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Investigation of synthesized polymer on the rheological and filtration performance of water-based drilling fluid system

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ABSTRACT

Based on the molecular structure requirement of the synthesized polymer resistant to higher temperature and the lower cost demand of water-based drilling fluid system, a kind of synthesized polymer Poly(SSS/AM/AMPS) was prepared by using 2-acrylamido-2-methylpropanesulfonic acid (AMPS), acrylamide (AM) and sodium *p*-styrenesulfonate (SSS) through inverse emulsion polymerization. Firstly, the molecular structure, molecular weight distribution and thermal stability were studied. Secondly, the Poly(SSS/AM/AMPS) was introduced into water-based drilling fluid system. As a result, when adding amount is 1.2 wt%, it was found that the water drilling fluids is more fitted to the Herschel - Bulkley flow model. Besides, before and after thermal aging test, the FL_{API} of drilling fluid system is 9.20 and 9.40 mL, respectively. Moreover, it was shown that the higher temperature resistance of drilling fluid system was also improved, and the operation cost was decreased. Furthermore, the results of adsorption analysis, zeta potential method and morphology analysis shows that Poly(SSS/AM/AMPS) improves the filtration properties of drilling fluid system by absorption and physical plugging.

1. Introduction

Drilling fluid system plays an extremely significant role in oil and gas drilling operation, such as suspending cutting from sedimentation and carrying cutting from the down-hole to surface, stabilizing well-bore and avoiding formation collapse (Li et al., 2015; Bailey et al., 1994; Kosynkin et al., 2011). Commonly, the excellent rheological and filtration properties are helpful to improve drilling quality and reduce drilling time (Yang et al., 2017; Fazelabdolabadi et al., 2015). Fluids invasion into porous formation can damage reservoirs and reduce productivity by blocking hydrocarbon exit flow paths or causing formation collapse. The loss of drilling fluids into porous formation could be retarded by fluid loss control additives through forming a dense layer of cake (Kosynkin et al., 2011). Moreover, the role of drilling fluid is to pass through formations with high porosity while keeping all its rheological properties and without causing damage to the crossed formations, which is desirable in drilling operation (Hamed and Belhadri, 2009). Besides, the similar formulations were studied for high temperature zone or permeability reservoirs (Zami-Pierre et al., 2016). Namely, for a high performance drilling fluids system, the rheological properties, such as shear-thinning behavior, apparent viscosity and yield-stress, are required to meet the standard of American Petroleum institute (API). Nowadays, some natural and synthetic polymers were introduced into drilling fluid system to improve rheological and filtration properties. Currently, some natural polymers, such as cellulose, guar, guargum, xanthan gum, polyacrylate and maleic anhydride derivative were used in water-based drilling fluids system. But, there are still many problems with natural polymers when used in drilling fluid system, such as poor thermal stability, poor salt resistance and higher construction costs (Safi et al., 2016; Jha et al., 2016). Thus, the synthetic polymer has received much attention attribute to their significant advantages in biodegradability, stability, water solubility and economical efficiency (Ma et al., 2017).

Simultaneously, it was confirmed that there are many problems with traditional synthetic polymer used in water-based drilling fluid system, such as high operation cost, poor stability, high reactive and corrosive (Wan et al., 2011; Khalil and Mohamed, 2012). Moreover, for high temperature drilling operation, the traditionally synthesized polymers are easy to decompose, consequently, the rheological and filtration performance of drilling fluid system was changed (Jiang et al., 2011; Ghasemi et al., 2017; Ghanbari et al., 2016; Wang et al., 2012). Namely, the traditionally synthesized polymers are usually used when the temperature is less than 150 °C (Ma et al., 2017; Zhong et al., 2016). Thus, it is necessary to develop a higher temperature resistance and lower cost polymer to meet the requirements of drilling operation.

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For non-Newtonian fluids, many mathematical models have been developed and used to fit the relationship between shear stress and shear rate. A large number of reports show that the Bingham, Power-law and Herschel-Bulkey models were commonly used in drilling fluid system (Dargahi-Zaboli et al., 2017). However, for a complex drilling fluid system, it was found that the Bingham plastic model is inadequate attribute to the relationship (shear stress and shear rate) is no longer linear. Moreover, it was also found that the Power-law model is not accurate to fit the rheological curves attribute to lack of yield point, especially at the low shear rates. Therefore, the Herschel-Bulkey model was developed and employed (Dargahi-Zaboli et al., 2017).

A large number of literature reports show that the rigidity of the molecular chain is enhanced by the large side chain groups in 2-acrylamido-2-methylpropanesulfonic acid (AMPS) molecules, and the temperature resistance and solubility of oil field chemical reagents were improved by using AMPS. Besides, the structure of benzene ring has good thermal stability, the sulfonate groups of sodium *p*-styrenesulfonate (SSS) have strong hydration property, thus, the temperature resistance of polymer was improved. Moreover, as the raw material of common oil field chemical reagents, the production process of acrylamide (AM) is mature and the price is relatively cheap. Besides, as a nonionic group, the ugline group can not only be adsorbed by the ammonia bond and clay particles, but also have a strong hydration ability (Wan et al., 2011; Khalil and Mohamed, 2012; Zhong et al., 2016). Commonly, the synthesized polymer has a large molecular weight and narrow distribution, besides, the dissolution rate of polymer is faster than that of the conventional polymer. Thus, the inverse emulsion polymerization was used in our currently study. Therefore, during this study, based on the higher temperature resistance and lower cost requirements, a novel kind of polymer, namely, Poly(SSS/AM/AMPS) was synthesized by using AMPS, AM and SSS through inverse emulsion polymerization. Moreover, the molecular structure of Poly(SSS/AM/AMPS) was investigated by FT-IR, ^{1}H-NMR and element analysis. Simultaneously, the molecular weight distribution and thermal stability of Poly(SSS/AM/AMPS) were measured by gel chromatography experiment and TG method. Then, Poly(SSS/AM/AMPS) was introduced into water-based drilling fluid system to improve the rheological and filtration properties. Besides, the filtration mechanism of Poly(SSS/AM/AMPS) was investigated through adsorption analysis, Zeta potential and morphology analysis.

2. Experiment section

2.1. Materials

During this study, the materials were used mainly include span 80, acrylamide, tween 80, 2-acrylamido-2-methylpropanesulfonic acid, sodium hydroxide and sodium carbonate, sodium p-styrenesulfonate, and the above materials are analytical grade. Ethanol, acetone, white oil, the above materials are industrial goods. All reagents were purchased from Chengdu Kelong Chemical Co., Ltd (Chengdu, China). Sulfonsted bitumen (FT-1), sulfonated phenolic resin SMP-II and sulfonated lignite (SMC) were purchased from Karamay oil field, Jinxin Environmental Protection Co., Ltd. (Xinjiang, China). Fresh water and deionized water were prepared in own laboratory.

2.2. Methods

2.2.1. Preparation of inverse emulsion

Different Span 80 and Tween 80 concentration inverse emulsions were prepared firstly. The experimental procedures are as follows: A certain volume of white mineral oil was measured and heated in the water bath (50 °C). Simultaneously, a certain amount of emulsifier was added into above solution and mixed by using a digital high-speed stirring apparatus (ZNJ-2, Qingdao Tongchun Oil Instrument CO.,China.) at 10 000 r/min for 30 min. Then, a certain volume of water was slowly added into the above mixed system, the inverse emulsion was obtained after high speed mixed at 10 000r/min for 60 min. It is worth mentioning here that the emulsion type was tested by dilution method. As a result, it was confirmed that the prepared emulsion type meets the expected design.

Secondly, the stability of inverse emulsion sample was measured by using a low field nuclear magnetic resonance analysis and measurement technology (low field NMR). The transverse relaxation time T_2 measurements are often accomplished using well CPMG radio-frequency pulse sequence, and the advantage of CPMG sequence as compared with other spin echo techniques is that it allows rapid multiple accumulations of the echo train signal-an important issue in increasing the detection sensitivity at low-fields. Generally, the degree of freedom of water was reflected by T_2 value, besides, the interaction between different water phases, and the influences of ion concentration, polymer state and pore structure on water were also reflected by T_2 value. Because the emulsion droplets consists of water and oil, and the water is covered by the oil phase, consequently, the water was restricted to emulsion droplets of different size. Therefore, the stability of inverse emulsion could be investigated by T_2 value. Firstly, the T_2 values of white mineral oil and water were measured before testing. As a result, it was found that the T_2 distribution curve of white mineral oil located in 32.96–160.0 ms, and the T_2 distribution curve of pure water located in 1629.0–10000.0 ms, which as shown in Fig. 1. Moreover, when the emulsifier (Span 80 and Tween 80) adding amount is 8.5 wt% and the oil to water ratio is 6:4, because the Emulsion 2# has a smaller T_2 value, thus, it was confirmed that the inverse emulsion system has excellent stability, which as shown in Fig. 2 (1# = 5:5 + 8.5 wt%, 2# = 6:4 + 8.5 wt%, 3# = 6:4 + 9.0 wt%). Besides, the influences of temperature and stir on the stability of inverse emulsion were studied (Fig. 3). Here, Emulsion 1# is the inverse emulsion without any treatment, and Emulsion 2# is the inverse emulsion was stirred at 170 s^{-1} and 80 °C for 8 h.

Fig. 3 shows the T_2 distribution curve of inverse emulsion system. As a result, it was found that the T_2 distribution curve emulsion 1# and 2# is very similar, and three relaxation time peaks was observed in T_2 distribution curve. The larger peak, T_{22}, is caused by the inverse emulsion droplet, and the right one, T_{23}, is produced by the free water in inverse emulsion system. Because the relative volume fraction of the different water phases could be estimated by the area, obviously, as shown in Fig. 3, the content of free water in emulsion system is relatively small. Therefore, the inverse emulsion system has excellent stability. Besides, the stability could be also confirmed by the photograph of inverse emulsion. Moreover, the investigations of the influences of pH value and salt on the stability of inverse emulsion system would be studied lately.

2.2.2. Synthesis of Poly(SSS/AM/AMPS)

During this study, the ammonium persulfate (APS) was used as

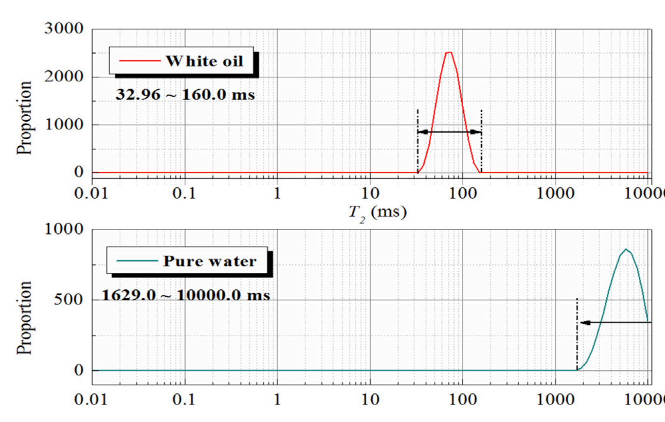

Fig. 1. The T_2 distribution curve of white oil and pure water.