Development and evaluation of a high temperature and high salinity resistant rheological enhancer for water-based drilling fluids

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Introduction

With the rapidly growing of energy demand, oil and gas exploration and development is evolving to deeper formations. In the drilling of deep formations, complex geological conditions like high temperature and high salinity can reduce the rheological properties of drilling fluids, thus making it difficult for drilling fluids to carry clippings and suspended weighting materials, and even leading to serious accidents such as wellbore scrapping and stuck drilling. Therefore, rheology enhancers that can tolerate high temperature and high salinity are essential for deep oil and gas development. Existing rheology enhancers for water-based drilling fluids are typically high-molecular weight polymers, which improve rheological performance by enhancing the reticulation in the drilling fluid. However, the existing additives of drilling fluids have serious viscosity reduction under high temperature and high salinity conditions, resulting in an inability with deep formation drilling. Therefore, a high-performance rheology enhancer of water-based drilling fluid for deep formations is urgently needed to be developed.

In this paper, a rheology enhancer MAA with hydrophobic conjugation properties was developed. MAA imparts NaCl-promoted viscosity building properties to the drilling fluid, significantly improving the stability of drilling fluid under extreme conditions.. The development of this additive can provide effective technical support for deep drilling fluids.

Experimental

Materials

Acrylamide (AM, AR), Sodium p-styrene sulfonate (SSS, 90%), Sodium dodecyl sulfate(SDS, GC), and Lauryl methacrylate(LMA, GC) were purchased from Aladin Reagent Co., Ltd. Maleic anhydride(MA, AR), Na_2CO_3(AR), NaOH (AR, and prepared as 35% solution), NaCl (AR) and Ammonium persulfate (AR) was supplied by Sinopharm Group Chemical Reagent Co., Ltd. Carboxymethylcellulose sodium(CMC) and poly anioniccellulose(PAC) were purchased from Hebei Renqiu Gaoke Chemical Co., Ltd. Driscal D, a polymer additive, was purchased from Chevron Philips Chemical Company LLC. Bentonite was bought from Huai'an County Tengfei Bentonite. Development Co., Ltd. Disperse 40g of bentonite into 1000ml of water, add 1.4g of Na_2CO_3, and stir the dispersion system at high speed for 24h to produce the water-based drilling fluid (WBDF).

Preparation method of polymer MAA

Dissolve 0.5g SDS into water, then add AM, SSS, MA and LMA (mass ratio 10.7:5.5:1.9:1.9) in sequence, and adjust the pH with NaOH. The solution was transferred to a three-necked flask, stirred at a constant speed and heated to Reaction temperature in a water bath. After half an hour, add the ammonium persulfate, and react at a constant temperature under the protection of N_2 for 5 h. The synthesis product was washed with acetone 3 times, dried at 85 ℃ and the grinded white solid powder was the target polymer. The optimal polymer optimized by orthogonal experiment was named MMA.

Orthogonal experiment

The synthesis conditions of the polymer were further optimized by orthogonal experiments. The polymer was added to WBDF with 36 wt% NaCl (Methods as in section 2.5), and its apparent viscosity (AV) was measured by Six-speed rotational viscometer after hot-rolling at 200℃ for 16 h. This AV was used as an evaluation index. The orthogonal experiment of three-level and four-factor design is shown in Table 1.

Polymer MAA characterization

The MAA structure was characterized by FT-IR (IRTracer-100, Shimadzu Switzerland) with the scanning resolution of 4 cm^{-1}.

The microscopic appearance was measured by TEMTEM (Tecnai G2 F20, America) at 1000nm.

MAA Property Evaluation

The MAA was added to WBDF, stirred it for 20 min at high speed and then added NaCl for another 20 min. Then the drilling fluid was loaded into the aging tank and hot-rolling in a roller oven at the set temperature for 16 h. The properties of the drilling fluid were measured at room temperature (25 ℃) according to API standards after hot-rolling.

Results

Table 1. Design of orthogonal experiments table

Factors	Concentration of reactants(%)	Reaction temperature (℃)	pH	Dosage of initiator(%)
1	20	50	5	0.25
2	30	60	7	0.5
3	40	70	9	0.75

Table 2. Orthogonal Experiment Results of MAA

Sample	A Concentration of reactants (%)	B Reaction temperature (℃)	C pH	D Dosage of initiator (%)	Apparent viscosity (mPa·s)
1	20	50	5	0.25	17.5
2	20	60	7	0.50	30.0
3	20	70	9	0.75	26.5
4	30	50	7	0.75	19.5
5	30	60	9	0.25	27.0
6	30	70	5	0.50	21.5
7	40	50	9	0.50	20.5
8	40	60	5	0.75	26.0
9	40	70	7	0.25	29.5
K1	74.0	57.5	65.0	74.0	
K2	68.0	83.0	79.0	72.0	
K3	76.0	77.5	74.0	72.0	
R	8.0	25.5	14.0	2.0	

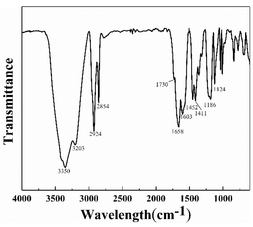

Figure 1. FTIR spectrum of MAA

The IR spectra analysis showed that all the target functional groups were present in MAA and the absence of double bonds proved that all monomers were fully reacted.

The results of the orthogonal experiment were shown in Table 2. All measurement errors were less than 0.5 mPas. The temperature of synthesis has the greatest influence on the product properties, followed by the pH and concentration of the reactants and the mass fraction of initiator has less influence on the product properties. The optimal synthesis conditions of MAA are: the concentration of reactants is 40%, the temperature is 60°C, the pH is 7, and the mass fraction of initiator is 0.25%. The MAA used in the subsequent measurements were prepared according to the optimal synthesis method.

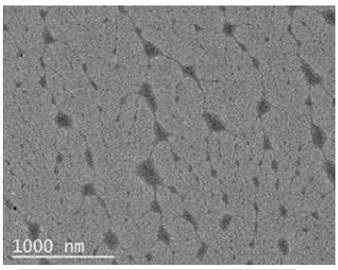

Figure 2. The morphology of MAA

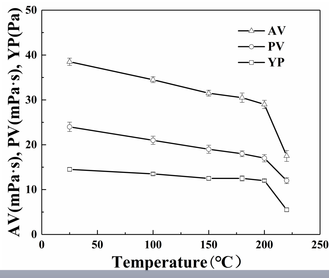

Figure 3. Rheological properties of MAA-WBDFs with temperature

The morphology of MAA in solution was shown in Figure 2. The fact that it can form an associative structure indicates the success of the synthesis. The formation of the hydrophobic association structure can give MAA well enhanced rheological and salt resistance properties.

At 25℃, the AV of MAA-WBDF containing 30% NaCl was 38.5 mPa·s. As the hot-rolling temperature increases, the AV, plastic viscosity (PV) and yield point (YP) of MAA-WBDF gradually decrease. The MAA still has a high apparent viscosity of 29.0 mPa·s under 200℃. When the hot-rolling temperature is higher than 200℃, its rheological properties decrease significantly, indicating that the temperature resistance of MAA in drilling fluids with 30% NaCl is 200℃.

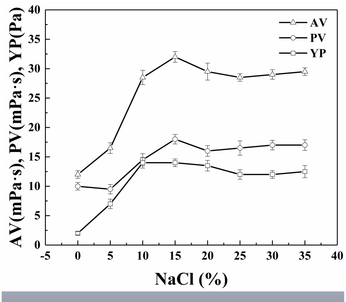

Figure 4. Rheological properties of MAA-WBDFs with NaCl

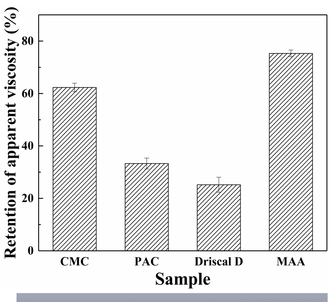

Figure 5. Apparent Viscosity Retention of Drilling Fluid

MAA-WBDFs have NaCl enhanced rheological properties, which are different from many drilling fluids. The viscosity and yield force of MAA-WBDF gradually increased with the increase of NaCl and reached the extreme value at the concentration of 15%. This is due to the fact that MAA can form hydrophobic association structures, and NaCl can further promote the association of MAA, resulting in an increase in the viscosity of MAA-WBDF with increasing NaCl concentration. With the further increase of NaCl concentration, the rheological properties of MAA-WBDF remained almost constant.

Table 3. FTIR spectrum of MAA

Sample	Before hot-rolling			After hot-rolling		
	AV	PV	YP	AV	PV	YP
CMC	30.5±1.32	25.0±0.71	5.5±0.82	19.0±0.00	8.0±0.00	11.0±0.00
PAC	60.0±1.63	42.0±1.22	18.0±1.04	20.0±0.28	9.0±0.00	11.5±0.28
Driscal D	51.5±2.45	27.0±1.32	24.5±0.91	13.0±0.82	11.0±0.41	2.0±0.00
MAA	38.5±0.82	24.0±0.65	14.5±0.51	29.0±0.41	17.0±0.41	12.0±0.00

Among the four additives with the same dosage in the drilling fluid with 30% NaCl, MAA-WBDF showed the best rheological performance after hot-rolling, and its viscosity changed minimally before and after hot-rolling as shown in figure5. This indicates that MAA has excellent viscosity building ability under high temperature and high salinity conditions.

Conclusions

(1) The unique high temperature resistant structure and hydrophobic association groups of polymer MAA give it high temperature and salt resistance in drilling fluids. At hot-rolling conditions of 200°C and 30% NaCl, the apparent viscosity of the MAA-WBDF was as high as 29.0mPas and had a 75.3% viscosity retention. MAA was substantially better than CMC, PAC and Driscal D in terms of temperature and salt resistance.

(2) MAA-WBDF has the property of NaCl-promoted viscosity enhancement, which is due to the unique hydrophobic association structure of MAA, and the increased NaCl content promotes the association to achieve viscosity enhancement.

(3) The study in this paper still has some limitations. Due to the limitations of experimental conditions, the MMA drilling fluid was measured at room temperature after hot-rolling. In the following, special experimental equipment will be designed to study the performance and mechanism of action of MMA under high temperature and high salt conditions. At the same time, the compatibility of MMA with various additives in drilling fluids will be investigated.