5ml. The high temperature and high pressure filtration test is carried out under 180℃, the high temperature and high pressure filtrate-loss is less than 12ml, and the temperature resistance is not less than 180℃ with comprehensive consideration.

2.2 Evaluation of Anti-Collapse Performance of Drilling Fluids

2.2.1 Clay Swelling Experiment

Table 4
Clay swelling test for different samples

Time	Clay swelling height /mm		
	Sea Water	Sample 2	Sample 3
30s	0.09	0.04	0.01
2min	0.50	0.11	0.04
8h	5.07	2.37	1.90

Table 4 shows that the swelling height of clay is significantly reduced after adding compound-salts, which means that the compound-salt system can effectively inhibit the hydration swelling of clay particles.

2.2.2 Shales Rolling Dispersion Experiment

Table 5
Test results of shale rock cuttings recovery

No.	Test Fluid	Recovery Rate of Rock Cuttings /%
1	Sea Water	29.50
2	2# Sample	88.98
3	3# Sample	94.25

The test result indicates that the cuttings recovery rate for the seawater compound-salt plugging system is higher than that of seawater and seawater polysulfonate system, and it also demonstrate that the seawater compound-salt plugging system has strong inhibition, can effectively improve the recovery rate of shale rock cuttings, and is conducive to the stability of wellbore and formation damage controlling.

2.3 Evaluation of Anti-Contamination Performance of Drilling Fluids

Table 6
Test results of cuttings contamination

No.	Formula	AV / mPa·s	PV / mPa·s	YP / Pa	FL / mL	Testing condition
1	Sample 2 +3% Cuttings	27	16.5	5.5	10.4	Room Temperature
		48	25	23	8	120℃/16h
	Sample 2 +5% Cuttings	29.5	17.5	6	9.6	Room Temperature
		59	33	26	7.6	120℃/16h
2	Sample 3 +3% Cuttings	26.5	18.5	8.5	4.4	Room Temperature
		31	21	10	4.0	120℃/16h
	Sample 3 +5% Cuttings	28	18	6.5	4.2	Room Temperature
		34	24	10	4.0	120℃/16h

It can be seen from Table 6 that the addition of mudstone cuttings of Dongying Group in Chengdao area has a great impact on the conventional polysulfonate system. However, the viscosity, shearing force and filtrate-loss of seawater compound-salt plugging system change little, indicating that the anti-contamination ability of compound-salt system is stronger than that of the conventional polysulfonate drilling fluid.

2.4 Evaluation of Lubrication Performance of Drilling Fluid

Table 7
Test results of friction coefficient of drilling fluids

Serial number	Drilling fluid	Friction coefficient
Sample 2	1% Oil Based Lubricant	0.093
	2% Oil Based Lubricant	0.076
	3% Oil Based Lubricant	0.063
Sample 3	1% Oil Based Lubricant	0.080
	2% Oil Based Lubricant	0.069
	3% Oil Based Lubricant	0.059

It can be seen from Table 7 that the compound-salt plugging drilling fluid has good lubrication performance.

3. FIELD TRIALS OF COMPOUND-SALT PLUGGING DRILLING FLUID

3.1 Pilot Tests in Well CB-GX18 and Well CB-G16

Well CB-GX18 is a key exploration well built in Shengli No. 10 platform. The total depth of this well is 5085 m. Well CB-G16 also is a key exploration well built in Shengli 6 platform with a total depth of 4964m. Both wells drilled into Archean formation. There are some difficulties during drilling in those well. Firstly, each well has a long open-hole interval in the third-spud which is about 1989.35m and 1605m. Secondly, it encountered many strata, such as Dongying Group, Shahejie Group and Mesozoic Group. Well CB-G16 drilled deeper into formation lower-Paleozoic. Especially the unstable oil-shale at the bottom of Dongying Group and Shahejie Group, and the Mesozoic Group are easy to seriously leak during drilling in well CB-GX18. In order to ensure the safe drilling, both wells used compound-salt plugging drilling fluid when drilled into to Dongying Group in the third spud. The application of drilling fluid shows the advantages of high penetration rate, strong cuttings-carrying capacity, good fluidity, good lubrication, and wellbore stability (Table 8, 9 and 10).

Table 8
Performance of compound-salt plugging drilling fluid in well CB-GX18

No.	Depth /m	ρ /g/cm3	FV /s	Filtrate loss /mL	Mudcake /mm	pH	PV /mPa•s	YP /Pa	G10s/10min/Pa/Pa
1	3206	1.19	40	4.8	0.5	8	20	7	2/7
2	3735	1.22	41	4.6	0.5	8	20	7.5	2/7
3	4162	1.35	59	3	0.5	8	25	8	3.5/9
4	4470	1.34	56	3.2	0.5	8.5	24	8.5	4/10
5	4660	1.34	58	3	0.5	9	25	8.5	4/10
6	4841	1.38	65	2.8	0.5	9	28	10	6/16

Table 9
Performance of compound-salt plugging drilling fluid in well CB-G16

No.	Depth /m	ρ /g/cm^3	FV /S	Filtrate loss /mL	Mudcake /mm	pH	PV /mPa•s	YP /Pa	G10s/10min/Pa/Pa
1	3260	1.19	55	3.8	0.5	8.5	24	12	2.5/6
2	3670	1.20	55	3.4	0.5	8.5	29	11	2.5/7
3	3888	1.23	59	3.4	0.5	8	27	8	3/8
4	3960	1.25	65	3	0.5	9	31	9.5	3/8
5	4230	1.29	64	4	0.5	9.5	28	8	2/7.5
6	4354	1.30	70	3	0.5	9	33	10	3/8

Table 10
Well diameters in both wells of CB-GX18 and CB-G16

Well Name	Reservoir section /m		Bit OD /mm	Average wellbore diameter enlarging rate /%
	From	to		
CB-GX18	2852	4496	215.90	7.71
CB-G16	2727	4354.4	215.90	3.76

It can be found from Table 10 that the average wellbore diameter enlarging rate of the drilled hole after using the compound-salt plugging drilling fluid with is less than 8%, and the well diameter is relatively regular, which ensures the success of subsequent completion of electrical logging.

4. CONCLUSIONS

(1) The compound-salt plugging drilling fluid has been optimized, and which has strong cuttings-carrying and suspension capacity, which can ensure the cleanness of the downhole and meet the safe drilling requirements of highly deviated wells and horizontal wells. The drilling fluid has good stability, good lubricity, and wellbore stability. The system is obviously superior to the traditional polysulfonate system in rheology, inhibition, temperature resistance, bentonite contamination resistance and lubricity.

(2) The application of compound-salt plugging drilling fluid in Block Chengbei of Shengli Oilfield shows that this drilling fluid system has the advantages of convenient maintenance, stable drilling fluid performance, strong plugging and collapse prevention, and good compatibility with conventional drilling fluid treatment agents.

(3) After using the compound-salt plugging drilling fluid, the mud-making problems in mudstone formation has been effectively reduced, and the corresponding induced problems such as bit-balling and wellbore shrinkage have been basically eliminated, the average well diameter enlarging rate is less than 10%.

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