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Original Article

A natural dye in water-based drilling fluids: Swelling inhibitive characteristic and side effects

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ABSTRACT

The development of eco-friendly shale inhibitors is still an area which has attracted a lot of attention in the drilling industry. Henna extract is a natural dye which has recently shown considerable inhibition and weak deflocculation properties in clay-water system. This study aims to investigate swelling inhibitive feature and side effects of Henna extract in water-based drilling fluids (WBDFs). It was carried out through extensive experiments including adsorption measurements on shale by batch equilibrium, inhibition evaluation by dynamic linear swelling and cuttings dispersion, wettability alteration via contact angle measurements, compatibility by rheological properties determinations and fluid loss measurements, and lubricity. Both in natural pH and adjusted pH to 9, Linear adsorption model was more suitable for anticipating the adsorption behavior of Henna extract on the given shale sample. The results of the linear swelling and cuttings dispersion tests demonstrated that Henna extract in drilling fluid formulations diminished the swelling and dispersion characteristics of the addressed shale sample. Moreover, contact angle measurements showed that Henna extract expanded the hydrophobicity of shale formations, preventing and promoting water adsorption and shale stability respectively. This issue definitely introduces wettability alteration as a mechanism for shale stability by Henna extract. Compatibility determinations additionally uncovered that Henna extract is compatible with common WBDFs additives. As indicated by the lubricity tests, Henna extract enhanced the lubricity of WBDFs, a finding which can be of an incredible significance in directional drilling. Among others, advantages such as environmental friendliness, low cost, accessibility, and the counter corrosion property make the applicability of Henna extract in WBDFs profoundly suitable.

1. Introduction

The first and perhaps the most costly step in oil and gas wells development is drilling the wellbore. This step has always been encountered with the problems of wellbore stability. These problems which could result in a waste of US$ 1 billion per year worldwide are both mechanical and physico-chemical [1,2]. Mechanical effects are potentially connected to drilling operation and could be handled by restoring the stress-strength balance and trajectory control [3]. Nevertheless, physico-chemical effects which are time dependent come from interaction between solid (i.e shale) and aqueous filtration of drilling fluids [1–3]. Shales are common sedimentary rocks with laminated layered characteristics and high clay content [4]. They account for about 75% of drilled formations and causing 90% of wellbore stability problems [5]. When drilling through water sensitive shales using conventional water-based drilling fluids (WBDFs), shales absorb water and find high potential to hydrate and swell. This results in a lot of operational problems which in some cases leads to suspension of the well prior to reaching the target [6]. The swelling characteristic of shales strongly relies on the amount and types

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of clay minerals present [7]. In contrast to other clay minerals, sodium saturated smectites have attained increasing attention owing to high hydration and swelling capacity as well as occurrence frequencies during drilling operations [8].

Inhibition of shale swelling was already achieved by use of oil-based drilling fluids (OBDFs). However, the high cost and environmental damage limited their wide use [9]. Since, a number of efforts have been made to improve the inhibitive properties of WBDFs through introducing typical additives known as "shale inhibitors". The literature reports the use of potassium chloride as an inorganic salt, partially hydrolyzed polyacrylamide (PHPA), silicates, polyoxyalkyleneamine, poly(-oxypropylene)diamine, polyether diamine, poly (oxypropylene)-amidoamine, dopamine, bis (hexamethylene) triamine, hydrophobized hyperbranched polyglycerols, amine-terminated polyamidoamine dendrimers, 4.4′ methylenebis-cyclohexanamine, and bio-based/chemical-based surfactants [10–25]. It is noteworthy that the inhibitive property of most of these inhibitors is assessed in the absence of WBDF additives, water-clay-inhibitor. Our belief is that this is not adequate for applicability of every product in WBDFs because one product may provides good inhibition performance while disturbs the performance of other additives or its performance becomes weak in presence of special additives. Therefore, a real study needs to be made in order to assess and identify the inhibition performance and side effects of every new inhibitor, respectively.

With increasing environmental restrictions, natural surfactants have attracted too much attention within the petroleum industry [26–31]. Henna extract, a natural dye, is a bio-based additive which recently showed deflocculation and inhibition features at low and high concentrations, respectively [15]. This has been achieved through a number of experiments carried out on clay-water-Henna extract system. However, the inhibitive feature of Henna extract and its side effects in form of WBDFs have not yet been reported in the literature. Since, this study is complementary and somehow terminative to previous study in connection with inhibition property of Henna extract. To this end, a wide range of experiments were carried out: adsorption onto shale cuttings via batch equilibrium, inhibition by linear swelling and shale cuttings dispersion, wettability alteration via contact angle measurements, compatibility by rheological properties determinations and fluid loss measurements, and lubricity.

2. Materials and methods

2.1. Materials

2.1.1. Henna extract

Henna, Lowsonia inermis L, is an odoriferous plant and a member of Lythraceae family. It is a shrub or small tree with 2–6 m in high and spine-tipped branchlets. Its leaves are characterized as smooth, opposite, sub-sessile, elliptically shaped and broadly lanceolate, with depressed veins clearly visible on the dorsal surface [32,33]. Henna is commonly found in Algeria, India, Pakistan, Egypt, Yemen, Iran, and Afghanistan. In addition to tattooing applications, it can also be employed for different purposes comprising treatment, dye, drug, etc [33,34]. Some features including being a naturally occurring material and thus environmentally friendly characteristics, low cost, high availability, acting as anti-corrosion in various metallic mediums, improving cement resistance against acid attack, and deflocculation as well as swelling inhibition of clay particles are the major reasons for more attention towards Henna in petroleum industry [15,35–41]. For purpose of this study, Henna extract which is derived from Henna leaves was provided by Ebnemasouyeh Company, Tehran, Iran. Ostovari et al. [34] showed that the main constituents of Henna extract are Lawsone (2-hydroxy-1,4 naphthoquinone, $C_{10}H_6O_3$), gallic acid (3,4,5- trihydroxybenzoic acid, $C_7H_6O_5$), dextrose (α−D-Glucose, $C_6H_{12}O_6$), and tannic acid (Fig. 1). Table 1 shows the major properties of Henna extract.

2.1.2. Water-based drilling fluid additives

In order to prepare WBDFs, different additives were used: green starch, low viscosity polyanionic cellulose (PAC-LV), xanthan gum (XC-Polymer), partially hydrolyzed polyacrylamide (PHPA), potassium chloride (Merck, 99.5%), sodium chloride (Merck, 99.5%), barite, caustic soda, and clouding glycol. These additives were provided by National Iranian Drilling Company.

2.1.3. Shales

Two shale samples named Pabdeh and Kazhdumi were used in this study (Table 2). Kazhdumi shale was extracted from the outcrop of Kazhdumi formation, Khuzestan, southern Iran. To do this, a large shale sample was extracted and preserved well. Several core plugs were obtained from the large shale sample and subsequently stored in oil tank for preventing any interaction. Another shale sample was taken from the drill cuttings during drilling through Pabdeh formation in Ahwaz oil field, Khuzestan, southern Iran. The cuttings were air dried at 105 °C and then utilized in different parts of this study. Kazhdumi shale was utilized in contact angle measurements due to required core sample for this test, while Pabdeh one was implemented for other experiments owing to its high swelling potential than Kazhdumi shale. X-ray diffraction (XRD) analysis was implemented to characterize the semi-quantitative mineral compositions of shale samples. In this analysis, the detector moved in a circle pattern around the sample and recorded the number of X-Rays (intensity which was recorded as counts per second or CPS) observed at each detector position (2-theta which was recorded as degree). Fig. 2 shows XRD patters, intensity versus 2-theta, for Pabdeh and Kazhdumi shales. After comparing these patterns with the standard patterns, the semi-quantitative mineral compositions of each shale sample were determined as shown in Table 3.

2.2. Methods

2.2.1. Adsorption measurements

In this study, batch equilibrium experiments were implemented to acquire the adsorption isotherms of Henna extract on shale cuttings. In this connection, different concentrations of Henna extract aqueous solution were prepared both in natural pH and adjusted pH of 9. The conductivity of each concentration was measured by Sartorius PP-20 conductivity meter in order to acquire reference conductivity curve. Thereafter, 100 ml of each concentration was mixed with 20 g dried (at 105 °C) shale cuttings with sieve mesh N.200 (particle size less than 75 microns). The dispersion was stirred by magnetic stirrer for 24 h to reach equilibrium and then a certain amount of them was centrifuged at 6000 rpm for 2 h. Finally, the conductivity of supernatant solution was measured and the left out concentration was obtained using reference conductivity curve. This phase of study was carried out at 28 °C and atmospheric pressure. The amount of Henna extract adsorbed per unit mass of shale was determined by the following equation.

$$q = \frac{1000 \times V_{Sol} \times (c^{\circ} - c)}{m_{shale}} \quad (1)$$