Journal of Molecular Liquids 252 (2018) 133–143

Contents lists available at ScienceDirect

Journal of Molecular Liquids

journal homepage: www.elsevier.com/locate/molliq

High molecular weight copolymers as rheology modifier and fluid loss additive for water-based drilling fluids

Hafiz Mudaser Ahmad [a], Muhammad Shahzad Kamal [b], Mamdouh A. Al-Harthi [a,*]

[a] Department of Chemical Engineering, King Fahd University of Petroleum and Minerals, 31261 Dhahran, Saudi Arabia
[b] Center for Integrative Petroleum Research (CIPR), King Fahd University of Petroleum & Minerals, 31261 Dhahran, Saudi Arabia

ARTICLE INFO

Article history:
Received 20 August 2017
Received in revised form 9 December 2017
Accepted 23 December 2017
Available online 27 December 2017

Keywords:
Drilling fluids
High molecular weight polymers
Bentonite
Filtration
Rheological properties

ABSTRACT

In this work, the impact of molecular structure such as the degree of hydrolysis (DOH) and nature of comonomers in acrylamide-based copolymers on the rheological and filtration properties of bentonite dispersions was assessed using three different water-soluble polymers for water-based drilling fluids. These polymers are (1) copolymer of acrylamide and 2-acrylamido-2-methylpropane sulfonic acid (AMPS) with 10% DOH (P1), (2) copolymer of acrylamide and 2-acrylamido-2-methylpropane sulfonic acid (P2) with 25% DOH, and (3) copolymer of acrylamide and acrylic acid (P3) with 15% DOH. Steady shear rheology data was fitted to the Herschel-Bulkley model and flowability test was performed at 25 °C and 85 °C. Aging of bentonite and bentonite/polymer dispersions was performed at 90 °C for 16 h. Results showed that the incorporation of polymers in bentonite enhanced the filtration and rheological properties. The bentonite/P3 dispersion showed better rheological properties compared to other bentonite/polymer dispersions. The better rheological properties of bentonite/P3 dispersion suggest that acrylamide-based copolymers containing smaller comonomers such as acrylic acid are better compared to the bulky comonomers such as AMPS for drilling fluids applications. The filtration properties are less affected by the DOH and nature of comonomers, nevertheless, all polymer/bentonite dispersions showed better filtration properties compared to bentonite dispersion. The use of this high molecular weight polymer provides high thermal stability, superior rheological properties and better filtration characteristics for water-based drilling fluids.

1. Introduction

Drilling fluids perform vital roles in oil and gas drilling operations, such as maintaining rheological properties, cooling the drilling bit, transporting the formation cuttings from bottom hole to the surface, balancing the formation pressure, inhibiting shale dispersion [1,2], and preventing the invasion of fluid into formations [3–6]. Drilling fluids are mainly classified into three categories, including oil-based drilling fluids, synthetic-based drilling fluids, and water-based drilling fluids [7–9]. Oil-based and synthetic drilling fluids are not frequently advised for drilling operations due to environmental concerns because they are health hazards and have high costs relative to the water-based drilling fluids [10]. Water-based drilling fluids are generally used worldwide to carry out drilling operations because they are environment-friendly, easy to prepare, cost-effective, safe, and most efficient compared to other drilling fluids [11–13]. Water-based drilling fluids have bentonite as a basic component to control drilling fluid properties. High concentration of bentonite in drilling fluids has various detrimental effects which include: (1) chances of pipe sticking, (2) lowering the penetration rate of the drill bit, and (3) enormous torque and drag are required for drilling operations [14,15]. Thus, less concentration of bentonite is desired to have low solid contents in drilling fluids. However, low concentration of bentonite is unable to maintain desired rheological properties required for smooth drilling operations. Hence, various natural and synthetic polymers are employed to accomplish the desired properties of drilling fluids [16–20].

Natural and synthetic polymers are widely used as rheology modifiers, shale inhibitors, and fluid loss additives in water-based drilling fluids. These polymers are primarily used to control rheological properties, filtration properties and shale inhibition properties of water-based drilling fluid [21–24]. Water interacts with shale and causes swelling of shale that leads to the well bore instability problems such as a tight hole, dispersion of shale, and bit balling [25,26]. The water-soluble polymers in water-based drilling fluids inhibit shale swelling and fluid loss by encapsulating shale with a thin layer of polymer and prevent the invasion of water into the formation. Recently, various synthetic and natural polymers are employed in water-based drilling fluids to prevent the fluid loss into the formations and to modify rheological properties [27]. Recently, Baba et al. have used two different biopolymers such as xanthan gum and sclera-glucan to modify rheological properties of water-based drilling fluids [28]. Jain et al. synthesized polyacrylamide

* Corresponding author.
E-mail address: mamdouh@kfupm.edu.sa (M.A. Al-Harthi).

https://doi.org/10.1016/j.molliq.2017.12.135
0167-7322/

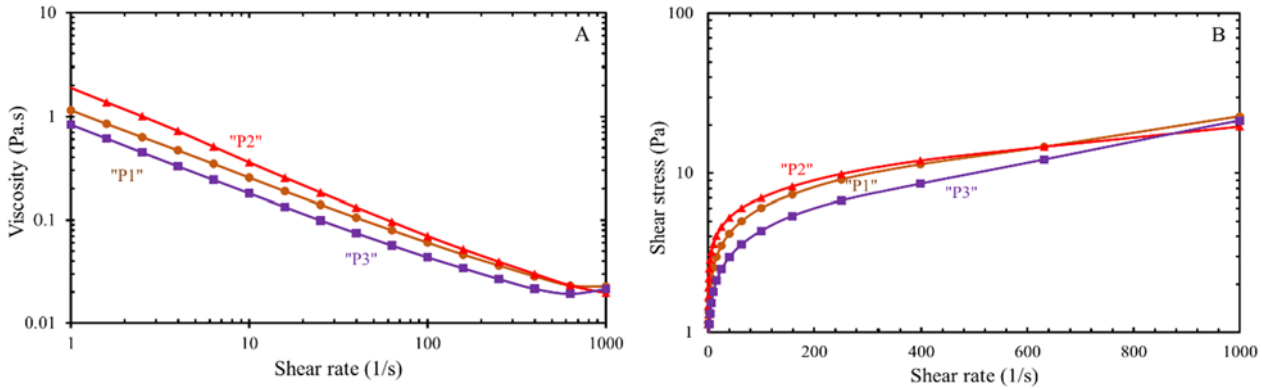

Fig. 1. Steady shear viscosity (A) and flow curves (B) of different polymer solutions at 25 °C in deionized water.

grafted xanthan gum with multiwalled carbon nanotube nanocomposite to investigate the rheological properties as one of the drilling fluid additives [29]. Other polymers employed in water-based drilling fluids include starch, polyacrylates, polyacrylamide, hydrolyzed polyacrylamide, partially hydrolyzed polyacrylamide, amphoteric cellulose, polyanionic cellulose, and carboxymethyl cellulose has been used to modify rheological properties and fluid loss control agent.

The use of high molecular weight polymers as water based drilling fluid additive could significantly enhance rheological properties and filtration characteristics compared to the low molecular weight polymers in the real field application of drilling process. The short chain low molecular weight polymers with 1000–6000 Da molecular weights are unable to bear hostile conditions of elevated temperature and pressure at the bottom hole. The low molecular weight polymers lose their viscosity and gel strength due to high temperature and pressure conditions. The issue can be resolved by using polymers having high molecular weights such 700,000–1,000,000 Da which provides efficient viscosity and gel strength to the drilling fluid. The use of high molecular weight polymers not only enhance thermal stability of drilling fluid but also minimize the fluid loss in to the formation my making a thin layer on the walls of well bore [30].

The primary challenge to use natural and synthetic polymers in drilling fluids is to maintain rheological and filtration properties at high temperature- high-pressure conditions of the bottom hole. These polymers lose their rheological and filtration properties due to degradation of polymers at high temperature and high pressure at deep well conditions [15,21,25]. Recently, the use of high molecular weight copolymer with rigid backbone polymer chains have caught much attention for water-based drilling fluids due to their unique structure, hydrophilic functional groups, the degree of hydrolysis (DOH) and ability to bear high temperature at bottom hole [31,32]. So, these high molecular weight polymers with distinctive functional groups could effectively control filtration and rheological properties due to their structural stability, hydrophilic functional groups along the backbone and high structural viscosity [33].

In this work, three high molecular weight copolymers containing temperature tolerant monomers were evaluated as potential additives of drilling fluids. These polymers have similar molecular weight but different anionicity and monomers. The impact of molecular structure and anionicity on the rheological properties, permeability, filter cake and filtration properties were studied. First, rheological properties of polymer solutions and bentonite/polymer dispersions were investigated at two different temperatures (25 °C and 85 °C). Second, the flow stability test was performed for polymer and bentonite/polymer dispersions for two hours at 25 °C and 85 °C to examine the flowability of the formulations. The comparison of rheological properties was carried out for all the formulations at 25 °C before and after aging the formulations at 90 °C. The experimental data obtained from steady shear experiments was fitted to the Herschel-Bulkley model to study the non-Newtonian behavior of polymer and bentonite/polymer dispersions. TEM analysis was performed to study the morphology of bentonite/polymer dispersions. Then standard API filtration measurements were performed to study the fluid loss volume for the formulations before and after aging. For the measurement of permeability of filter cakes, Darcy's law was used, and SEM analysis was performed for filter cake morphology.

2. Experimental procedure

2.1. Materials

Bentonite (BT) was acquired from BDH Chemicals (UK) having a pale brown appearance with a pH ranges from 9.5–10.5 and a density of 2.5 g/cm^3 at 20 °C. Three different high molecular weight copolymers were obtained from SNF FLOERGER. Each copolymer has 9 million g/mol

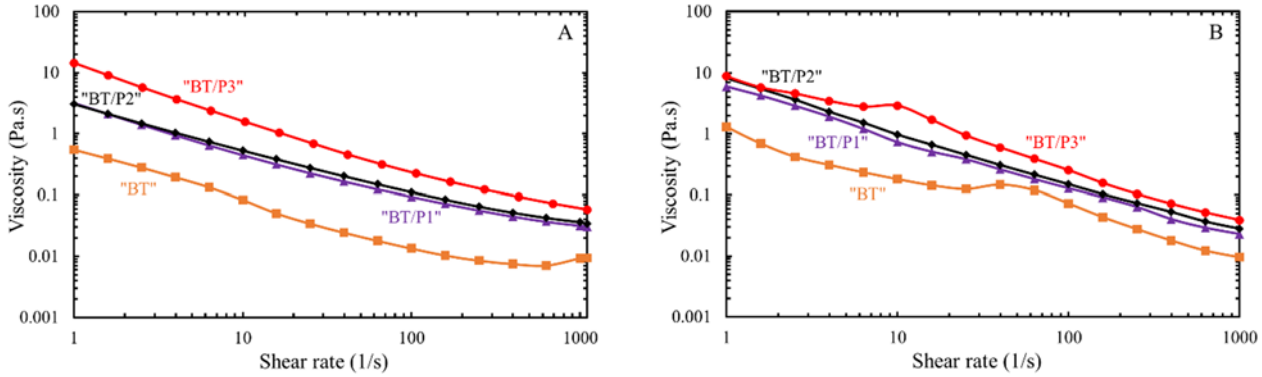

Fig. 2. Steady shear viscosity of bentonite and bentonite/polymer suspensions in deionized water (A) at 25 °C (B) at 85 °C.