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A study of nanofluid stability in low–salinity water to enhance oil recovery: An extended physicochemical approach

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ABSTRACT

We examined the stability of SiO_2 and Al_2O_3 NPs in both deionized (DI) water and low–salinity water (LSW). Stability was evaluated by measuring absorbance, hydrodynamic diameter, and zeta potential. NP stability was also manipulated by dispersion techniques and surfactant addition. To shape our experiments and explain results, we relied on an extended version of Derjaguin, Landau, Verwey, and Overbeek theory that accounts for hydrophobic and steric interactions. We attribute the observed stability of the examined NPs in DI to their highly negative zeta potential, which maintained absorbance and hydrodynamic diameter and produced a high energy barrier (EB). In LSW, SiO_2 was stable because of its hydrophilicity, which maintained the EB, while Al_2O_3, which is naturally hydrophobic, strongly aggregated when a decrease in zeta potential decreased the EB. After applying various dispersion methods to Al_2O_3, including ultrasonication, surfactant addition, heat agitation, and pH control, we observed that the best stability occurred at pH 2 with cationic and nonionic surfactant. Although Al_2O_3 did not show an EB under any conditions, stability nevertheless occurred after surfactant addition, which we attribute to the steric interaction and manipulation of the primary minima. In sum, our physiochemical analysis produced stable nanofluids with potential LSW flooding applications.

1. Introduction

Enhanced oil recovery (EOR) is important to improving reservoir productivity and the incorporation of waterflooding methods into EOR processes is inevitable (Esmaeili and Maaref, 2019; Goolsby and Anderson, 1964; Hussain et al., 2013; Rausch and Beaver, 1964; Warner, 2015). Low salinity (ionic strength (IS)) water used for waterflooding more efficiently recovers oil than high salinity water (Alshakhs and Kovscek, 2016; Erke et al., 2016; Kakati et al., 2017; Nasralla et al., 2013; Pooryousefy et al., 2018; Xie et al., 2016). Low–salinity waterflooding (LSWF) was first introduced when more oil was recovered using sodium chloride (NaCl) brine in the range of 0–10,000 ppm (0–0.1711 mol/l) than when distilled water, which has an IS of nearly 0 mol/l, was used (Bernard, 1967). Bernard (1967) injected various concentrations of NaCl brine and fresh water into a sand pack core for oil recovery. Oil recovery was not affected when the NaCl concentration was higher than 10,000 ppm, however an increase in oil recovery was observed when the NaCl concentration was between 0 and 10,000 ppm. Subsequent to this finding, the injection of low–salinity water into reservoirs has been actively researched due to the high efficiency and low cost of the method (Katende and Sagala, 2019). The main mechanism by which LSWF operates is wettability alteration (Al Shalabi et al., 2014). Specifically, the low–salinity of water influences wettability and the thickness of the electric double layer between rock and oil surfaces at an inversely proportional rate to IS (Tang and Morrow, 1999). For example, decreasing IS increases the thickness of the double layer as well as wettability, resulting in enhanced oil recovery (Shaik et al., 2020). In previous studies, LSWF has been applied to boost oil production by up to 20% (Gupta et al., 2011; Yousef et al., 2010).

Another alternative EOR method, nano–EOR, injects nanofluid into a reservoir to increase oil recovery, relying on diverse mechanisms including changes in wettability, a decrease in interfacial tension (γ),

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