A new anti-slough drilling fluid study and application

X Y Zhao¹,², Y F Meng¹,³, X T Hou², C Xiao², G Li¹ and C C Niu²

¹State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, China
²Research Institute of Petroleum Engineering, SINOPEC Beijing 100101, China

E-mail: swpuzxy@163.com

Abstract. Currently the BIOCAT drilling fluid system adopted in oil field results in wellbore collapsing frequently, borehole enlargement rate over 100%. In order to settle these problems, the Impermeable anti-collapsing inhibitive Polymer Drilling Fluids System is developed by optimizing the inhibitors with high anti-collapsing inhibitive instead of BIOCAT inhibitor, adding impermeable agent SMT3, sealing materials such as graphite, calcium carbonate, etc. Laboratory experiments results show that the developed drilling fluid system has stronger inhibitive and anti-collapse capacity. The swelling increment decreases by over 10% and recovery rate increases by 60%-70%, also, it can efficiently prolong the borehole wall stable period by over 100%. 24 wells applications with the Impermeable anti-collapsing inhibitive Polymer Drilling Fluids System achieved good results, comparing to adjacent wells with BIOCAT drilling fluid system, wellbore collapsing decreasing significantly and borehole diameter enlargement of unstable hole section in wells decreased from 100% to 10%, well drilling time decreased by 15%, drilling cost decreased by 10%. It shows that the developed Impermeable anti-collapsing inhibitive Polymer Drilling Fluids System KPAM-NH4PAN can provide strong and long-term inhibition, close to oil-based drilling fluid, so it is suggested that it be used in subsequent drilling operations to enhance the wellbore stability in an oilfield.

1. Introduction

SJ Basin was influenced by compression and nappe (fault) cutting during the tectonic evolution. The formation has large dip, with fragmented strata, micro-fractures developed, and average width of core fractures is 4.3 micron. The upper formation is mainly mudstone and tuff, and the lower mainly tuff and mudstone. Formation has high content of montmorillonite and quartz, strongly water-sensitive. The well drilling process is prone to collapse, lost circulation and formation damage.

1.1. Borehole collapse

Serious borehole collapse occurred during drilling Well PCC3027 in PCC Block, which led to sticking of logging tool twice, sticking of casing, when density of drilling fluid was increased from 1.2 g/cm³ to 1.26g/cm³, more serious borehole sloughing occurred. For other wells in PCC Block, borehole collapse was even more serious at the interval of 300-800m, with relatively big hole diameter.

³ Address for correspondence: Y F Meng, State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, China. Email: swpuzxy@163.com.
The hole diameter for second spud-in of Well EHH4103 in EHH Block was irregular, with the average hole diameter enlargement rate of almost 30%. Baker Hughes analyzed and believed that the action of drilling fluids to clay resulted in hole instability, so this problem should be solved by using a proper drilling fluid system that could reduce the reaction between mud and clay formation.

1.2. Soft and thick mud cake
The well log data indicated that the thickness of mud cake at the reservoir interval was up to 25.4mm, and tight hole resulted in serious sticking of logging tool. Besides, the cake thickness also indicated serious water loss of drilling fluid under the downhole environment and deep formation damage might be resulted from filtration into the formation.

1.3. Poor inhibition performance of drilling fluids
The bentonite content of drilling fluids for the stage of second spuding was 25kg/m$^3$, however, it became over 85kg/m$^3$ after finishing drilling, with bit balling happened during drilling, which indicated that drilling fluid could not inhibit mud making.

2. Borehole instability mechanisms study

2.1. Core Analysis
The purpose of the experiment was to analyze the mineral composition of cores, the clay mineral content in the cavy interval, so as to provide basis for optimization of new drilling fluids and some inhibited treating agents.

| Core No. | Well No. | Depth (m) | Quartze | Potassium Feldspar | Albite | Calcite | Barite | Total Content of Clay Minerals (%) |
|----------|----------|-----------|---------|--------------------|--------|---------|--------|-----------------------------------|
| 13       | EHH3111  | 2212      | 38.7    | /                  | 26.1   | 3.0     | /      | 32.2                              |
| 25       | EHH3111  | 1733      | 64.8    | /                  | 12.0   | 0.1     | /      | 23.1                              |
| 28       | EHH3111  | 1391      | 25.5    | 1.2                | 19.7   | 6.8     | 7.9    | 38.9                              |

| Core No. | Well No. | Depth (m) | Relative Content of Clay Minerals (%) | Mixed-layer Ratio (%S) |
|----------|----------|-----------|---------------------------------------|------------------------|
|          |          |           | S I/S I K C                           | I/S                    |
From the experiment, the content of clay minerals in cavey interval is up to 30%, dominated by water-sensitive montmorillonite and illite-montmorillonite layers, formation strength reduced by the hydration of clay minerals, leading to borehole collapse. Besides, the samples have high contents of feldspar and quartz with strong hardness and brittleness, and the inhomogeneous stress distribution resulted from expansion of clay minerals, water absorption may also lead to borehole collapse.

2.2. Electron microscope picture of the core taken from sloughing formation

Microscope photos show that the sample is unconsolidated with developed fracture. During drilling process, drilling fluids and filtrate could invade the formation through these fractures, which could cause clay hydration swelling and lead to borehole collapse.
2.3 Water-Sensitive experiment with cuttings from sloughing formation
Figure 5. Fresh Water Swelling (2690m)

It can be seen from the picture that the formation water sensitivity of the EHH block in an Oilfield is strong, with swell capacity varying in different depths. It is the strong water absorbent or swelling formation at 1690m, with fresh water swelling amount up to 70%; while at 2670 and 2690m, it is the easy-swelling formation, with the fresh water swell capacity of 35%. During drilling, the cuttings are easy to disperse in the drilling fluid, and cause increasing of bentonite content; consequently, the formation tends to be hydrated, which causes formation strength reduction and makes formation lose stability.

1.4.2.4 Recovery rate experiment

Table 3. Roller recovery rate with fresh water

| Depth (m) | Cuttings quality before rolling (g) | Cuttings quality after rolling (g) | Recovery rate (%) |
|-----------|-----------------------------------|----------------------------------|------------------|
| 1532      | 19.9                              | 2.04                             | 10.3             |
| 1735      | 20.1                              | 1.98                             | 9.9              |
| 1895      | 19.8                              | 2.1                              | 10.6             |
| 2070      | 20.2                              | 2.37                             | 11.7             |
| 2410      | 20.2                              | 1.94                             | 9.6              |
| 2630      | 20.2                              | 3.57                             | 17.7             |

Seen from the result of roller recovery rate experiment, the recovery rate of Well EHH4103 is relatively low, indicating that the cuttings are strong in dispersibility, easy to cause cutting solids contamination. The borehole wall tends to lose stability when soaked in fresh water or drilling fluids for a long time.

3. New anti-slough drilling fluid system study

The effects to drilling fluid rheology caused by polyamine are large; drilling fluid inhibitive capability can’t fully meet the needs of anti-sloughing, the HTHP filtrate loss of drilling fluid is larger at lower section in EHH block. The initial idea is to change polyamine into KCl as clay anti-swelling agent, in higher temperature EHH block, use SPNH to improve high temperature inhibitive capability of the drilling fluids[1-5]. The drilling fluid formula and test results for PCC and EHH blocks (well depth 1800 m) are as follows:

Table 4. The drilling fluid prescription in 300m-1800m well section of PCC and EHH blocks

| Treating agents | Concentration (kg/m³) | Treating Chemical | Concentration (kg/m³) |
|-----------------|-----------------------|------------------|-----------------------|
| Water           | 855.54                | BARITINA (3,8 Pe) | 100.00                |
| BENTONITA       | 25.00                 | SOLTEX           | 18.00                 |
| NaOH            | 3.00                  | MARPAC GOLD LV / HV | 6.00                 |
| MARPOL 507      | 2.00                  | KCl              | 50                    |
| MAR VIS XCD     | 1.50                  |                  |                       |

Table 4. The drilling fluid formula at well section 1800m-2700m in EHH block

| Treating Chemical | Concentration (kg/m³) | Treating Chemical | Concentration (kg/m³) |
|-------------------|-----------------------|------------------|-----------------------|
| Water             | 855.54                | BARITINA (3,8 Pe) | 100.00                |
| BENTONITA         | 25.00                 | SOLTEX           | 18.00                 |
| NaOH              | 3.00                  | MARPAC GOLD LV / HV | 6.00                 |
| MARPOL 507        | 2.00                  | KCl              | 50                    |
| MAR VIS XCD       | 1.50                  | SPNH             | 20                    |
3.1 The drilling fluid inhibitive capability experiments and research
From the immersing experiments in optimized drilling fluid, we can find that the drilling cuttings remain hard after 24 hours immersion, which illustrates the drilling fluid, has a strong inhibitive capability, and is able to prevent bit balling and borehole instability[6-10].

3.2 Drilling cuttings swelling experiments
The experiment procedures can be seen in “water swelling experiment”, the optimized drilling fluid is employed and drilling cuttings are taken from well EHH4103. The experiment results are as follows:

![Figure 6. Comparison of swelling test results with four drilling fluids (cuttings taken from the depth of 2690m in EHH4103)](image)

The above picture show that the cuttings swelling amount drops from 35% in fresh water to 6% in optimized drilling fluids, which has stronger anti-swelling capability than on-site drilling fluids.

![Figure 7. Comparison of swelling test results with four drilling fluids (cuttings taken from the depth of 2670m in EHH4103)](image)

The above picture show that the cuttings swelling amount drops from 30% in fresh water to 3% in optimized drilling fluids, and the anti-swelling capability enhances by 60% compared to on-site drilling fluids.
Figure 8. Swelling test results comparison of four formulas (1690m of EHH4103)

The picture show swelling test results respectively in fresh water, on-site drilling fluids (800-2700m), optimized drilling fluids (special for PCC block, resistance temperature of 90 ℃), and in optimized drilling fluids (special for EHH block, resistance temperature of 120 ℃).

The test results show that swelling amount is 61% in fresh water, it is 23% in on-site drilling fluids, but the swelling amount is only 13% in optimized drilling fluid, which means that the optimized drilling fluid has stronger anti-swelling capability.

3.3 Drilling cuttings rolling recovery test

The test procedure of drilling cuttings rolling recovery test in optimized drilling fluid is the same with that in fresh water. The drilling cuttings of well EHH4103 rolling recovery test results using optimized drilling fluid are as follows:

| Well Depth (m) | Drilling cuttings quality before rolling (g) | Drilling cuttings quality after rolling (g) | Drilling cuttings recovery rate (%) |
|---------------|---------------------------------------------|---------------------------------------------|-----------------------------------|
| 1532          | 20.1                                        | 7.32                                        | 36.4                              |
| 1735          | 20                                          | 6.89                                        | 34.5                              |
| 1895          | 20                                          | 7.98                                        | 39.9                              |
| 2070          | 20.7                                        | 8.14                                        | 39.3                              |
| 2410          | 19.9                                        | 5.9                                         | 29.6                              |
| 2630          | 20                                          | 5.37                                        | 26.9                              |

The experimental data show that drilling cuttings recovery rate in optimized drilling fluid is 26%-40%, enhancing by 5%-26% comparing with on-site drilling fluid, which illustrates the optimized drilling fluid can prevent drilling cuttings dispersion [11-14].

4. Field Application

The optimized drilling fluid system was used in two wells with good effect; the wellbore enlargement in sloughing intervals in wells PCC3033 and LH3018 have reduced from 100% to 10%, and the average wellbore enlargement has reduced from 30% to 5%. In Well PCC3033, two layer blowing during testing, and the production met the anticipated requirements, so fracturing job was eliminated, and the target on wellbore stability and reservoir protection were obtained.

For the caliper of the whole well, the maximum borehole diameter enlargement rate of test well Lh-3018 is less than 10% and that of the contract wells LHH2077 and LHH2078 is greater than 100%.
Figure 9. Caliper comparisons of collapsing section of 375-425m among Wells LH2078 and LH2077 and test wells

5. Study Conclusions

- The main reasons that cause wellbore unstable include micro-fractures, high clay mineral content and strong water sensitivity as well as crushing formation. It is suggested that enough drilling fluids and gel liquids should be stored at well site, so as to supplement drilling fluid or maintain its property.
- The optimized drilling fluid system KPAM-NH4PAN can provide strong and long-term inhibition, close to oil-based drilling fluid. This fluid system has good rheology and filtration performance, so it is suggested that it can be used in other oilfield with similar formation to enhance the wellbore stability.
- Test results show that KCl polymer drilling fluid has stronger inhibitive and anti-collapse capability than drilling fluid used before, and has good rheology as well as less filtration. It is suggested to choose KCl polymer drilling fluid for drilling deep formation. In order to better use the system and have good performance in oilfield, drilling fluid properties maintenance measures need to be developed scientifically and implemented strictly.

References

[1] Chesser B G 1987 Design considerations for an inhibitive, stable water-based mud system Spe Drilling Engineering 2
[2] Dearing H L and Ali S A 1996 Drill-In fluid selection crucial to well productivity Petroleum Engineer International
[3] Durand C, Lecourtier J, Rosenberg and Loeber L 1996 Relationship between composition, structure, and permeability of drilling filter cakes Oil & Gas Science & Technology 51 777-8
[4] Fjær E, Holt R M, Nes O M and Sønstebo E F 2002 Mud chemistry effects on time-delayed borehole stability problems in shales SPE 78163
[5] Li Y, Rosenberg E, Argillier J F, Durrieu J and Montes J 1995 correlation between filter cake structure and filtration properties of model drilling fluids (Richardson, TX: Society of Petroleum Engineers, Inc.)
[6] Zhang J L 2013 Anti-sloughing drilling fluid technology of deep formation in offshore of shengli oilfield Drilling Fluid & Completion Fluid 30 40-2
[7] Xu J F, Qiu Z S, Wang W G, Li S J, Huang C J and Qiao G W 2006 Study and application of a strong inhibitive drilling fluid KCC-TH Petroleum Drilling Techniques 34 36-8

[8] Li F, Yu Y L and Pu X L 2013 Research on novel anti-caving drilling fluid system Drilling Fluid & Completion Fluid 30 1-3

[9] Peden J M, Arthur K G and Avalos M 2013 The analysis of filtration under dynamic and static conditions (Bakersfield, California: 1984 SPE Formation Damage Control Symposium) SPE 12503

[10] Fordham E J and Ladva H K J 1989 and 1992 Cross flow filtration of bentonite suspension I and II J. Colloid Interface Science 148 29-34

[11] Altun G, Osgouei A E and Ozyurtkan M H 2014 An alternate mud proposal to minimise borehole instability (Kuala Lumpur, Malaysia: International Petroleum Technology Conference)

[12] Aadnoy B S 1987 A complete elastic model for fluid-induced and in-situ generated stresses with the presence of a borehole Energy Sources 9 239–59

[13] Aadnoy B S and Chenevert M E 1987 Stability of highly inclined boreholes Spe Drilling Engineering 2 364–74

[14] Fraser L J, Reid P I, Williamson D and Enriquez J 1995 Mechanistic investigation of the formation damaging characteristics of mixed metal hydroxide drill-in fluids and comparison with polymer base fluids Spe Driling & Completion 14