Research on High Density Water-Based Drilling Fluid of Complete Tectonic for the Southern Edge of the Junggar Basin

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Abstract: The southern edge of the Junggar basin in China has great potential for oil and gas exploitation. However, during drilling in this area, many borehole problems occurred, which leads to low rate of penetration and long drilling cycle. The main reasons from the geological aspect was that this area was affected by tectonic process, which leaded to development of complete tectonic, formation nappe along fault, big dip angles and poor stability. The Formation $E_{2\text{-}3a}$ was dominated by mudstone which was sensitive to water and can easily cause shale hydration expansion and dispersal. The instability of the formation is one of the major causes of borehole collapse and tight hole shrinkage. In order to improve the drilling speed and accelerate the process of exploration of southern edge in Juggar basin, the drilling fluids used in this region are studied based on data of geology and drilling data in this paper, Based on the characteristics of the formation $E_{2\text{-}3a}$, a new high density PRT-organic salt drilling fluid is selected by conducting a large number of laboratory tests. Test results of the inhibitory, sealing and stain resistance of this fluid indicates that it could satisfy the drilling requirement in southern edge of the Junggar basin. And field applications also turned out to be positive, the drilling speed was increased by 22% and drilling cycle was reduced by 4 days.

Keywords: Junggar basin, southern edge, complete tectonic, PRT-organic salt drilling fluid system.

1. INTRODUCTION

The southern edge of the Junggar Basin in Xinjiang of China was one of areas which have rich oil and gas [1]. The southern edge was in piedmont of north Tianshan Mountain, affected by tectonic movement, fold formed in the plane. This area was good for oil and gas gathering, which has great potential for exploitation. But the geological conditions is complex, affected by tectonic process, middle-upper part has big dip angles, development of fault, repeat of old and new strata, broken formation and poor stability; in the middle-downer part, Crack hard brittle shale and strong water sensitive shale could easily cause shale hydration expansion, borehole collapse and borehole shrinkage. Among these formations, the $E_{2\text{-}3a}$ formation is the worst. The lower part of the formation comes with the high stress and abnormal high pressure, high density drilling fluid is needed.

Because of the complex geological conditions and difficulties in engineering the southern edge always encounters with borehole problems during drilling [2]. Low drilling speed, long drilling cycle and high cost were constraints for exploitation activities in this area. This paper aims at reducing borehole problems, improving drilling speed, cutting cost and accelerating prospecting by studying the drilling fluid technology in the southern edge.

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2. GEOLOGICAL CHARACTERS AND DRILLING FLUID DIFFICULTIES

2.1. Geological Characters

According to the data from 66 wells drilled in southern edge area between 1996~2015, 44 wells (66.7%) encountered borehole problems during drilling. The data of the recent 5 years shows that the average drilling speed is lower than 3m/h, drilling cycle is above 100 days. The complex borehole problems, high accident rate and low drilling speed largely extends the drilling cycle and constraints the drilling activities. The geological characters of the area are shown below:

1) Affected by sedimentation and rock character, the formation layer is sensitive to water. The analysis of formation $E_{2\text{-}3a}$ in southern edge shows that clay minerals mainly include illite and smectite. Table **1** shows the experimental data by XRD analysis. The content of smectite was above 40%, clay minerals is above 30% (the maximum was 70%), which indicates that there is large amount of water sensitive clay minerals in formation $E_{2\text{-}3a}$.

2) Affected by high horizontal stress from piedmont tectonic, the maximum horizontal stress is higher than the overburden pressure. The pressure gradient was high (the maximum was above 2.50g/cm^3), which indicates that the area belongs to high pressure and extreme high pressure category.

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Table 1: Clay Mineral Analysis of Formation E_{2-3a} by XRD Analysis

Depth (m)	Lithology	Clay Mineral Concentration (%)					
		K	I	C	I/S	S	Total
Outcropping rock	Gray claystone	8	23	8	61	45	70
2480-2550	Auburn pelitic siltstone	5	22	6	67	40	57
2850-2855	Auburn pelitic siltstone	2	28	2	68	40	39
2994-3005	Brown clayey sandstone	8	25	6	61	40	57
3040-3045	Brown sandy shale	2	32	2	64	40	37

Notes: K is kaolinite; I is illite; C is chlorite; S is smectite; I/S is illite and smectite mixed layer and Core sample taken from well H8A.

3) The broken nappe, high steep and weak bond between layers can easily cause borehole instability. Because of nappe extrusion and tectonic movement, many tectonics have faults with large dip Angle, broken faults, micro fracture. Many drilling accidents, such as lost of circulation, borehole collapse and drill pipe stuck are likely to happen.

4) The coexistence of high pressure and low pressure at the same well is easy to cause lost circulation. Due to the existence of unconformity plane, low pressure layer, and different pore pressure coefficient in the same well, lost circulation, blow out, borehole collapse, drill pipe stuck are very likely to happen. Accounting the inaccuracy in pore pressure prediction, drilling fluid design is extremely difficult.

2.2. Drilling Fluid Difficulties

A lot of studies in high density and ultra-high density drilling fluids have been conducted around the world, such as: Shengli oilfield [3], Tarim oilfield [4], and Sichuan oilfield [5] in China, the Baker Hughes Drilling Fluids Co. [6] and Saudi Aramco Co. [7]. The special difficulties for formation E_{2-3a} in southern edgeare:

1) Strong water sensitivity leads to sever dispersion of mudstone. The directly harm is shale hydration, which would cause borehole shrinkage, borehole collapse and difficulties in controlling the fluid rheological property. The drilling technology was the key to success; both physical and chemical inhibition must be taken into account in order to keep borehole stability.

2) High or extremely high density drilling fluids are needed for the high stress, and extremely high pressure. The solids in high and extremely high fluids made it difficult to control the fluid rheological property, loss control property, and other properties. Tectonic stress is large in the piedmont nappe fault fold belt, especially in the area of high stress concentration, the release of stress during drilling is very likely to cause drilling accidents, such as borehole collapse, tight hole and drilling pipe stuck. High density fluid is needed to stabilize the borehole because of the high stress, big dip angles and strong hydration. The drilling speed was extremely slow because of high fluid density, which extended the drilling cycle and the open whole time.

3) The broken nappe, high steep and weak bond between layers were easy to cause borehole instability. It's the main cause of drill pipe stuck and borehole problems in formation E_{2-3a}. The control and maintenance of high density drilling fluid [8] is difficult, which leads to high cost [9].

3. THE TECHNOLOGY OF HIGH DENSITY WATER-BASED DRILLING FLUID SYSTEM

In the past, organic salt drilling fluid system and potassium-calcium base polymer-sulfonates drilling fluid system (referred to as PRT in China) was mainly used in the southern edge. These two fluids have different advantages. PRT is good in rheological property, loss control property and other properties. But its inhibitory is relatively low, which is not suitable for the borehole stability purpose. Organic salt system has good inhibitory, but the rheological property is hard to control in high density fluid, which leads to reduction in drilling speed and sealing problems. In order to find a better system, we studied the drilling fluid used in the past. Organic salt in the PRT potassium calcium system is added to the fluid to improve inhibitory without changing the rheological property, filtrate loss control property.

3.1. The Drilling Fluid System

Through adding different materials and its dosage in the lab, the final drilling fluid system is:

Bentonite+ 0.1%FA367 (a polymer encapsulator)+ 0.02%XY-27 (a polymer thinner)+ 5%TX (a lignite fluid loss control agent)+ 1%KOH+ 2%RSTF (a prolective colloid fluid loss control agent)+ 10%PPL (a bitumoid fluid loss control agent)+ 0.5% LV-CMC (lower viscosity carboxymethyl cellulose) +10%KCL+ 1%Asphalt+ 0.3-0.5% CaO+ high quality barite to adjust its density to 2.50 ~ 2.60g/cm^3.

3.2. Property Evaluation

By using drilling fluid performance evaluation methods in reference [10], the properties of the new fluid is compared to the old properties of the fluids previously used in this area.

3.2.1. Inhibitory

The inhibitory of the old organic salt fluid system, PRT potassium calcium fluid system and PRT-Organic salt fluid system were tested; the results are shown in Table **2**.

From the Table **2**, it can be concluded that the cuttings recycle rate of organic salt fluid and PRT-Organic salt fluid are similar, which is significantly higher than the recycle rate of the PRT fluid. This indicates that the inhibility of the PRT-Organic salt fluid performs fairly well in inhibiting shale.

3.2.2. Sealing Property

The sealing property of the old organic salt fluid, PRT potassium calcium fluid and PRT-Organic salt fluid were tested; the results are shown in Table **3**.

The HTHP filtrate loss of the three fluids under the pressure of 3.5MPa and 5MPa at the same temperature. The results show that the HTHP filtrate loss of the PRT-organic salt fluid system is lower than the other two systems under these two conditions, which indicates that the HTHP filtrate loss property of the PRT-organic salt fluid is good.

3.2.3. Stain Resistance

The following additives: 5% salt, 2% CaOH, 8% bentonite, and 5% cement, were added in the PRT-organic salt fluid (replaced by M in Table **4**) to test its stain resistance, the result are shown in Table **4**.

Table 2: Inhibition Performance Comparison of Drilling Fluid System

System and used well	PRT in H001		Organic salt in H002		PRT-Organic salt	
Cuttings size (mesh)	40	6-10	40	6-10	40	6-10
Recycle (%)	74	61	89	86	89	87

Table 3: Sealing Performance Comparison of Drilling Fluid System

Pressure (MPa)	HTHP Filtrate Loss of PRT in H001 (ml)	HTHP Filtrate Loss of Organic Salt in H002 (ml)	HTHP Filtrate Loss of PRT-Organic Salt (ml)
3.5	8.6	14.0	8.4
5.0	7.1	14.6	5.6

Table 4: Stain Resistance Experiment of PRT-Organic Salt Drilling Fluid

Subjects	Density (g/cm^3)	FV (s)	AV (mPa·s)	PV (mPa·s)	YP (Pa)	GEL (Pa/Pa)	FL (ml)	HTHP (ml/mm)
M	2.6	80	92.5	72.0	20.5	9.0/17	2.1	7.2/2
M+5%Salt	2.6	81	92.5	72.0	20.5	10.0/18	2.3	8.0/2
M+2%CaOH	2.6	78	89.0	71.5	18.5	9.0/16	2.4	9.6/2
M+8%bentonite	2.6	90	101.0	76.0	25.0	12.0/23	1.5	5.2/2
M+5% cement	2.6	77	91.5	72.0	19.5	9.0/18	2.2	7.3/2

Notes: FV is funnel viscosity, AV is apparent viscosity, PV is plastic viscosity, YP is yield point, GEL is gel strength at 10 seconds and at 10 minutes, FL is API filtration and HTHP is filtration at high temperature and high pressure and thickness of the filter cake.

The results show that the properties of the high density PRT-organic salt fluid is stable after respectively adding 5% salt, 2% CaOH, 8% bentonite and 5% cement, which indicates that the high density PRT-organic salt fluid has good resistance to salt, CaOH, bentonite and cement.

The lab experiments show that the rheological property of the PRT-organic salt fluid is easy to adjust, its capacity to inhibit shale is improved and the property of stain resistance is also good; which indicated that the system could satisfy the drilling need in formation $E_{2\text{-}3a}$.

4. FIELD APPLICATION

4.1. Case Data

Well A5 is a preliminary exploration well in this area, its designed depth was 3850 m, and the drilling depth was 3950 m. When drilled to formation $E_{2\text{-}3a}$, because of its high pressure, strong dispersion, and easy to collapse features, the PRT-Organic salt drilling fluid was applied. During the drilling process, 25 swipe trips were conducted and all the trips were smooth, no sever torque occurred, the sand has good representativeness, cuttings are angular, which is the original shape. Geological survey to the bottom of the well finished at once, electronic logging showed it's a smooth borehole. There was no borehole enlargement and borehole collapse. The average rate of over cut was 3.2% and the maximun was 4.6%, the case in was finished smoothly. In the whole drilling process, the construction was safe and successful, no drill pipe stuck appeared during drilling and trip and the well bore quality was good.

4.2. Handle and Maintain

1) The formation of formation $E_{2\text{-}3a}$ has high stress and it is easy to collapse, shrinkage and contaminate the drilling fluid. Before entering formation $E_{2\text{-}3a}$, 1.3% TX lye and low density polymer glue was added, to obtain 25% organic salt, 10% KCL, 10% PPL, in the fluid. The FV is 50~55s and the HTHP is less than 5ml.

2) The rheology property of the high density fluid is maintained by using TX lye as the main additive and organic salt as supplementary additive.

3) In addition to its capacity to stabilize shale, the sealing and lubrication properties of the fluid is kept within the optimum window by adjust the HTHP filtrate loss and rheological properties.

4) Adjust the K^+ content in 38000~42000mg/l, Ca^{2+} content in 180~300mg/l, bentonite content in 22~29g/l.

5) Control the density of the fluid in reasonable range according to the operational requirements.

6) By adding PPL, RSTF and MFG to improve sealing property and make sure borehole stability based on the down hole situation.

7) Prepare for possible loss of circulation, which comes with the extreme high density fluid by preparing enough loss circulation material and reserving fluid.

8) Strengthen the solid control measure. Use 100~120 mesh to filter the fluid and reduce the harmful solid content.

9) To maintain to fluid property under extreme high density, it's better to get the fluid prepared in the ground and evenly add them into the fluid to keep the property stable.

10) By adding PPL, RSTF and asphalt to improve sealing property and make sure its HTHP filtrate loss less than 5ml and K ≤0.15g/l.

11) Strict fixed wall, short trip every drilling 50 ~ 100 meters a short trip.

4.3. Application Effect

The application of the PRT-Organic salt drilling fluid in Well A5 (2257~3056m) achieved good effect. Compare to the Well A6 drilling speed was improved by 22% and drilling cycle was shorten by 4 days of. The property comparison is shown in Table **5**.

Table 5: Drilling Index Comparison in 311.1mm of A5 and A6 Well

Well	Depth (m)	Section (m)	Drilling Speed (m/h)	Density (g/cm^3)	Cycle Time (d)
A5	2257~3056	799	1.44	2.26~2.50	51
A6	2463~3300	837	1.18	2.19~2.48	55

CONCLUSIONS

Through lab experiments and field applications, the following conclusions can be obtained:

1) The difficulties of the drilling in southern edge area include strong water sensitivity, high horizontal stress, high pressure in formation, unstable borehole, loss of circulation, fluids influx, borehole collapse, and drill pipe stuck. The average drilling speed is less than 3m/h, which could not satisfy the economical requirement.

2) The PRT-Organic salt drilling fluid with a set of mature processing technology could fit in and satisfy the drilling need of complex formation in southern edge. Although its formula is simple, maintenance is convenient and the cost is low.

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