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Enhancement of surfactant flooding performance by the use of silica nanoparticles

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HIGHLIGHTS

- Surfactant nanoparticle mixtures were studied for enhancing oil recovery purpose.
- Hydrophilic and hydrophobic silica nanoparticles were thoroughly investigated.
- Nanoparticle inclusion into surfactant solution caused unique interfacial behavior.
- Surfactant adsorption onto the rock surface was reduced by nanoparticle addition.
- Oil recovery was remarkably enhanced by addition of silica to surfactant solutions.

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ABSTRACT

One of the most significant current discussions in petroleum industry is the use of nanotechnology to improve oil recovery. The aim of this study is the implication of silica nanoparticles in combination with anionic surfactant to see if the surfactant properties are influenced in the presence of nanoparticles and to investigate the capability of these particles to enhance oil recovery. Extensive series of interfacial tension and adsorption measurement experiments were performed. It was observed that surfactant adsorption amount was mostly reduced when mixed with nanoparticles. Interfacial tension measurements revealed strange behavior in low and high surfactant concentrations. The optimum conditions for various scenarios of surfactant flooding were selected upon various experimental results. The flooding experiments showed that nanoparticles could efficiently improve surfactant performance by enhancing the governing mechanisms and the oil recovery was consequently increased by a considerable amount.

1. Introduction

Surfactant flooding has been regarded as a potential tertiary oil recovery technology in depleted reservoirs after water flooding. In a surfactant flooding process, the residual oil is recovered by reducing the surface tension between the oil and water phases [1]. Lower oil–water surface tension reduces the capillary pressure and water can displace extra oil. Effectiveness of surfactant solution to reduce oil–water interfacial tension (IFT) is impaired by the adsorption of surfactant in porous media and renders the process unfeasible [2]. Large amount of surfactants is required to produce small amount of extra oil if the adsorption is too high. The success of this enhanced oil recovery (EOR) method is crucially dependent on surfactant selection. There is a large volume of published studies describing extensive experimental research prior to implementation of the process to assure that the surfactant properties are suitable for the reservoir of interest [3–12].

In recent years there has been an increasing interest in application of nanotechnology in petroleum industry. Reservoir engineering, however, have received the most attention for nanotechnology applications. Nanoparticles have been implemented in different enhanced oil recovery processes. Wettability alteration effects and considerable oil recovery were observed for hydrophilic polysilicon nanoparticles [13]. Yu et al. [14] introduced iron-oxide cored particles with paramagnetic properties as potential EOR agents of which the behavior can be controlled by imposing an external magnetic field. Onyekonwu and Ogolo [15] studied capability of three different polysilicon nanoparticles as an agent for wettability alteration and oil recovery purposes. Skauge et al. [16] investigated the oil mobilization properties of nano-sized silica particles and discussed the underlying mechanism of

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Table 1
Physico-chemical properties of nanoparticles used in this study.

Property	Unit	Typical value for AEROSIL®300	Typical value for AEROSIL®R816
Behavior in the presence of water	–	Hydrophilic	Slightly hydrophobic
Appearance	–	Fluffy white powder	Fluffy white powder
BET surface area	m^2/g	300 ± 30	190 ± 20
Average primary particle size	nm	7	12
Tamped density	gr/l	50	60
PH value	–	3.7–4.7	4.0–5.5
C-content	wt.%	–	0.9–1.8
SiO_2	wt.%	⩾99.8	⩾99.8
Al_2O_3	wt.%	⩽0.050	⩽0.050
Fe_2O_3	wt.%	⩽0.003	⩽0.010
TiO_2	wt.%	⩽0.030	⩽0.030
HCI	wt.%	⩽0.025	⩽0.025

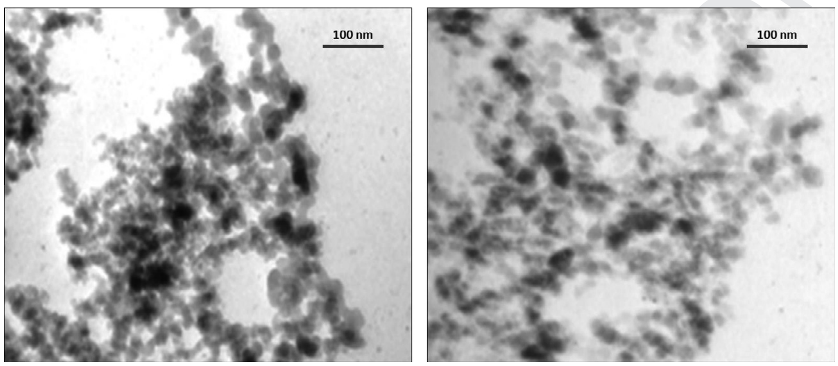

Fig. 1. TEM images of nanoparticles used; (left) hydrophilic nanoparticle, (Right) slightly hydrophobic nanoparticles.

Table 2
Sandpack characteristics.

Sandpack property	Unit	Typical value
Average length	mm	400
Average diameter	mm	19.05
Pore volume, $S_w = 1$	cc	24.3
Irreducible water saturation	–	0.3
Porosity	vol%	21.34
Absolute permeability	mD (10^{-15} m^2)	367.96

microscopic flow diversion by colloidal dispersion gels. Surface-coated silica nanoparticles have been used to stabilize both water-in-oil and oil-in-water emulsions [17]. CO_2-in-water foams have been created using these same particles by Espinosa et al. [18], even at high temperatures (up to 95 °C). Remarkably, in both cases, emulsions and foams were created without the aid of surfactants. Qiu [19] investigated nanoparticle and surfactant-stabilized solvent-based emulsion under laboratory conditions. Using hydrophilic/hydrophobic synthesized nanoparticles, Zhang et al. [20] made oil in water emulsions and stabilized CO_2 foams with quite high stability. Hamedi Shokrlu and Babadagli [21] could achieve higher oil recovery through steam stimulation process in the presence of stabilized metal nanoparticles. Roustaei et al. [22] investigated the capability of different polysilicon nanoparticles as enhanced oil recovery agents with main focus on interfacial tension reduction and wettability alteration mechanisms. Haroun et al. [23] proposed a procedure including physical processes in nano-EOR on carbonate core plugs. The main objective of their work was reducing HSE concerns associated with nanoparticle transport as well as targeting un-recovered oil. Ogolo et al. [24] investigated nine different kinds of nanoparticles dispersed in different fluids as EOR agents and identified how some particles could boost hydrocarbon recovery. Viscous carbon dioxide in water foams were generated by shearing CO_2 and an aqueous phase of

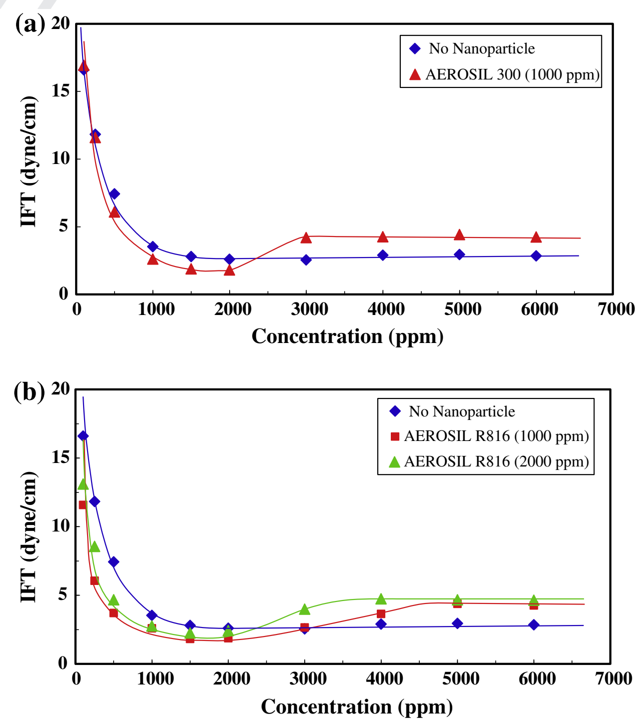

Fig. 2. Oil/water interfacial tensions for aqueous nanoparticle-augmented surfactant solutions of different surfactant concentrations at constant nanoparticle concentrations. (a) AEROSIL 300, and (b) AEROSIL R816.

partially hydrophobic silica nanoparticles by Worthen et al. [25]. Hendraningrat et al. [26] performed several experimental studies to investigate oil recovery using hydrophilic silica nanoparticle injection. Both secondary and tertiary processes were evaluated.

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