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Novel bio-based surfactant for chemical enhanced oil recovery in montmorillonite rich reservoirs: Adsorption behavior, interaction impact, and oil recovery studies

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ABSTRACT

Owing to the problems associated with clay swelling, the implementation of surfactant flooding, a well-advised chemical enhanced oil recovery (EOR) technique for sandstone reservoirs, should be implemented with more sensitivity. This paper conducts for the first time a comprehensive study for assessing the performance of a novel natural surfactant, Mulberry leaf extract, on oil recovery from montmorillonite (MMT, as swelling clay) rich reservoirs. From batch equilibrium tests, it was found that MMT appears to have a high potential for attracting the surfactant. In addition, Freunlich isotherm suited the equilibrium adsorption data very well. Based on linear swelling and plugging tests, the adsorption of surfactant restrained the hydration and swelling potential of MMT effectively, thereby no concern about surfactant loss. Micromodel observations exhibited that the proposed surfactant improved the sweep efficiency of water flooding about 11.73%. It was concluded that interfacial tension reduction and swelling inhibitive feature are responsible for excellent performance of the proposed surfactant.

1. Introduction

Primary oil recovery refers to the initial expulsion of the oil right after accomplishment of the drilling operation caused by inherent energy of the reservoir. When this inherent energy weakens, further oil can be produced by applying unnatural energy to the reservoir (secondary oil recovery), generally via injection of locally available water into the reservoir (Howe et al., 2015). It is generally accepted that the primary and secondary oil production methods lead to recovery factor of not greater than 0.45 (Koottungal, 2008; Xie et al., 2004), owing to several barriers including capillary forces, unfavorable

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Nomenclature

Acronyms

EOR	enhanced oil recovery
MMT	Montmorillonite
IFT	interfacial tension
CMC	critical micelle concentration
ZSCE	Zyziphus spina christi extract
XRD	X-ray diffraction
XRF	X-ray fluorescence
OOIP	oil originally in place
LSCA	linear swelling cup assemblies

Variables

q	surfactant adsorption on MMT powder (mg/g-MMT)
m_{sol}	total mass of solution in original bulk solution (g)
C^0	surfactant concentration in initial solution before equilibrium with MMT powder (ppm)
C	surfactant concentration in aqueous solution after equilibrium with MMT powder (ppm)
m_{sam}	total mass of MMT powder (g)
q_e	equilibrium adsorption (mg/g-MMT)
C_e	equilibrium concentration (mg-L)
q_0	adsorption capacity in Langmuir model (mg/g-MMT)
K_{ad}	energy of adsorption (L/mg)
K_F	Freunlich constant related to the capacity of adsorption
n	Freunlich exponent related to the adsorption intensity
K_H	constant for the linear isotherm model in units of L/m^2
A_T	Tamkin isotherm equilibrium binding constant (L/mg)
B	constant related to the heat of sorption
PI	plugging index (%)
$V_{t\text{-oil}}$	total volume of micromodel which can fill by injected oil (Pixel)
$V_{f\text{-oil}}$	final volume of oil in micromdel after accomplishment of each injection rate (Pixel)

mobility ratio, and reservoir rock heterogeneities (Farouq-Ali and Stahl, 1970; Kazempour et al., 2013; Yuan, 2012). In order to dispel the proliferation of the energy consumption worldwide successfully, it is urgent to implement tertiary recovery techniques such as chemical flooding, gas flooding and thermal recovery for extracting the residual oil in place (Bai et al., 2014). Surfactant flooding is one the subsets of chemical flooding methods which refers to a process during which a slug of surfactant is injected into the reservoir from one or several injection wells in a particular pattern (Kamranfar and Jamialahmadi, 2014). In this process, surfactants are being used to lower the oil/water interfacial tension (IFT) in order to boost the displacement efficiency during oil recovery (Bera et al., 2013; Olajire, 2014; Zendehboudi et al., 2013). In fact, IFT reduction by surfactants decreases capillary forces and allows the trapped oil bank to flow (Olajire, 2014).

A large quantity of the world's oil reserves is stored in sandstone reservoirs where the presence of swelling clays (e.g., smectites) could potentially affect the efficiency of chemical flooding. In fact, clay swelling caused by the interaction between the rock and injected fluid could reinforce the potential of formation damage yielding to a decrease in reservoir quality (i.e., porosity and permeability) and subsequently oil recovery factor (Abbasi et al., 2011; Kazempour et al., 2013; Zhou et al., 1996). Among all the clays, smectite clays (e.g., montmorillonite, MMT) have received a lot of interest, mainly because of their high hydration and swelling potential when exposed to the non-inhibitive aqueous solution as well as high occurrence frequencies within oil fields (Anderson et al., 2010; Zhao et al., 2014). Therefore, surfactant flooding, as a path-finding technique in sandstone reservoirs, must be carried out with a more sensitive analysis.

In recent years, natural surfactants have attracted increasing attention within the research sector compared to those of industrial basically due to the performance, cost and environmentally friendly characteristics. The application of natural surfactants was introduced by Pordel Shahri et al. (2012), who showed the positive impact of Zyziphus spina christi extract on oil recovery. After that, several extensive studies have been carried out about the adsorption behavior of the addressed surfactant in different minerals at various conditions (Ahmadi and Shadizadeh, 2012, 2013a,b, 2015). Mulberry leaf-derived surfactant is a natural surfactant which is introduced as an effective stimulator in oil reservoirs essentially owing to its potential to decrease the IFT of oil–aqueous system (Ahmadi et al., 2014; Ravi et al., 2015). So far, no information about the performance of this natural surfactant for EOR in MMT rich reservoirs has been published in the literatures. This paper conducts a comprehensive study for assessing the performance of the Mulberry leaf-derived surfactant, a newly developed natural surfactant, on oil recovery from a porous media rich in MMT. Initially, adsorption behavior of this surfactant on MMT was investigated through batch equilibrium tests and then evaluated through employing four famous adsorption isotherm models. Next, linear swelling and plugging tests were carried out to investigate the effect of adsorbed surfactant on reactivity of MMT in aqueous solution. Finally, the performance of surfactant on oil recovery from porous media rich in MMT was investigated using heterogeneous glass micromodel. The results are presented and discussed in more detail in the following pages.

2. Experimental

2.1. Material

2.1.1. Surfactant

The Mulberry tree (Fig. 1) is widely distributed in tropical, subtropical and regions with a high temperature. It is deciduous tree shedding its leaves in a particular season of the year. Although Mulberry tree is very common in Iran, it has been naturalized in several regions of Europe where the climatic condition is mild. The fruits, leaves, shoots, and root bark of the Mulberry tree are all utilized for different purposes such as anti-rheumatic arthritis, anti-diabetes, anti-atherosclerosis, and anti-inflammatory (Chen et al., 1995; Kim and Park, 2006; Naowaboot et al., 2012; Park et al., 2013; Yang et al., 2011). The composition of Mulberry leaf has been analyzed by Cheema et al. (2011). They found that the dry matter is about 25% comprising 93% organic and 7% mineral matters. The organic compounds and elements are presented in Table 1.