ARTICLE IN PRESS

Egyptian Journal of Petroleum xxx (2017) xxx–xxx

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Contents lists available at ScienceDirect

Egyptian Journal of Petroleum

journal homepage: www.sciencedirect.com

Full Length Article

Silica nanofluid flooding for enhanced oil recovery in sandstone rocks

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ARTICLE INFO

Article history:
Received 26 September 2016
Revised 26 December 2016
Accepted 24 January 2017
Available online xxxx

Keywords:
Enhanced oil recovery (EOR)
Porous media
Dispersed silica nanoparticle
Nanoflooding
Nanoparticles stability
Nanofluid

ABSTRACT

Enhanced oil recovery is proposed as a solution for declining oil production. One of the advanced trends in the petroleum industry is the application of nanotechnology for enhanced oil recovery. Silica nanoparticles (SiNPs) are believed to have the ability to improve oil production, while being environmentally friendly and of natural composition to sandstone oil reservoirs.

In our work, we investigated the effect of silica nanoparticles flooding on the amount of oil recovered. Experiments were carried using commercial silica of approximately 20 nm in size. We used sandstone cores in the core flooding experiments. For one of the cores tertiary recovery is applied where brine imbibition was followed by nanofluid imbibition. While in the other cores secondary recovery was applied where primary drainage is directly followed by nanofluid imbibition. We investigated the effect of concentration of nanofluid on recovery; in addition, residual oil saturation was obtained to get the displacement efficiency. Silica nanofluid of concentration 0.01 wt%, 0.05 wt%, 0.1 wt% and 0.5 wt% were studied.

The recovery factor improved with increasing the silica nanofluid concentration until optimum concentration was reached. The maximum oil recovery was achieved at optimum silica nanoparticles concentration of 0.1 wt%. The ultimate recovery of initial oil in place increased by 13.28% when using tertiary flooding of silica nanofluid compared to the recovery achieved by water flooding alone. Based on our experimental study, permeability impairment was investigated by studying the silica nanoparticles concentration, and the silica nanofluid injection rate. The permeability was measured before and after nanofluid injection. This helped us to understand the behavior of the silica nanoparticles in porous media. Results showed that silica nanofluid flooding is a potential tertiary enhanced oil recovery method after water flooding has ceased.

1. Introduction

Due to the declining oil production in many oil reservoirs, advanced techniques are necessary to continue oil production and to recover more oil in place [1]. Among those techniques are the enhanced oil recovery techniques. The use of nanotechnology for enhanced oil recovery is considered to be a new emerging trend. This nanotechnology application began at the end of 1980's and has been developed to synthesize new nanomaterials by rearranging atoms and molecules [2]. Based on the small size of the nanoparticles (1–100 nm), the optical, thermal, chemical, and structural properties of the nanomaterial differs totally from those displayed by either their atoms or the bulk materials [3].

For enhanced oil recovery purpose, the smaller the nanoparticle size, the larger the surface area, and the larger the contact surface between the nanoparticles and the oil phase. This allows better interaction between the nanoparticles and the oil phase for further recovery [4]. The most commonly used nanoparticles in enhanced oil recovery are silica nanoparticle (SiNPs). About 99.8% of silica nanoparticle are silicone dioxide, which is the main component of sandstone. Silica nanoparticles are an environmentally friendly material compared to other nanomaterials. In addition, silica nanoparticles are cheap and their chemical behavior could be easily controlled by surface modification.

There are possible displacement mechanisms, by which silica nanoparticle could enhance oil production, are believed to occur. The first mechanism is the disjoining pressure mechanism. This mechanism occurs when silica nanoparticle are present in the dis-

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Peer review under responsibility of Egyptian Petroleum Research Institute.

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http://dx.doi.org/10.1016/j.ejpe.2017.01.006
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Please cite this article in press as: M.I. Youssif et al., Silica nanofluid flooding for enhanced oil recovery in sandstone rocks, Egypt. J. Petrol. (2017), http://dx.doi.org/10.1016/j.ejpe.2017.01.006

persing medium, so these particles tend to rearrange themselves in a wedge-shaped film in contact with the discontinuous oil phase [5,6]. The wedge film acts to detach the oil phase from the rock surface, hence recovering more oil as illustrated in Fig. 1. The disjoining pressure represents the pressure difference between the pressure in the wedge film region and that in the bulk liquid [7]. This pressure is driven by Brownian motion and the electrostatic repulsion between molecules.

The second mechanism is the Log-Jamming mechanism. Due to the smaller size of pore throats and the constant differential pressure in the pores, the velocity of the silica nanofluid will increase at the pore throat compared to the pore body. This may cause the water molecules to move faster than the silica nanoparticles, causing the nanoparticles to accumulate and eventually block the pore entrance. This may force the water flow to change pass to other non-invaded pores, possibly oil filled, resulting in more oil recovery. The third mechanism is the wettability alteration mechanism. Silica nanoparticles have the ability to change rock wettability and to reduce the interfacial tension and the contact angle between two immiscible fluids [1,8–10].

Oil recovery by nanofluid flooding is affected by various parameters such as nanofluid concentration, particle size, injection rate, and slug size. Nanofluid concentration is considered one of the major parameters to enhance oil recovery. The goal of this study is to investigate the effect of silica nanofluids as an enhanced oil recovery agent in Sandstone rocks.

2. Materials and methodology

2.1. Materials

Three Sandstone cores of different permeability ranges were used. The properties of the cores are listed in Table 1. Black oil of 32.5 API and 4.6 cp obtained from the North Sea was used in the flooding experiments. The synthetic brine used is of concentration of 3.0 wt% NaCl (GPR grade, purity 99.5%, from Alpha Chemicals Company).

Commercial hydrophilic mono dispersed silica (SiO_2) nanoparticles of 370 m^2/g specific area were used in the experiments. The average particle size was 22 nm. They consist of basically more than 99.8% of silicon dioxide (SiO_2) (Al_2O_3) $\leqslant$0.06%, Titanium Dioxide (TiO_2) $\leqslant$0.03%, Hydrogen Chloride (HCl) $\leqslant$0.028% and other traces elements.

Hydrophilic silica nanoparticles were suspended in 3 wt% brine; this solution will be referred as silica nanofluid. The Nanofluid was prepared with different concentrations, 0.01 wt%, 0.05 wt%, 0.1 wt %, 0.2 wt% and 0.5 wt%. Each solution was mixed by using magnetic stirrer for several minutes. To avoid precipitation of nanoparticles from solution, ultrasonic probe (400 W and 0.5 Hz) is used for 1 h to assurance the homogeneity and stability of prepared solutions. The properties of the used nanofluid at different silica nanoparticles concentrations are listed in Table 2.

2.2. Methodology

The equipment used for cores flooding was manufactured by Vinci Company, in France. The experimental set-up is shown in Fig. 2. Two flooding scenarios were studied; one with silica nanofluid as a secondary recovery technique, and the other where silica nanofluid are used as a tertiary recovery technique.

In the first scenario, silica nanofluid were used as a tertiary recovery technique. Core# 1 was first cleaned and dried then placed in glass desiccator to be fully saturated with brine of 3 wt % NaCl concentration. The weight of the core was recorded many times until the weight remained constant. The core was placed in the core holder and black oil injection took place. The injection flow rate was increased until irreducible water saturation was reached. At this point the core was saturated with oil. Then imbibition process was initiated by using brine to displace oil at injection rate of 0.5 ml/min, and then continued until no more oil produced. Pore volume of the injected brine was 1.77 PV. At this stage, residual oil saturation (S_{or1}) was determined, and recovery factor was calculated. The next step was to continue injection by nanofluid of different concentration at injection rate of 0.5 ml/min. At this stage, residual oil saturation (S_{or2}) was determined again, and recovery factor was calculated to determine how much oil would be produced at this concentration.

The displacement efficiency was calculated from the following equation:

$$E_D = \left[1 - \frac{S_{or2}}{S_{or1}}\right] * 100 \tag{1}$$

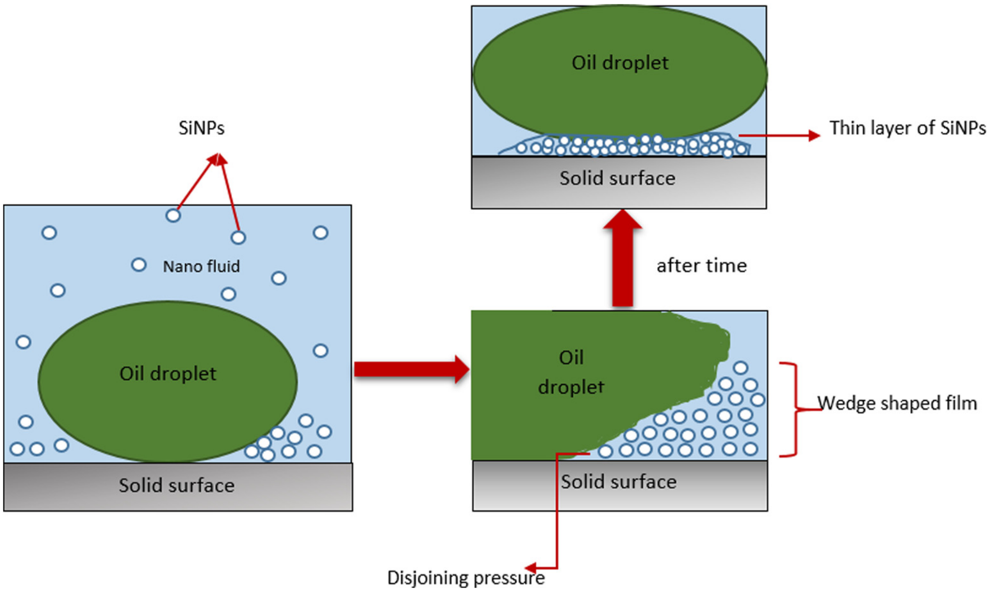

Fig. 1. Illustration of nanoparticle schematic and structural disjoining pressure gradient mechanism among solid, oil and nanofluids as aqueous phase.

Please cite this article in press as: M.I. Youssif et al., Silica nanofluid flooding for enhanced oil recovery in sandstone rocks, Egypt. J. Petrol. (2017), http://dx.doi.org/10.1016/j.ejpe.2017.01.006