AN ENVIRONMENTALLY FRIENDLY WBM SYSTEM CAN PREVENT HARD BRITTLE SHALE INSTABILITY

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ABSTRACT

In the Weizhou Southwest oilfields, drilling delays and suspension of wells prior to reaching the targets due to wellbore instability had occurred frequently. The hard brittle shale played a problematic role. Conventional water-based drilling fluids didn't conquer the problematic formation due to intrinsically performance deficiencies. While Oil based drilling fluids are routinely preferred in the more technically demanding applications, they are cause for increasing concern due to offshore environmental restrictions and expensive disposal costs. An environmentally acceptable water-based drilling fluid was developed to challenge the problematic formation based on the combination of methylglucoside-silicate concept. It stabilized the reactive shale by the same mechanism as did oil-based drilling fluid in preventing shale hydration, pore pressure increase and weakening of shale by effectively developing sufficient osmotic force to offset hydraulic and chemical forces acting to cause filtration flux into the hard brittle shale. A field trial was initiated on the CNOOC 931 platform in Weizhou oilfield. The data from the pilot well showed that the novel drilling fluid exhibited excellent inhibition and lubricity which approached or even exceeded oil-based fluids.

Key words: drilling fluid, environmentally friendly, hard brittle shale, hole instability, methyglucoside, ideal packing theory

I. INTRODUCTION

For several decades, wells drilled in Weizhou field, a region of growing importance in oil and gas production in South China Sea, had experienced serious hole-instability problems related to drilling fluids. The hard brittle shales in the Weizhou and Liushagang formations played problematic role. They are characterized by complex geological structures, a lot of faults and fractured zones with a large number of micro fractures. Hole enlargement, drilling fluid a great loss to the formation, poor hole cleaning as well as severe shale collapse were inevitably encountered. Wiper trips were indispensible while drilling. The difficulties resulted in drilling accidents occurred frequently, thereby drilling costs soared upwards. The hard brittle shale had been a bottleneck in the development of the Weizhou offshore oil&gas exploration and production.

Conventional water-based drilling fluids didn't conquer the problematic formation. Historically, a number of conventional water-based drilling fluids, such as KCl/polymer system, KCl/lime/polymer system, PHPA system, PEM system as well as KCl/Silicate system have been ever employed to challenge the hard brittle shale in the Weizhou offshore oilfield. They were plagued by excessive hole enlargement, clay instability, problematic trips, pack-off and lost circulation events. Smooth penetration was hardly documented. They failed in getting gauged hole and alleviating caving, as shown in Figure1 and Figure 3. Big cavings were observed on scalping shale shakers while drilling as shown in Figure 2.

OBM are routinely preferred in difficult situations. The superior drilling performance of such non-aqueous fluids has been well documented, showing

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Figure 1
Cavings from WZ12-1N-B6 well

Figure 2
Cavings from WZ6-9-1 well

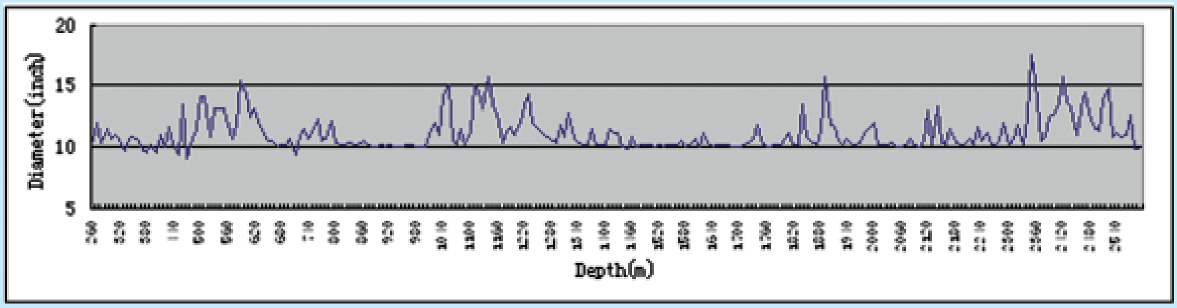

Figure 3
Caliper data graph for WZ12-1N-B6 well

ideal shale inhibition and chemical wellbore stability, coupled with high ROP, good levels of lubricity, and lower risk of stuck pipe. However, the employment of oil-based drilling fluids is cause for increasing concern due to offshore environmental restrictions and expensive disposal costs. WBM replacement that can provide ultra-low invasion OBM system like performance would be more available in Weizhou offshore area.

II. TECHNICAL CHALLENGES AND STRATEGY OF WBM

Samples taken from the L_{II} hard brittle formation for three wells were subjected to the analysis of XRD and SEM respectively.

From Table 1 and Table 2, it is shown that all the shale samples examined are highly dispersive and reactive. The results indicate that the shale sections of L_{II} formation contain high levels of both reactive and dispersive clays, with the smectite/illite mixed layer levels as high as 50%~60%, and kaolinite levels as high as 20%~30%. In some cases, the total concentration of reactive and dispersive minerals is as high as above 60% of the total bulk samples.

By SEM analysis as shown in Figure4 and Figure 5, a lot of microfractures were observed on the representative bulk sample obtained from L_{II} section which is typically composed of hard and brittle shale in Weizhou offshore area. The micro-fracture provides a passage for drilling fluid to go through the inner section of shale. These movements usually weaken the strength of shale, and finally result in washed out hole. Accordingly, for the hard brittle shale, wellbore sealing and strengthening are supposed to be the most important strategy.

Based on these analyses, the newly designed drilling fluid should be capable of providing strong inhibitive ability, as well as packing micro-fractures. In addition, most of the wells in Weizhou offshore area had to experience directional works. The average well on the platforms had an angel of 45°. Lubricity of the drilling fluid is very important and determines the success in directional section. Correspondingly, the strategy of newly designed water-based drilling fluid should also pay more attention to lubrication ability to reduce torque and drag, which facilitates transfer of weight to the bit required for the aggressive directional plans.

III. FLUID SELECTION AND FORMULATION

Various types of water-based muds such as KCl/polymer, KCl/lime/polymer and also KCl/PHPA had ever been tried in Weizhou offshore oilfieds. Hole instabilities were inevitably witnessed. A review of various water-based muds was conducted to determine which system would be a preference for these fractured hard brittle shales.

Earlier literatures (Walker, T.O. et al., 1994) had reported that the methylglucoside (MEG) fluid was an environmentally acceptable water-based drilling fliud with excellent shale inhibition. It stabilized shale by a chemical osmotic effect originated from semi-permeable membrane and water activity chemistry involving a combination of methylglucoside and salt. This drilling fluid can alleviate WBM related drilling problems (Headley, J.A. et al., 1995). Furthermore, insoluble particles presented in the MEG fluid can be employed as deformable bridging particles to seal micro-fractures exsited in shale. MEG drill-in fluid is also a reservoir friendly WBM (Zhang yan, et al., 1998) and is capable of minimizing the formation damage especially when combined with ideal packing technique (Yan Jienian, Feng Wenqiang., 2006). In addition, MEG is also classified as a perfect lubricant according to "1995-1996 Enviroment Friendly Drilling & Completion Fluids Handbook". It was believed that the MEG drilling fluid would be a preferred WBM to challenge the problematic formation in Weizhou offshore oilfields.

Table 1
Composition of shale samples for total minerals obtained from XRD analysis

Wells	Type of sample	Quartz %	K Feldspar %	Na Feldspar %	Calcite %	Pyrite %	Clay content %
FN-1	Clay shale	23.7	1.2	1.6	1.6	5.5	66.4
FN-21	Clay shale	29.4	1.5	2.3	/	4.2	62.6
FN-68	Clay shale	12.5	0.9	1.2	2.0	~20	63.4

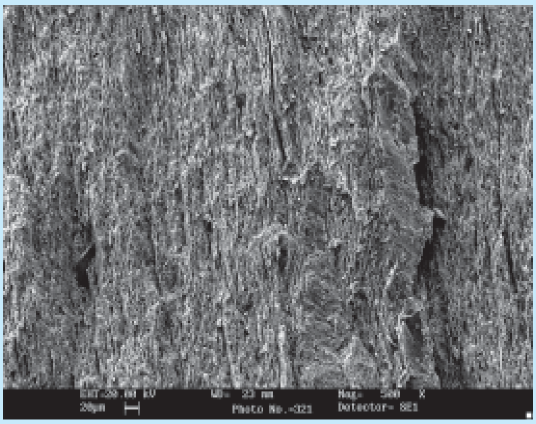

Figure 4
Sample SEM Photograph (×500)

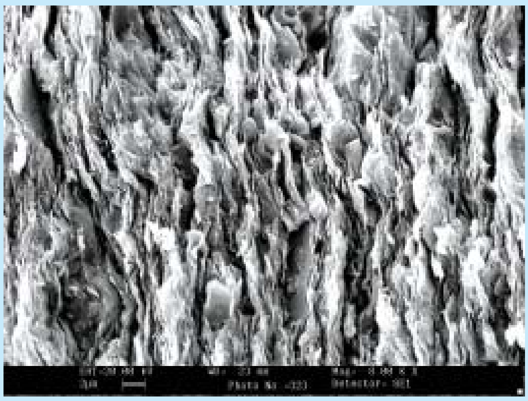

Figure 5
Sample SEM Photograph (×8000)

Table 2
Composition of shale samples for clay minerals obtained from XRD analysis

Wells	Type of sample	Mixed layer (I/S) %	Illite %	Kaolinite %	Chlorite %	Ratio of (I/S) %
FN-1	Clay shale	61	7	20	12	40
FN-21	Clay shale	58	5	20	17	40
FN-68	Clay shale	53	10	27	10	45

Table 3
Typical formulation of the MS drilling fluid

Composition	Concentration (Kg/m^3)	Component or Function
MEG (Powder)	>250	Methylglucoside
PAC	8.0-10.0	Filtration control
XC	1.0-3.0	Xanthan Gum
PF-ZP	20	Sealing material, Filtrate Invasion Control
OCL-JB	2.0	Fluid Loss Control
SS-1	2.0	Modified Starch
KCl	50	Activity Control
Sodium Silicate	30	Inhibitive and sealing agent
Caustic Soda	10	pH Control
QS-2	30-40	Bridging solids

Depending on the results of extensive lab tests, the strongly inhibitive MS system was developed based on the combination MEG/salt concept. Its typical formulation and properties are presented in Table 3 and 4.

In the formulation, the polymer additives, such as XC, PAC and OCL-JB, are used to obtain the desired rheological properties and filtration control character. The significantly strong inhibitive charater of the MS system chiefly comes from chemical membrane and sealing directions.

The chemical osmotice effect is obtained through the application of new water-based chemistry involving a combination of methylglucoside and salt to form a semipermeable membrane and to reduce water activity of the drilling fluid. The water activity (A_w) of

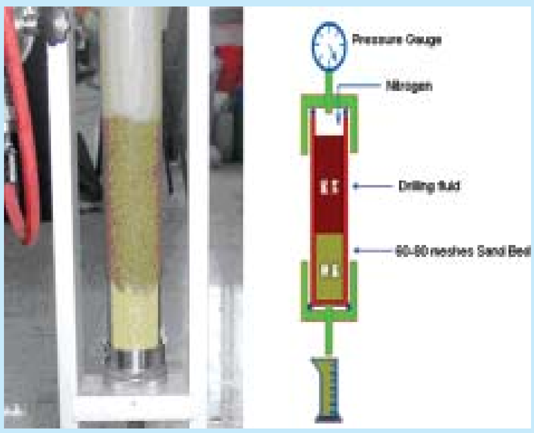

Figure 6
FA Sand Bed Filter Press

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the MS mud was intended to be in the range of 0.84 to 0.86 through the addition of potassium chloride, sufficient to stabilize the shales estimated to have an A_w of 0.90 to 0.92.

Ultra-low invasion lost circulation material PF-ZP provides packing of widely distributed particles into microfractures, thereby preventing adverse pressure transmission effectively between the drilling fluid and shale. The effective packing can also come true through a series of chemical reactions between sodium silicate and clay minerals present in shale. Once the soluble silicate contacts the surface of shale, a reduction in the pH value will take place and the reaction of silicate with the divalent cations (Ca^{2+} or Mg^{2+}) on/in the shale will occur and form a film-like barrier that can prevent the solid particles and the filtrate of drilling fluids from invading into the micro-fractures of shale. Moreover, the self-polymerization of silicate also provides a physical barrier to play the same role. Sometimes, a commercial available ultra-fine calcium carbonate, designated as QS-2, is utilized to enhance packing availability.

IV. LABORATORY EVALUATION OF MS DRILLING FLUID

The MS drilling fluid was proven to be quite easily mixed and sufficient for barite suspension. When weighted up to about 1.40g/cm^3, no any barite settling was observed in the laboratory sample. The typical properties were similar to those of a clean polymer mud system. The yield point was greater than the plastic viscosity, gel strengths were low and flat, filtration rates were quite low, and a very thin filter cake was obtained.

The contamination test was performed to assess the stability of the MS drilling fluid to cuttings contamination. The Rev-Dust for the test was taken from the underflow of centrifuge. It can be seen from Table 5 that the concentration of contaminant, Rev-Dust, has only a slight effect on the rheological parameters and filtration rate for the MS drilling fluid. It is believed that the newly made WBM exhibits good and stable properties not only when it is freshly built, but also during drilling operations.

Table 4
Typical properties of the MS drilling fluid

Properties	Values
AV (mPa·s)	31
PV (mPa·s)	11
YP (lb/100ft^2)	20
6 rpm Reading (lb/100ft^2)	7
Gel 10sec/10min (Pa/Pa)	4/8
API Filtration (ml/30min)	2
Cake Thickness (mm)	0.5
Chlorides (mg/L)	22,000
P_f	0.8
A_w	0.85
pH	12.0

Table 5
The properties of MS drilling fluids after contaminated with different concentration of Rev-Dust

Number of Formulation	*Density (g/cm3)*	*PV (mPa.s)*	*YP (Pa)*	*Gel strength (Pa)*	*API filtration (ml)*	*HTHP filtration 120[illegible] /3.5MPa (m*
1	1.25	21	11.5	3/6	2.0	8
2	1.27	21	9.5	2.5/2.5	2.0	9
3	1.29	24	11	2.5/3.0	2.5	9
4	1.30	25	12	3.0/3.5	2.0	10

Note: No.1 -- formulation shown in table 1; No.2 -- No.1+ 4%(w/v) Rev Dust; No.3 -- No.1+ 6%(w/v) Rev Dust; No.4 - -No.1+ 8%(w/v) Rev Dust

Table 6
Sealing simulated testing result

Drilling fluid	Simulated fracture size (mm)	Sealing time (minute)	Loss volume (mL)	Testing condition
MS drilling fluid	0.01	0.5	5	725psi, 90℃
	0.05	0.5	6	
	0.10	1.5	9	
	2	3	20	
	4	4	25	

Table 7
Lubricity of MS drilling fluid

Drilling fluid	Filter cake stuck factor	Lubricity coefficient	Testing condition
MS	0.0875	0.0756	120℃/16h rolling
PLUS/KCL	0.1763	0.286	120℃/16h rolling
OBM	0.0216	0.0817	120℃/16h rolling

Table 8
Results of formation damage tests

Test No.	Fluid type	HTHP fluid loss 500 psi, 300°F (mL)	Initial perm. (mD)	Return perm. (mD)	Return* (%)	Breakthrough pressure** (MPa)
#1	MS RDF	10	101	92	92	0.03
#2	MS RDF	12	302	300	100	0.02

* Percentage of Return permeability is the value obtained by dividing the final permeability to oil of the core by the initial permeability to oil and then times 100 for the whole core.

** The calculation of breakthrough pressure: the maximum pressure minus the stable pressure when determining the final permeability. It takes into account the changes in flow rate by normalizing pressure to flow rate.

The new generation filter press shown in Figure 6 was employed to assess MS drilling fluid's sealing ability which is a crucial factor to stabilize hard bittle shale. No more than 2 mL filtrate was observed when 1000mL MS drilling fluid was injected into the cell with a constant pressure of 500psi provided by a nitrogen tank.

Additional sealing&filtration tests were conducted by utilizing OWC-8015 Sealing Simulated Test Cell, as shown in Figure 7. Even a 4mm width simulated fracture was sealed successfully within 4 minutes by the same fomulated MS drilling fluid as presented in Table 1. A wide size range of simulated fractures between 0.01mm and 4mm were all sealed effectively at the cost of a little fluid loss no more than 25 mL as shwon in Table 6. It is obvious that the MS drilling fluid behaves remarkable sealing ability.

MS drilling fluid had a lubricity coefficient (coefficient of sliding friction for steel against steel) of 0.0756 as tested by the procedure given in API RP-13B presented in 1978. Oil-base muds tested by this procedure typically have coefficients of less than 0.1, while conventional KCl/polymer muds usually have coefficients of 0.2 to 0.3, seen in Table 7. Perfect lubricity character permits MS mud to drill high angle or even extended-reach wells with minimum risks of high torque and differential pressure sticking of pipe.

To transform the drilling fluid to the reservoir fluid (RDF), proper bridging agents are indispensable. Laboratory work focused on formulating a fluid with the minimum amount of bridging solids required to form a good quality filter cake. The particle-size distribution of the calcium carbonate was optimized utilizing Ideal Packing Theory (Dick M A, Heinz T J, et al., 2000). After extensive testing, a final formulation containing a minimum concentration of 4% calucium carbonate blend was selected. It exhibited perfect fluid loss and return permeability, as shown in Table 8.

Figure 7
Simulated Cell and sealing effect

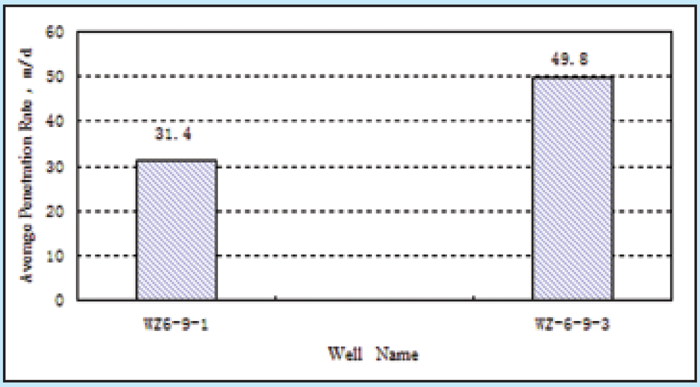

Figure 8
Comparison of average penetration rate of two WBMs in the hard brittle formation

V. FIELD TRIAL OF MS DRILLING FLUID

The first field trial was initiated on the CNOOC 931 platform. The well WZ6-9-3 was chosen as the pilot well. The WZ6-9 field is approximately northeast 36km of Weizhou Island and is a highly environmental sensitive area. Due to the close proximity of Weizhou Island, the use of any oil-based drilling fluid is not a realistic option. The 12 $^{1}/_{4}$” interval was drilled with the MS system from 1595m to 2453m. Based on the ideal packing technique (Yan Jienian, Feng Wenqiang., 2006), a carefully designed MS RDF developed by optimizing previous MS drilling fluid was employed to drill 8 $^{1}/_{2}$” interval. Coring was operated before TD according to the geological proposal.

Drilling challenges such as difficult to steer, poor hole cleaning, hard to run cement and poor cementing job were experienced in an adjacent well WZ6-9-1 drilled with KCl/KPAM (potassium polyacrylate) system. A lot of big cavings were observed on the scalping shale shaker when penetrating in hard brittle shale, as shown in Figure 3.

A. *Drilling Performance*

Smooth penetration in 12 $^{1}/_{4}$” interval was witnessed. The mud weight increased in steps from 8.93

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to 10 lb/gal, the maxium of which was 0.8 lb/gal lower than the KCl/Polymer system used in this area previously. Although sometimes over pull and tight hole spots were experienced, back reaming was not required. BHA and bit balling was minimized although not completely eliminated. Washing out on short trips was almost eliminated. No excess drag was observed and the hole took the proper amount of fill. No problem was recorded in pulling the lower BHA into the casing. In previous wells, the normal condition would likely have required pumping some of the stands out of the hole and excess drag would have been seen in pulling into the casing. The drilling practice testified the penetration rate for the hard brittle shale with MS mud was 25% higher than the adjacent well drilled with KCl/KPAM mud, as shown in Figure 8.

Figure 9
Cuttings from shale shaker

Figure 10
Cuttings firm and dry inside

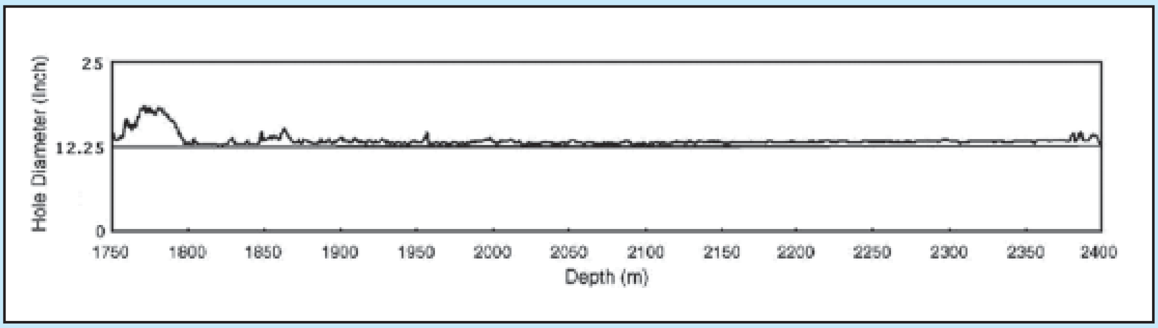

Figure 11
Caliper data graph for 12 1/4” interval of WZ6-9-3 well

B. *Drilled Cuttings*

Angular and hard cuttings with remarkable nicks were observed throughout the entire interval, as shown in Figure 9. They were promptly removed by 120 mesh screens on the scalping shakers. Most drilled cuttings even remained dry inside as shown in Figure 10.

C. *Caliper and Hole Enlargement*

A near-gauged hole is crucial to smooth logging, cementing and even advanced formation evaluation. MS drilling fluid provided a near-gauged 12 $^{1}/_{4}$" hole. One spot of out-of-gauge was unexpectedly observed **d**ue to the mud weight lower than 8.93 lb/gal which was the minimally proposed mud weight when drilling commenced, as shown in Figure 11. The 9 $^{5}/_{8}$" casing was ran to the bottom of 12 $^{1}/_{4}$" interval without difficulty and was successfully cemented in place utilizing conventional practices.

Figure 12
Cores obtained from WZ6-9-3 well

D. *Coring*

In the following 8 $^{1}/_{2}$" interval, corings were operated twice successfully in MS drill-in fluid. One core colume was 6.05 meters long obtained at 2595m depth and another was 6.35 meters long obtained at 2614m depth. Core recoveries were 97.5% and 100% respectively. Clear evidences of oil and gas were observed, as shown in Figure 12.

VI. CONCLUSION

MS drilling fluid stabilizes the fractured hard brittle shales by the combination of an osmotic chemical flow and a unique sealing. The shale drilled with the MS drilling fluid could keep stable with lower mud density due to its strongly inhibitive ability, compared with the KCl/KPAM drilling fluid used previously. It exhibited favorable rheological properties, filtration control and lubricity characters, which allowed safe and smooth drilling operations. To assure availablility of MS fluid, it is crucial to maintain the MEG content no less than 250kg/m^3. It is believed that the specially designed MS drilling fluid could be a competent and environmentally accepted WBM alternative to challenge hard brittle shale in Weizhou offshore area. MS drilling fluid is also proven to be a competent WBM for onshore drilling by the successful applications in Ying 2-1 and Hongnan-6 wells in Xinjiang oilfields in the northwest of China.

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GLOSSARY

KCl	potassium chloride
KPAM	potassium hydrolyzed polyacrylamide
MS	methyglucoside & silicate
OBM	oil based mud
PHPA	partial hydrolyzed polyacrylamide
RDF	reservoir drilling fluid
SEM	Scanning Electron Microscope
WBM	water based mud
XRD	X-Ray Diffraction

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