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Designing Injection Water for Enhancing Oil Recovery from Kaolinite Laden Hydrocarbon Reservoirs: A Spectroscopic Approach for Understanding Molecular Level Interaction during Saline Water Flooding

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Supporting Information

ABSTRACT: Numerous experiments were performed to understand the mechanism(s) behind incremental oil recovery from hydrocarbon reservoirs during low saline water flooding (LSWF). It is believed that the roles of clay minerals present in the hydrocarbon reservoir rocks and the salt concentration in the injected water have a significant effect on the oil recovery during LSWF. Yet, the exact interaction mechanism(s) is still doubtful for designing injection fluids for enhancing oil recovery from subsurface reservoirs. For understanding the interaction between reservoir components explicitly, kaolinite and crude oil, and the interaction between reservoir components and injection saline water, three dead crude oil samples collected from different reservoirs of Cambay basin, India, and two kaolinite powder samples were used in this study. The kaolinites are different on the basis of their exchangeable cations, Fe^{3+} substitution in octahedral sites, and cation exchange capacity (CEC) values. The three crude oils show differences regarding asphaltene content and the abundance of polycyclic aromatic hydrocarbon in asphatenes. The interaction between reservoir components, particularly, kaolinite and crude oil, was demonstrated by keeping both the kaolinite and crude oil mixtures for two months. Detailed analysis of X-ray diffraction patterns, Fourier transform infrared (FTIR) spectra, and CEC values indicated that the polar oil components are adsorbed onto the interlayer surfaces of kaolinite, making it oil wet, and the interaction depends highly upon the composition of kaolinite and crude oil. The oil removal capacity of three brine concentrations of 500 (low saline), 3000 (intermediate saline), and 8000 ppm (high saline) of NaCl, $CaCl_2$, and $MgCl_2$ from oil adsorbed kaolinites was investigated using UV−visible and fluorescence spectroscopy techniques. The present study demonstrated that low saline water (500 ppm) rich in Na^+ ion is more capable of desorbing the maximum amount of 4−6 ring size polycyclic aromatic hydrocarbon (PAH) components from kaolinite interlayer surfaces with respect to Ca^{2+} and Mg^{2+} ions. The composition of polar oil components, particularly, asphaltenes enriched with 4−6 ring PAH, greatly influences the recovery of oil from a mixed wet to oil wet kaolinite laden hydrocarbon reservoir during saline water flooding. Thus, apart from the concentration level of the saline water, the type of cation present in the saline water plays the major role during LSWF. The kaolinite composition, its crystallinity, and ring size of PAH in asphaltenes present inside a hydrocarbon reservoir also influence the enhanced oil recovery (EOR). These molecular level insights are valuable for designing effective injection fluids for enhancing oil recovery during LSWF in kaolinite laden hydrocarbon reservoirs.

1. INTRODUCTION

The worldwide increase in petroleum demand has resulted in the development of new or modified, economically viable enhanced oil recovery (EOR) techniques from subsurface hydrocarbon reservoirs. Low saline water flooding (LSWF) into the hydrocarbon reservoir is one of these techniques that has gained importance because of its low cost and minimal adversity towards the environment. A literature survey shows that different cations and their salinities in the flooding fluid are the key factors for the enhancement of oil recovery in sandstone and carbonate reservoir rocks.[1−7] There are several existing mechanisms that can explain how low salinity water (LSW) works better for oil recovery from reservoirs. These mechanisms are clay particle (fine) migration,[8] osmosis,[9] increased pH, and reduced interfacial tension (IFT) similar to the alkaline flooding,[10] multicomponent ion exchange (MIE),[11−14] expansion of the double layer,[12,15,16] mineral dissolution,[17] salting-in effect,[18] and salting-out effect.[19] Numerous core flooding experiments in sandstone rocks[6−9] have proven that LSWF has good potential to enhance oil recovery but the suitable range of salinity, preferable cations, their contributions, and most importantly the type of crude oil components released by the saline water are still debatable.

It has been proven that presence of clay minerals in reservoir rock is necessary for successful implementation of LSWF for EOR.[9,20] A number of studies have shown that most sandstone reservoir rocks are rich in different types of clay minerals, predominantly kaolinite.[21,22] This is a negatively charged particle[23] having a high affinity for polar fractions[24−27] of crude oils. According to Soraya et al.,[28] the polar crude oil components are adsorbed by negatively charged clay particles through cation exchange. Moreover, the polar resins and asphaltenes are adsorbed parallel to the layers of the kaolinites predominantly by van der Waals energy with the smaller contribution of

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