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Research on deepwater synthetic drilling fluid and its low temperature rheological properties

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Abstract: With the rapid development of deepwater drilling operations, more and more complex technical challenges have to be faced due to the rigorous conditions encountered. One of these challenges is that the drilling fluid used must had good rheological properties at low temperatures and high ability to inhibit hydrate formation. Synthetic drilling fluid has been widely applied to deepwater drilling operations due to its high penetration rate, excellent rheological properties, good ability to prevent hydrate formation, and high biodegradability. A synthetic drilling fluid formulation was developed in our laboratory. The rheological properties of this drilling fluid at low temperatures (0-20 °C) were tested with a 6-speed viscometer and its ability to inhibit hydrate formation was evaluated at 20 MPa CH_4 gas and 0 °C by differential scanning calorimetry (DSC). Several factors influencing the low temperature rheological properties of this synthetic drilling fluid were studied in this paper. These included the viscosity of the base fluid, the amount of CEMU and organic clay, and the water volume fraction.

Key words: Deepwater drilling, synthetic drilling fluid, low temperature rheological properties, gas hydrate

1 Introduction

There are abundant oil and gas resources in deepwater areas, and deepwater oil and gas exploration has expanded greatly over the years. Drilling fluid plays a key role in all deepwater drilling operations, and its low temperature rheological properties and gas hydrate formation in the fluid brings severe challenge to deepwater drilling fluid technology. The temperature changes during deepwater drilling operations greatly influences the rheological properties of drilling fluids; especially it is difficult to control the yield point and viscosity of drilling fluids. This can initiate lost circulation, high equivalent circulating density (ECD), and increasing difficulty of pressure control (Cameron, 2000; Zamora et al, 2000; Herzhaft et al, 2001; Amanullah and Boyle, 2006; Korloo, 2007; Xu et al, 2008; Wang et al, 2009; Smith et al, 2010; Yue et al, 2011). Once formed in the deepwater drilling fluid, gas hydrates can plug the wellbore, annular space or blowout preventer, thus leading to accidents, extending the operation cycle, and increasing operation cost. Meanwhile, the decomposition of gas hydrates also brings about serious problems such as wellbore instability, lost circulation, and blowout. During deepwater drilling, the formation of gas hydrates is not only an economic issue but also more importantly a safety issue (Hu and Liu, 2008).

Synthetic drilling fluid is widely used in offshore oil and gas drilling due to its high penetration rate and high biodegradability. However, the apparent viscosity and yield point of conventional synthetic drilling fluid increases significantly with a decrease in temperature in deepwater drilling operations. It is difficult to control the pressure fluctuations associated with conventional synthetic drilling fluid and then downhole lost circulation often occurs during drilling, tripping drill pipe, running casing and cementing. Based on conventional synthetic drilling fluid, a new synthetic drilling fluid, which has constant rheological properties and is suitable for deepwater drilling, was developed by optimizing and modifying treatment agents. The difference between the newly-developed synthetic drilling fluid and conventional synthetic drilling fluid is that the newly-developed synthetic drilling fluid exhibits near constant rheological properties over a wide temperature range, i.e. some key rheological parameters of the new synthetic drilling fluid, such as the yield point, the 6 & 3 rpm readings were nearly independent of temperature and remained stable over a wide temperature range. The new synthetic drilling fluid overcomes technical problems met by conventional synthetic drilling fluid during deepwater drilling (Zevallos et al, 1996; Jenkins et al, 2003; Van Oort et al, 2004; Rojas et al, 2007; Vajargah et al, 2009; Gandleman et al, 2007; Geng et al, 2010).

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2 Properties of the synthetic drilling fluid for deepwater drilling

2.1 Optimization of basic formulation and basic properties

A synthetic drilling fluid formulation was developed in the laboratory for deepwater offshore drilling. This drilling fluid was formulated from linear alpha olefin ($CH_3(CH_2)_{12}CH{=}CH_2$) + $CaCl_2$ solution (concentration 20wt%) + 3% (wt/vol) CEMU (compound emulsifier containing calcium phytate and an amide surfactant) + 3% (wt/vol) organic clay + 3% (wt/vol) HiFLO (sulfonated asphalt, a filtrate reducer) + 2% (wt/vol) CaO + 30% (wt/vol) barite. In this formulation, the volume ratio of linear alpha olefin to $CaCl_2$ solution is 80:20. The organic clay was prepared by changing the inorganic cation of sodium bentonite with quaternary ammonium cation.

This synthetic drilling fluid was prepared as follows: CEMU was added in the linear alpha olefin under stirring at a rate of 8,000 r/min. After fully stirring the mixture, 20wt% $CaCl_2$ solution was added. After stirring for 10 min, the organic clay, HiFLO, and CaO were added. After continuously stirring for 10 min, barite was added to adjust the fluid density to 1.15 g/cm^3 and then the synthetic drilling fluid was stirred for 20 min. The rheological properties, filter loss, and electric stability of the synthetic drilling fluid were measured following the standard procedures (GB/T 16782-1997, China) and listed in Table 1. High temperature/high pressure (HTHP) filtration tests were performed at 100 °C and 3.5 MPa.

Table 1 The basic properties of the newly-developed synthetic drilling fluid for deepwater drilling

Experimental conditions	Density g/cm^3	Apparent viscosity mPa·s	Plastic viscosity mPa·s	Yield point Pa	Φ6/Φ3	Electric stability V	Gel strength 10″/10′ Pa	API filtrate mL/30min	HTHP filtrate mL/30min
Room temperature	1.15	31	23	8	5/4	589	2/4	0.4	–
After aging at 100 ºC for 16 h	1.15	34	28	6	4/3	676	1.5/4	0.4	3.0

2.2 Low-temperature rheological properties

The apparent viscosity and yield point of a drilling fluid increase significantly with a decrease in temperature, and finally gelling occurs. The rheological properties of the synthetic drilling fluid were measured at low temperatures (0, 4, 10, 15, 20 °C, respectively) with a viscometer and the experimental results are listed in Table 2. The results showed that the drilling fluid viscosity increased with a decrease in temperature when the temperature was lower than 20 °C, but the 6 & 3 rpm readings and the yield point of the drilling fluid were nearly independent of temperature.

Table 2 Rheological properties of the synthetic drilling fluid at low temperatures

Temperature, °C	Apparent viscosity, mPa·s	Plastic viscosity, mPa·s	Yield point, Pa	Φ6/Φ3
20	34	28	6	4/3
15	39	33	6	4/3
10	43	37	6	4/3
4	47	41	6	4/3
0	50.5	44	6.5	4/3

2.3 Inhibition of gas hydrate formation

Once gas hydrate forms in the drilling fluid, it can plug the wellbore, annulus, and blowout preventers, thus causing accidents, extending the operating cycle and increasing operation cost. Differential scanning calorimetry (DSC) is a rapid and sensitive technique, broadly used for the characterization of any kind of phase change. In this study, DSC was used to investigate whether gas hydrate had formed in the deepwater drilling fluid. This method was unaffected by the density, viscosity and the solids of drilling fluid. The main principle of DSC is: the gas hydrate releases heat during decomposition into gas (Wang et al, 2008). A HP-micro DSC VII was used to study whether gas hydrate forms in the synthetic drilling fluid at low temperature. In this experiment, CH_4 was used as the guest molecule for forming a gas hydrate. Detailed procedures were as follows: 1) 10 mg of the synthetic drilling fluid was added into a sample channel. 2) The pressure was increased to 20 MPa by injection CH_4 into the sample channel. 3) The synthetic drilling fluid was quickly cooled to 0 °C and kept for 5 hours. 4) Then the fluid was slowly heated to 20 °C at a constant rate of 0.5 °C/min. The process was tested whether there is an endothermic peak. Fig. 1 shows that no endothermic peak was observed in the heat flow curve of the synthetic drilling fluid during the temperature increase. This indicates that no gas hydrate formed in the synthetic drilling fluid at 20 MPa CH_4 and 0 °C.

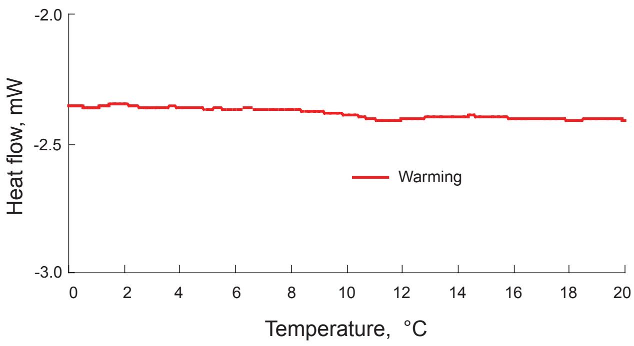

Fig. 1 Heat flow curve of the synthetic drilling fluid

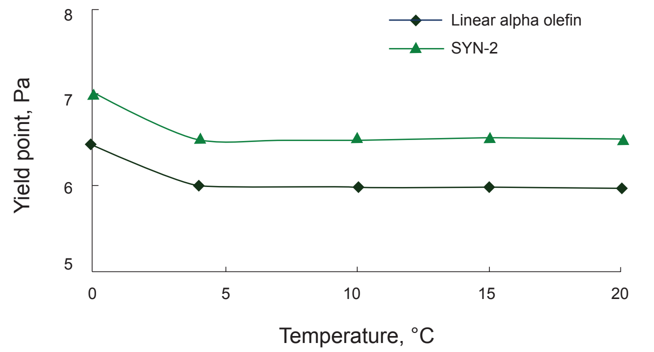

Fig. 3 The influence of the viscosity of the base fluid on the yield point-temperature curves of synthetic drilling fluids

3 Factors influencing the low temperature rheological properties of the drilling fluid

Factors governing rheological properties of the synthetic drilling fluid include the viscosity of the base fluid, emulsifier and organic clay contents, the volume ratio of continuous and dispersed phase (i.e. linear alpha olefin and water), the size and distribution of dispersed phase droplets, the characteristics and electric properties of interfacial film of emulsifier, the temperature and the pressure (Ghalambor et al, 2008). Based on the optimized deepwater synthetic drilling fluid formation, the influences of the viscosity of the base fluid, CEMU and organic clay contents, the water volume fraction on the rheological properties of the deepwater synthetic drilling fluid were investigated.

3.1 Effect of the viscosity of the base fluid

The linear alpha olefin and SYN-2 (a fatty acid ester, $CH_3(CH_2)_mCOO(CH_2)_nCH_3$) had a viscosity of 3.5 and 7 mPa·s respectively at 20 °C, but 5 and 12 mPa·s at 4 °C. According to the formulation of the synthetic drilling fluid, the linear alpha olefin and SYN-2 were selected as the base fluid for studying the rheological properties of synthetic drilling fluids at low temperatures, and experimental results were shown in Figs. 2 and 3. The apparent viscosity of the drilling fluid containing SYN-2 increased more significantly than that of the drilling fluid containing linear alpha olefin. The viscosity of the base fluid influenced the apparent viscosity of the drilling fluid at low temperatures. For both drilling fluids, the variations of the yield points of drilling fluids at low temperatures were basically identical; the viscosity of the base fluid had little effect on the low temperature yield point of the drilling fluid. A base fluid with a low viscosity was recommended for use in deepwater drilling (Burrows et al, 2001).

3.2 Effect of the addition amount of CEMU

Based on the optimized deepwater synthetic drilling fluid formulation, the influence of CEMU content on the low temperature rheological properties of drilling fluids was studied. The amounts of CEMU added in the drilling fluids were 3%, 4%, and 5%, respectively. The experimental results were shown in Figs. 4 and 5. With the content of CEMU increasing, the apparent viscosity and the yield point of the drilling fluid changed significantly with temperature when the content of CEMU was high (e.g. 5%). When the CEMU content in the drilling fluid was 3%, the curve of apparent viscosity-temperature was relatively flat, and the yield point basically remained stable. The CEMU content influenced the size and distribution of the dispersed phase droplets. With an increase in the CEMU content, the average particle size of the dispersed droplets decreased, thus the interaction between the interfacial area and dispersed droplets strengthened, and the interaction between the dispersed and continuous phases increased. The increase in the CEMU content of the drilling fluid was beneficial to forming an interfacial film of high mechanical strength. The interfacial film properties and dispersed phase particle size influenced the apparent viscosity and yield point of the synthetic drilling fluid at low temperatures.

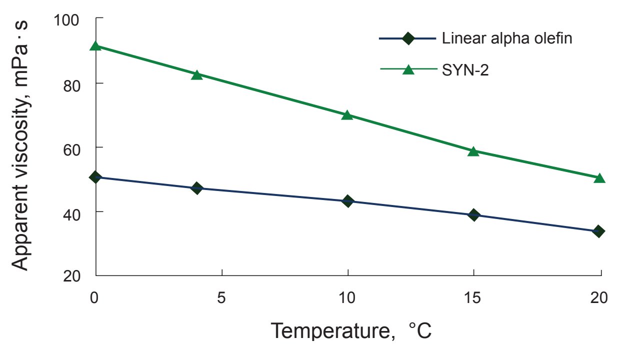

Fig. 2 The influence of the viscosity of the base fluid on the apparent viscosity-temperature curves of synthetic drilling fluids

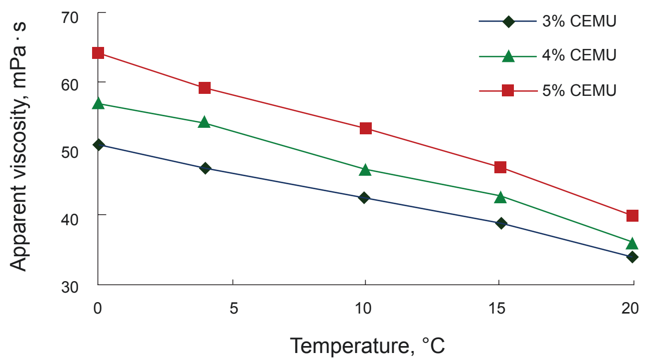

Fig. 4 The amount of CEMU influences the apparent viscosity-temperature curves of synthetic drilling fluids

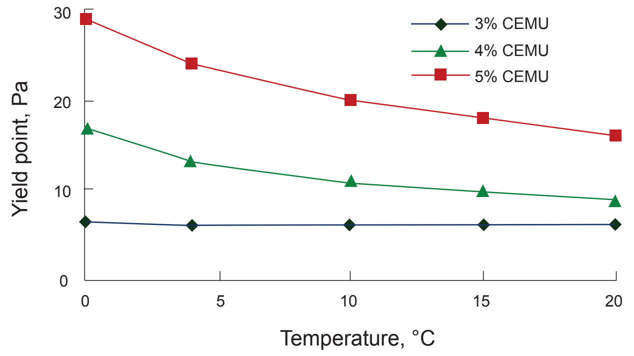

Fig. 5 The amount of CEMU influences the yield point-temperature curves of synthetic drilling fluids

3.3 Effect of the addition amount of organic clay

Figs. 6 and 7 show the influence of the content of organic clay on rheological properties of the synthetic drilling fluid at low temperatures. The amount of organic clay added was fixed at 3%, 4%, and 5%, respectively. Figs. 6 and 7 indicate that the apparent viscosity and the yield point of the drilling fluid changed significantly with temperature when the content of organic clay was high (e.g. 5%). There was some affinity between the organic clay and water drops, some micro water drops would be adsorbed on the surface of organic clay spontaneously and wetted part of clay. The interaction between organic clay and micro water drops increased with the amount of organic clay, especially at low temperatures. This was due to the formation of card-house structure between organic clay and water drops, which had higher structure strength at lower temperatures.

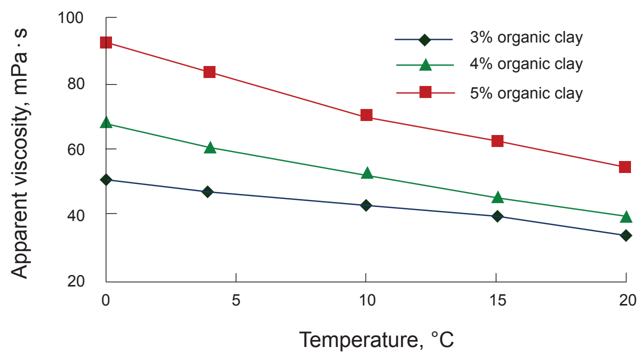

Fig. 6 The influence of organic clay on the apparent viscosity-temperature curves of synthetic drilling fluids

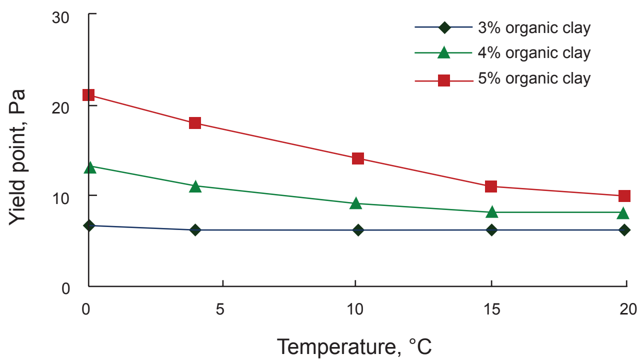

Fig. 7 The influence of organic clay on the yield point-temperature curves of synthetic drilling fluids

3.4 Effect of the water volume fraction

With the linear alpha olefin as the continuous phase and water as the dispersed phase, small water droplets are generated in the continuous phase (linear alpha olefin), therefore the water volume fraction also influences the low temperature rheological properties of the synthetic drilling fluid. Experimental results were shown in Figs. 8 and 9. In these experiments the water volume fraction was 20%, 30%, and 40%. The apparent viscosity and yield point of the drilling fluid changed significantly with temperature when the water volume fraction was high (e.g. 40%). With the volume fraction of water phase increasing in the drilling fluid, the number of dispersed droplets (i.e. water droplets) increased in the continuous phase, and then the distance between the water droplets decreased rapidly. Therefore, the interaction force among water droplets increased due to their collisions or relative sliding, leading to aggregation of water droplets and subsequent formation of complex structure aggregates. The increase in the water volume fraction increased the numbers of water droplets in the continuous phase and then their aggregation. The aggregation rate increased as the temperature decreased. With the volume fraction of water phase increasing, the water droplet content increased. The strength of card-house structure formed by the interaction of organic clay with water droplets increased. The structural strength was higher at lower temperatures.

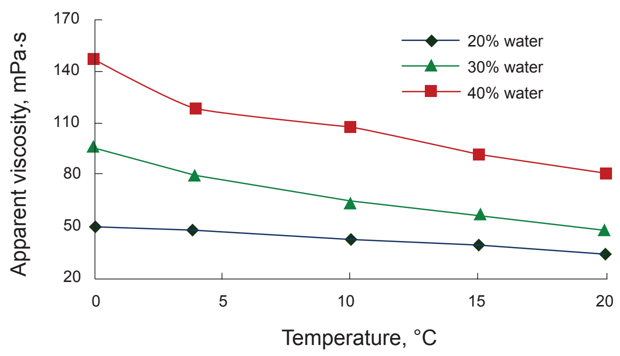

Fig. 8 The influence of water volume fraction on the apparent viscosity-temperature curves of synthetic drilling fluids

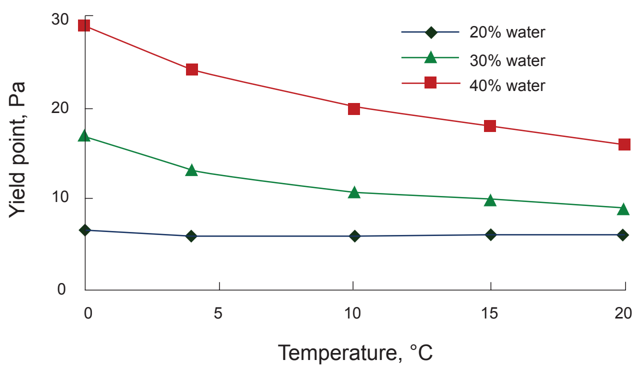

Fig. 9 The influence of water volume fraction on the yield point-temperature curves of synthetic drilling fluids

4 Conclusions

1) The optimized synthetic drilling fluid had excellent rheological properties at low temperatures and gas hydrate did not form in the drilling fluid at 20 MPa and 0 °C. This optimized synthetic drilling fluid could be applied to deepwater drilling.

2) The base fluid viscosity, the amounts of emulsifier and organic clay, and the water volume fraction influenced the low temperature rheological properties of the synthetic drilling fluid. Linear alpha olefin of low viscosity was used as the base fluid in the synthetic drilling fluid.

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