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Research paper

Rheological and filtration properties of clay-polymer systems: Impact of polymer structure

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ABSTRACT

In this study, the effect of polymer structure, the degree of hydrolysis, chemical structure of monomer in the backbone, and charge distribution of monomer groups on rheological and filtration properties of Bentonite (Bent)/polymer dispersions were assessed. Two different water-soluble polymers were employed to investigate the rheological and filtration properties of Bent/polymer dispersions. The polymers evaluated are a copolymer of acrylamide and 2-acrylamido-2-methylpropane sulfonic acid (AM-AMPS) (P1) and a terpolymer of acrylamide, 2-acrylamido-2-methylpropane sulfonic acid, and N-Vinylpyrrolidone (AM-AMPS-NVP) (P2). The objective of this work was to study the rheological and filtration properties of Bent/polymer dispersions in deionized and salt water at different temperatures (25 °C and 85 °C). The steady shear rheological data was fitted to Herschel-Bulkley model to compute rheological parameters like yield stress, consistency index, and flow behavior index. The incorporation of polymers in Bent dispersions improved the rheological properties of the Bent dispersions. Addition of electrolyte in Bent/polymer dispersions led to a slight decrease in the rheological properties of all developed dispersions. The Bent/P2 dispersion revealed superior rheological properties compared to the other Bent and Bent/polymer dispersions in both deionized and salt water. TEM analysis of Bent/polymer dispersions was carried out to study the morphology of dispersions. LP/LT and HP/HT filtration experiments were performed in deionized and salt water at 25 °C and 85 °C, respectively, and results showed that Bent/P2 dispersion had minimum filtrate volume and filter cake thickness compared to the Bent dispersion. The permeability of filter cakes was determined using Darcy's law and filter cake morphologies were studied using SEM analysis. The excellent rheological and filtration properties of Bent/P2 dispersion was attributed to the presence of NVP monomer group in P2 polymer, which is stable towards elevated temperatures and high salinity environments. The exceptional filtration and rheological properties of P2 polymer make it a suitable candidate for the development of high-performance drilling fluids.

1. Introduction

Drilling fluids are designed to carry out a wide range of functions such as to transport rock cuttings to the surface, to reduce the formation damage, to cool and lubricate the drilling equipment, to maintain wellbore stability, to control formation pressure and to minimize fluid loss and lost circulations (Reilly et al., 2016; Sadeghalvaad and Sabbaghi, 2015; Song et al., 2016). There are several types of drilling fluids such as water-based drilling fluids, oil-based drilling fluids, pneumatic drilling fluids and synthetic-based drilling fluids (Iscan and Kok, 2007; Luo et al., 2017). Careful selection of drilling fluid is essential to avoid several problems like wellbore instability, formation damage, drag and torque reduction (Abdo and Haneef, 2013). Water-based drilling fluids are widely recommended due to excellent shale inhibition capacity, easy preparation, environmentally friendly, and remarkable rheological properties (Aftab et al., 2017; Li et al., 2015a). To perform successful drilling operations, the selection and quantity of drilling fluid additives are very important to achieve the desired fluid properties (Al-Zubaidi et al., 2016). Bent is one of the essential constituents of water-based drilling fluids which controls the viscosity and fluid loss of drilling fluids (Agwu et al., 2015; Benslimane et al., 2016; Omole et al., 2013). The high contents of Bent in water-based drilling fluids can have detrimental effects on drilling operations which include the reduction of drill bit penetration rate, thick filter cake, differential pipe sticking and formation damage (Gatlin, 1960; Jilani et al., 2002). Furthermore, harsh temperature environment at bottom hole severely affects rheology and filtration properties of Bent dispersions. The best rheological and filtration characteristics were observed, when Bent

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particles are present in dispersed and deflocculated state in Bent dispersions. The higher temperature at the bottom hole leads to the aggregation (flocculation) and thermal induce swelling of Bent particles in dispersions which could be avoided with various additives such as synthetic polymers, thinners such as starch, polysaccharides and cellulose (Abdo et al., 2014; Kelessidis et al., 2007a; Vryzas et al., 2017).

The incorporation of organic additives (polymers) in water-based drilling fluids has significant industrial importance to compensate for Bent deficiencies and to modify the fluid filtration and rheological properties (Kafashi et al., 2017). Polymers in water-based drilling fluids can perform various functions such as shale inhibition, as viscosifiers, as Bent extenders and fluid loss control agents (Jain et al., 2015a; Lal, 1999; Ma et al., 2017). The interactions between Bent platelets and polymer molecules are very important which significantly affect the properties of Bent/polymer dispersions. It is well known that when polymers added to clay dispersion, the interaction among clay platelets and polymers results in the adsorption of polymer chains on the surface of clay particles (Rossi et al., 1997). This interaction among clay platelets and polymers depends on polymer structure, the chemical structure of monomer in the backbone, charge distribution in monomer groups and their distribution along the polymer chains (M'bodj et al., 2004). The polymer in Bent dispersion will adsorb on Bent platelets results in enhanced rheological properties and the adsorption of polymer on clay platelets also prevents the clay platelets to form aggregates at elevated temperature. The adsorption of polymer on the inner walls of the wellbore via interionic interaction form a thin layer and prevent the invasion of drilling fluid into the formations. The adsorption of polymer on clay significantly reduced the fluid loss of drilling fluids. (Luckham and Rossi, 1999; M'bodj et al., 2004).

Recently various polymers (natural and synthetic) have been employed to tailor the rheological and filtration properties of drilling fluids. Different polymers were added into water-based drilling fluids such as polyanionic cellulose (PAC) (Kelessidis et al., 2013), sodium carboxymethyl cellulose and xanthan gum to obtain the desired filtration and rheological properties (Benchabane and Bekkour, 2006). (Song et al., 2016) used novel cellulose based biopolymer with water-based Bent mud to improve rheological properties (gel strength, yield point, and viscosity), to minimize the formation damage and reduce the fluid loss into the formations. The enhanced rheological properties were attributed to the formation of strong hydrogen bonding network in the drilling fluid which also reduced the fluid loss and enhanced the pore connectivity in the filter cake to minimize the formation damage. (Kelessidis et al., 2013) studied the effect of PHPA polymer on rheological and fluid loss properties. He studied various concentrations of PHPA polymer with Bent base mud and found that increasing concentration of PHPA exponentially increases the yield stress of bentonite dispersions. SEM analysis of filter cakes showed that PHPA polymer covers the bentonite particles and significantly reduced the fluid loss. (Zhao et al., 2016) studied the effect of inorganic cations on viscosity polyacrylamide/xanthan gum solution for drilling fluids. He found that, crosslinking among polyacrylamide and xanthan gum enhanced the resistance towards the inorganic cations. The presence of high concentration of inorganic cations severely affects the viscosity and drilled cutting lifting capacity (Temraz and Hassanien, 2016). Many other polymers such as cellulose (Li et al., 2015b), partially hydrolyzed polyacrylamide (PHPA) (Lam et al., 2015), polyacrylamide (PAM), hydrolyzed polyacrylamide (HPAM) (Xin et al., 2007), polyanionic cellulose, starch (Kafashi et al., 2017), and carboxymethyl cellulose (CMC) (Yang et al., 2009) were used to enhance the rheological properties, minimize the fluid loss of drilling fluid into the formation and to control the filter cake characteristics using water-based Bent drilling fluids.

The natural and low molecular weight synthetic polymers degraded at bottom-hole high pressure and high temperature environment which results in high fluid loss in to the formation and low rheological properties (Allahvirdizadeh et al., 2016; Boul et al., 2017). In this study, two different anionic polymers (copolymer and terpolymer) were employed as water-based drilling fluid additive. The copolymer contains two monomers which include acrylamide and 2-acrylamido-2-methylpropane sulfonic acid. The copolymer structure has thermal stability up to 95 °C and can bear high salinity environment. The terpolymer contains three monomers which include acrylamide, 2-acrylamido-2-methylpropane sulfonic acid, and N-Vinylpyrrolidone. Terpolymer has additional N-Vinylpyrrolidone monomer which has high thermal stability up to 120 °C and can bear harsh salinity environment (Kamal et al., 2015).

In this work, two different polymers were studied as a potential additive for water-based drilling fluids containing monomers which were stable at elevated temperature and high salinity. The effect of different polymers, the chemical structure of monomer in backbone and charge distribution in monomer groups on the filtration and rheological properties were investigated. The rheological properties of polymer solutions, Bent, and Bent/polymer dispersions were studied in deionized and salt water at 25 °C and 85 °C from ($0\ s^{-1}$) to ($1000\ s^{-1}$) shear rate. The rheological properties such as yield stress, consistency index, and flow behavior index were determined by fitting steady shear rheology experimental data to the Herschel-Bulkley model to study the non-Newtonian behavior. TEM analysis of Bent/polymer dispersions was performed to study the morphology of Bent/polymer dispersions. The filtration properties of Bent and Bent/polymer dispersions were measured at 25 °C using standard API filter press apparatus. HP/HT filtration characteristics were determined at 85 °C temperature and 200 psi pressure. The fluid loss characteristics of all the formulations in deionized and salt water were compared. Permeability analysis of filter cakes was carried out for LP/LT and HP/HT filtration characteristics using Darcy's law of permeability. SEM images of filter cakes were taken to study the morphology of filter cakes.

2. Experimental

2.1. Materials

Bentonite was acquired from BDH chemicals (UK) in powder form having a density of 2.5 g/cm^3 at 20 °C, pH ranges from 9.5–10.5 and pale brown in color. XRF analysis of Bent was carried out to determine the chemical composition and results showed that the main components are SiO_2 (59.7%), Al_2O_3 (22.35%), Fe_2O_3 (5.5%), Na_2O (2.23%), CaO (2.55%), K_2O (1.31%), MgO (2.77%), P_2O_5 (0.55%) and TiO_2 (0.31%). The x-ray diffraction analysis of Bent was performed using D8 DISCOVER instrument usually used for powder and thin film applications. Copper tube anode was employed as a source with 30 mA generators current to produce the wavelength of 1.54 Å. The x-ray spectrum of Bent is presented in Fig. 1. Sodium chloride (S) was obtained from SIGMA-ALDRICH in powder form with purity of > 99%, as per vendor specifications. Two different polymers having molecular weights 9 million (g/mol) were purchased from SNF FLOERGER. The first polymer P1 is a copolymer of acrylamide (AM) and 2-acrylamido-2-methylpropane sulfonic acid (AMPS). The second polymer P2 is a terpolymer of acrylamide (AM), 2-acrylamido-2-methylpropane sulfonic acid (AMPS) and N-Vinylpyrrolidone (NVP).

2.2. Preparation of drilling fluid formulations

In the group I, polymer solutions were prepared in deionized water and 0.1 M salt water having 0.25 wt% polymer concentration with magnetic stirring at 200 rpm. Magnetic stirring on each polymer solution was applied for 2 h for complete dissolution of polymer and followed by 2 h hydration time for complete homogenization of polymers in deionized water. In the group II, 5 wt% Bent dispersions were prepared in deionized water and 0.1 M salt water using mechanical stirrer for 1 h at 1500 rpm and left undisturbed for 24 h for the hydration of Bent according to API standard (API recommended Practice 13B-1,