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Experimental investigation of wettability alteration on residual oil saturation using nonionic surfactants: Capillary pressure measurement

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ABSTRACT

Introducing the novel technique for enhancing oil recovery from available petroleum reservoirs is one of the important issues in future energy demands. Among of all operative factors, wettability may be the foremost parameter affecting residual oil saturation in all stage of oil recovery. Although wettability alteration is one of the methods which enhance oil recovery from the petroleum reservoir. Recently, the studies which focused on this subject were more than the past and many contributions have been made on this area. The main objective of the current study is experimentally investigation of the two nonionic surfactants effects on altering wettability of reservoir rocks. Purpose of this work is to change the wettability to preferentially the water-wet condition. Also reducing the residual oil saturation (Sor) is the other purpose of this work. The wettability alteration of reservoir rock is measured by two main quantitative methods namely contact angle and the USBM methods. Results of this study showed that surfactant flooding is more effective in oil-wet rocks to change their wettability and consequently reducing Sor to a low value. Cedar (Zizyphus Spina Christi) is low priced, absolutely natural, and abundantly accessible in the Middle East and Central Asia. Based on the results, this material can be used as a chemical surfactant in field for enhancing oil recovery.

1. Introduction

Wettability is a tendency of a fluid to spread on or adhere to a solid surface in the presence of other immiscible fluid. The fluid that spread or adheres to the surface is known as the wetting fluid. In the petroleum reservoir, the solid surface is the reservoir rock which may be sandstone, limestone, or dolomite, together with cementing material. The fluids are water, oil, and gas. Normally either water or oil is the wetting phase. Gas is always a nonwetting phase [1,2]. Wettability is perhaps the most important factor that affects the rate of oil recovery and the residual oil saturation, which is the target of enhanced oil recovery technology. Wettability controls the rate and amount of spontaneous imbibition of water and the efficiency of oil displacement by injection water, with or without additives [3]. Wettability of a system can range from strongly water-wet to strongly oil-wet depending on the brined interactions with the rock surface [3]. In a water-wet system, water will occupy the narrowest pores and will be present as a film on the pores wall while oil will reside as oil droplets in the middle of the pores. The reverse fluid distribution will exist in the case of an oil-wet reservoir. A core sample which imbibes only water spontaneously is said to be water-wet; one that imbibes oil spontaneously is called oil-wet. Samples imbibing neither water nor oil are said to be neutral wet [4].

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Capillary pressure (P_c) is the difference in pressure between two immiscible fluids across a curved interface at equilibrium. Curvature of the interface is the consequence of preferential wetting of the capillary walls by one of the phases [3]. In other word the capillary pressure is defined as the pressure difference between the non-wetting and wetting phases:

$$P_c = P_{nw} - P_w \quad (1)$$

Where P_w is wetting phase pressure and P_{nw} is non-wetting phase pressure. In water-oil-rock system (the rock is water-wet), this formula can define:

$$P_c = P_o - P_w \quad (2)$$

Where P_w is the water pressure and P_o is the oil pressure. Now consider the rise of a fluid in a capillary tube as shown in Fig. 1 [5].

There are three laboratory methods that are commonly used to measure primary drainage capillary pressure in a rock, (1) the porous plate (restored-state) method, (2) the centrifuge method, and (3) the mercury injection technique [6].

For the first time, in 1990, Glotin et al. [7] compute capillary pressure curves from centrifuge and developed for both drainage and imbibition. The methods were applied to experimental data. Results showed that accurate determination of drainage capillary pressure curve can be obtained and negative capillary pressure in imbibition and residual oil saturation were also determined.

Dullein and Fleury (1994) [8] were analyzed the Pc curves attained by centrifuge in order to achieve the USBM wettability test. Their results showed: A) Capillary pressure curves represent saturation vs. capillary pressure relations in capillary equilibrium. B) Both in drainage and in imbibition displacement the non-wetting fluid is the under higher pressure than the wetting fluid. C) In drainage the non-wetting fluid is the displacing fluid, whereas in imbibition the wetting fluid is the displacing fluid.

Chattopadhyay et al. (2002) [9] perform an experimental study about Effect of Capillary Pressure, Salinity and Aging on Wettability Alteration in Sandstone and Limestone. They perform centrifuge core flow tests (Berea sandstone and Texas Cream limestone) with a range of fluids under different conditions to identify the factors influencing the residual wetting and non-wetting phase saturations and oil recovery. Results of their tests conducted with Prudhoe Bay and Moutray crude oil show that remaining water (Swr) and residual oil saturation (Sor) vary systematically with Bond number for both sandstone and limestone samples. Differences in the shape of the wetting phase capillary desaturation curves were observed during primary and secondary drainage. They represented that this suggests that the distribution of fluids in the rock during secondary drainage was different from primary drainage due to a change in wettability of the core from a water-wet state to mixed-wet state. These trends were not observed with decane. They also expressed both limestone and sandstone cores become more susceptible to wettability alteration as the salinity is increased.

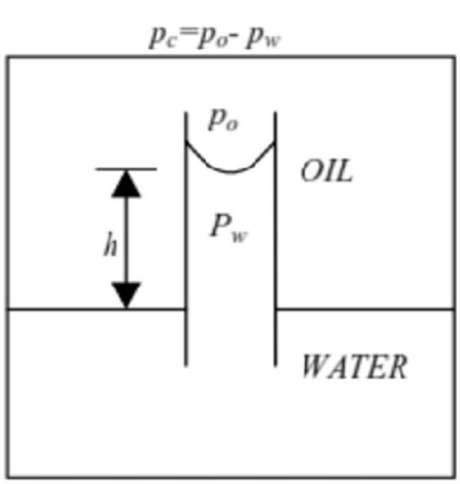

Fig. 1. Fluid rise in capillary tube [5].

Masalmeh (2002) [10] studied the effect of wettability heterogeneity on the capillary pressure curves using the centrifuge technique. Masalmeh In this work, created wettability heterogeneity in the core by partial filling of the pore space with oil, which creates parts of different wetting in the core. The effect of heterogeneous wettability on the capillary pressure was studied in a systematic way using the centrifuge technique in combination with numerical simulation of the experimental data.

The results of his study showed that aging a core sample at low oil saturation introduces significant wettability alteration in the pores filled with oil, while the rest of the core is not affected. The results also suggest that aging time to restore wettability may decrease as oil saturation increases.

Moreover, Masalmeh (2003) [11] investigated the effect of wettability heterogeneity on drainage capillary pressure and relative permeability by creating a special kind of mixed-wet system where big pores have different wettability than small pores. In the study, he found that only the part of the pore space exposed to crude oil undergoes wettability changes on both core scales and pore scale. Also, he found that a step in the Pc curve is observed when oil moves from the oil-wet pores to the water-wet pores. The step is mainly due to wettability contrast between the two parts of the plug and water trapping.

Esfahani and Haghighi (2004) [12] evaluated the wettability of carbonate rock samples of Iranian formations using relative permeability curves, Amott tests, and USBM method. They show that there is a good agreement between USBM index and Amott–Harvey index using the core flooding system. There is poor agreement between the USBM index and the Amott–Harvey index measured using the centrifuge.

Al-Garni and Al-Anazi (2008) [13] perform an experimental study which irreducible oil saturation and capillary pressures using rock centrifuge measurements for Berea Sandstone rock samples. Saudi oils will be tested during drainage and imbibition's cycles by varying each time the wettability of the tested samples by using different Saudi oils (Heavy, Medium, and Light). The capillary pressure for the aged samples will be measured again by the rock centrifuge. Hence, the changes in capillary pressure curve before and after wettability alteration will be obtained.

Sharma et al. (2013) [14] did an experimental study to change the wettability of carbonate rock from mixed-wet toward water-wet, at high temperature and high salinity. Three type of surfactant were used. Their obtained results showed: A) mixture of cationic and nonionic surfactants can recover approximately 70–80% of the oil by spontaneous imbibition. B) Secondary water flooding with a dilute wettability-altering surfactant increased the oil recovery significantly over the water flooding without the surfactants (from 29 to 40% of OOIP (Original Oil in Place)).

Mohammed and Babadagli (2015) [15] provided a systematic approach for a wettability alteration processes. The subsequent results are the some highlights from their study: A) Although contact angle measurement gives a fast and economical mean to evaluate the alteration of surface wettability, the results might be misleading; therefore, it should be integrated with another