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Research paper

Enhancing the rheological properties and thermal stability of oil-based drilling fluids by synergetic use of organo-montmorillonite and organo-sepiolite

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ABSTRACT

This work focused on improving the rheological properties and thermal stability of oil-based drilling fluids by using the mixture of organo-montmorillonite (OMt) and organo-sepiolite (OSep) as the rheological additive. OMt and OSep were prepared in water. X-ray diffraction (XRD), scanning electron microscope and transmission electron microscope were applied to characterize the structure of organoclays (OC). The OC/oil gels were characterized using an appropriate XRD method. Dynamic rheological test was used to appraise the rheological behavior, viscosity, gel strength and thixotropy of OC/oil fluids aged at different temperatures. OMt firstly swelled in oil at low temperature, and then exfoliated above 150 °C. OSep maintained its crystal structure all the time. The mixing of these two OC did not obviously influence their structures. However, the gel formation ability was promoted, resulting in improvement of rheological properties and thermal stability of oil-based drilling fluids. The nanolayers of OMt and nanofibers of OSep interweaved with each other, reinforcing the network structure and protected them form collapse at high temperatures. The mixture of OMt and OSep with mass proportion of 50% for each displayed the optimal rheological properties and thermal ability.

1. Introduction

Over the next 30 years, global energy is projected to rise almost 60%, a challenging trend that may be met only by revolutionary breakthroughs in energy science and technology (Esmaeili, 2011). Although the technologies of some new or renewable energies (such as new battery, wind energy, nuclear energy, etc.) are developing fast, oil and gas, as the traditional energy, are the main energy resource in the world. The demand of oil and gas is increasing due to the rapid development of the society. However, the petroleum industry is increasingly drilling more technically challenging and difficult wells. Drilling of deeper wells worldwide requires constants searching for adequate drilling fluids to overcome extreme conditions (Williams et al., 2011).

Drilling fluids are compared as “the bloods of drilling operations”. By drilling operations, oil and gas can be extracted from the earth. Drilling fluids serve several fundamental functions, such as (i) to remove the cuttings generated by the drill bit from the borehole, (ii) to control the downhole formation pressures, (iii) to overcome the fluid pressure of the formation, (iv) to avoid damage to the producing formation and (v) to cool and lubricate the drill bit, etc. (Chilingarian and Vorabutr, 1983; Caenn and Chillingar, 1996; Meng et al., 2012). Generally, drilling fluids can be divided into two types based on the continuous phase, i.e., water-based drilling fluids and oil-based drilling fluids. Water-based drilling fluids are limited by their abilities of dissolving salts, interfering with the flow of oil and gas through porous rocks, promoting the disintegration and dispersion of clay minerals, and effecting the corrosion of iron (Caenn et al., 2011). Oil-based drilling fluids, owing to their excellent lubricity, high rate of penetration, shale inhibition, wellbore stability, high lubricity, high thermal stability (Caenn and Chillingar, 1996; Khodja et al., 2010), are advised to be used to drill difficult wells. In spite of the advantages of oil-based drilling fluids, drilling practice always demand drilling fluids with greater rheological properties and better thermal stability.

Organoclays (OC) are used in oil-based drilling fluids to control the rheological behavior. They perform specific functions in a base oil and are varied in amount to furnish the properties required for satisfying the conditions of use. Organo-montmorillonite (OMt) is mostly used in oil-based drilling fluids (Caenn et al., 2011; Dino and Thompson, 2013;

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Zhuang et al., 2016, 2017b). Hermoso et al. (2014) reported that the viscous flow behavior of oil-based drilling fluids is deeply influenced by OMt nature and concentration. (Schmidt et al., 1987) proposed that OC did not viscosify the oils but built the structure through interactions with the aqueous face (water phase is usually included in oil-based drilling fluids). But later work (Burgentzle et al., 2004) demonstrated that OMt can viscosify organic solvents without water. Previous work (Zhuang et al., 2017b,d) reported the exfoliation of OMt in oil aged at high temperatures. Exfoliated OMt produced many nanolayers to build a “house of cards” structure, resulting in the improvement of gel formation and rheological properties. By comparing studies on different modifiers, surfactants containing two long alkyl chains were proved to be easier to result in exfoliation of OMt in oil and excellent rheological properties. However, distinct decline of the rheological properties occurred when best fluids aged above 180 °C, because of two potential ways, i.e., thermal decomposition and desorption of organic surfactants.

Recently, the OC from palygorskite-sepiolite family were reported to be used in oil-based drilling fluids (Dino and Thompson, 2002; Zhuang et al., 2017a,c,d, 2018b; Weng et al., 2018). They exhibited excellent rheological properties in oil by forming a “haystack” structure. These clay minerals are natural nanofibrous materials. For sepiolite (Sep), its fiber sizes generally range from 0.2 μm to 2 μm in length, 100 nm to 300 nm in width and 50 nm to 100 nm in thickness (Alvarez, 1984; Álvarez et al., 2011). Accordingly, Sep shows preeminent rheological properties in polar solvents. By organic modification, organo-sepiolite (OSep) displays the lipophilicity and can perform excellent rheological properties in oil (Zhuang et al., 2018a).

Some recent literature reported about the joint use of Mt. and fibrous clay minerals (Neaman and Singer, 2000; Chemeda et al., 2014; Al-Malki et al., 2016) to enhance the rheological properties of clay minerals in solvents. Al-Malki et al. (2016) found that bentonite-based drilling mud with Sep nanoparticles showed a great stability in plastic viscosity and yield point over a wide range of temperature and pressure, especially at high temperatures and pressures. The previous work enlightened that synergistic use of OMt and OSep may also promote the rheological properties and thermal stability of oil-based drilling fluids. This is a promising way to sustain oil-based drilling fluids work in difficult wells.

Aiming to improve the rheological properties and thermal stability of oil-based drilling fluids, OMt and OSep was synergistically used in oil-based fluids aged at different temperatures and their structures and rheological properties were characterized.

2. Materials and methods

2.1. Materials

Na^+-treated Mt. was obtained from Kazuo, Liaoning, China, with the purity of ca. 84% and cation exchange capacity (CEC) of 120 cmol/kg. Sep was obtained from Spain, with the CEC of 35 cmol/kg. The purity of clay minerals was defined X-Ray diffraction method according to the Chinese standard SY/T 5163-2010. Details of this method were reported in previous literature (Zhuang et al., 2018a). Some quartz (12%), calcite (4%) and albite (2%) were included in the Mt sample (see Fig. 1(A)). XRD pattern of Sep (Fig. 1(B)) matches well with the JCPDS card of Sep and no other reflections are observed, indicating the high purity of Sep. The chemical composition of Mt. and Sep were characterized by X-ray fluorescence (XRF) analysis and the results are listed in Table 1. Both of these two clay minerals were milled and sieved with a 200-mesh sieve before use. Benzyl dimethyl octadecyl ammonium chloride (C18, purity of 97%) and dimethyl dioctadecyl ammonium chloride (DC18, purity of 98%) were bought from Anhui Super Chemical Technology Co., Ltd., China. The white oil (No. 5) was bought from China National Petroleum Corporation.

2.2. Preparation of OC

OMt was prepared in aqueous solution as the following steps: 100 g of Mt. was added into 1 L deionized water, stirring for 0.5 h; then DC18 (1.0 CEC of Mt) was added into the previous dispersion, stirring for 1 h; at last, by centrifugation, drying at 60 °C for 24 h, milling and sieving

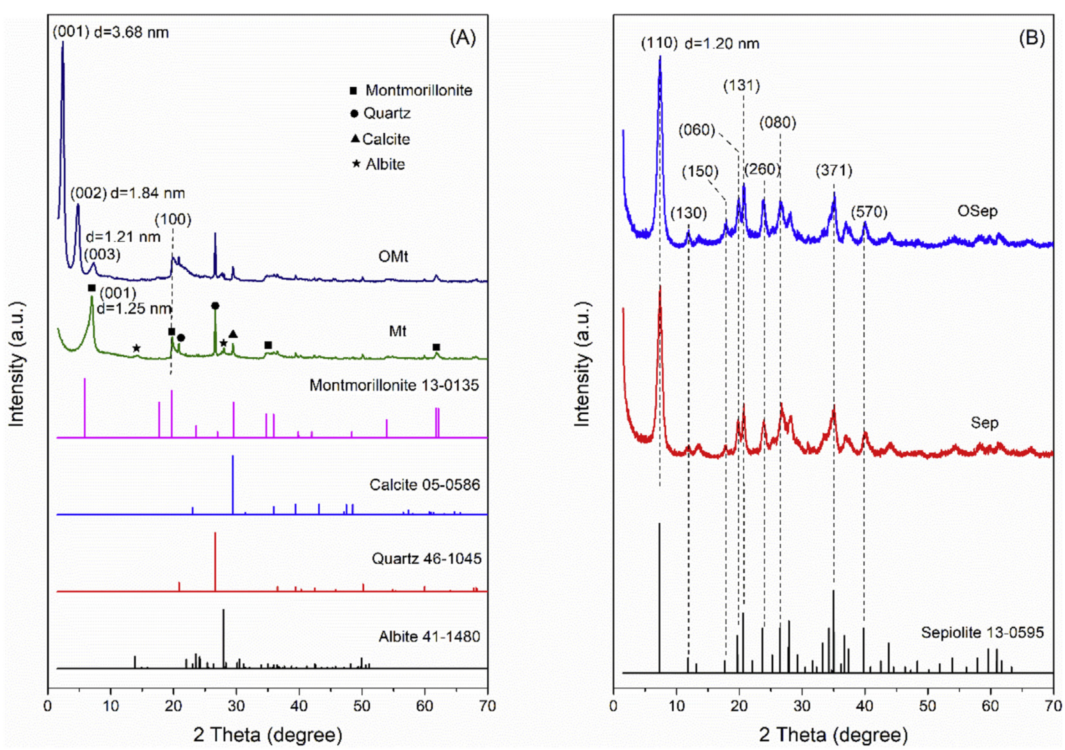

Fig. 1. XRD patterns of (A) Mt, OMt, (B) Sep and OSep.