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The Influence of Hydrophobic Multiwall Carbon Nanotubes Concentration on Enhanced Oil Recovery

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Abstract

One of the main challenges facing the oil and gas industry is the need to develop novel techniques forenhanced oil recovery (EOR). In this study, nanofluid injection was proven to be potential tool for increasing oil recovery. Experiments were conducted to examine the impact of multi wall carbon nanotubes (MWCNTs) concentration on recovery efficiency and fluid mobility. BET analysis was used to investigate the surface area of MWCNTs. High Resolution Transmission Electron Microscope (HRTEM) was used to provide morphological description, and to evaluate the physio-chemical surface properties of the MWCNTs based on contact angle. Nanofluids of three different concentrations (0.01, 0.05 and 0.10 wt. %) were prepared from the MWCNTs. A water flooding experiment was then carried out to assess the impact of the nanofluid. From the results of, the MWCNTs fluid was found to be a good EOR agent. The highest recovery efficiency 31.8% of residual oil in place (ROIP) was achieved with the nanofluid of 0.05wt.% MWCNTs concentration. However, by observing the values of mobility reduction factor (MRF) used to investigate the fluid behaviour, it can be concluded that the behaviour of hydrophobic MWCNTs in water fluid is unpredictable.

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Keywords: Multi Wall Carbon Nanotubes (MWCNTs); recovery efficiency; and Enhancement Oil Recovery (EOR)

1. Introduction

One of the key issues confronting the oil and gas industry is the extraction of oiltrappedin reservoirs. After secondary recovery, an estimated 35-65% of the total oil in a reservoir is still trapped within the reservoir pores and oil channels [1]. Several EOR methods have been utilized over the years, such as chemical, thermal. These methods didn't success to increase the production remarkably due

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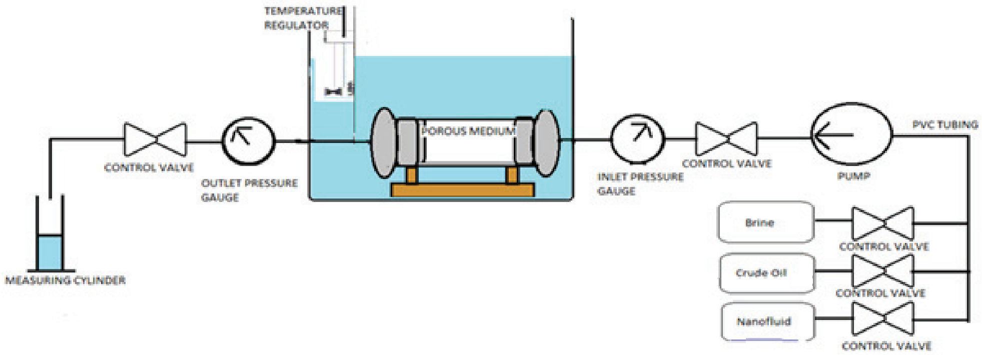
to the salinity of reservoir fluid phase. However, it was discovered that this has no significant impact on hydrophobic nanoparticles in oil water phases due to the tendency of hydrophobic nanoparticles to attach to oil and ions of salt dispersed in water [2].

On the contrary, it was observed that glass micromodel has negative surface charges which confirms the hydrophilic nature of the glass beads surface [3]. Moreover, nanoparticles with size of 10^{-9} meters are capable of detaching themselves due to their Brownian motion [4]. The nanoparticles tend to aggregate, which reduces their active surface area and leads to rock surface adsorption and blogging of pore throat. This phenomenon spontaneously reduces permeability and fluid mobility [5]

Alternatively, carbon nanotube (CNT) is being used in oil and gas researches as a viable solution appropriate for complex environments [6, 7]. Recently, MWCNTs-Silica nanohybrid were proposed to be used in EOR stage [8]. However, hydrophobic MWCNTs have not been used, to date, in EOR.

This present study involves the use of MWCNTs to investigate the impact of hydrophobic MWCNTs concentration on fluid mobility and recovery efficiency. The surface area (BET) of MWCNTs was measured, while TEM was used to study their morphology. The contact angle was measured using the sessile drop method to examine the physio-chemical surface properties of MWCNTs.



2. Experimental setup and procedures

Glass micromodels with diameter between 30- 60μm were used as porous media. Brine with concentration of 0.3wt. % was prepared by dissolving salt in distilled water. The measured density was 1.005 g/cc while pH= 6.85 at 23.0˚C. Nanofluid was prepared by dispersing 0.01, 0.05, and 0.10wt. % of MWCNTs in distilled water to be used as EOR agent. The suspension was stirred for 10 minutes using a magnetic stirrer to ensure the nanofluid dispersed well, and then sonicated for another 10 minutes to obtain a homogeneous solution. The setup of the experiment is shown in Fig.1.

The experiment was maintained at a constant temperature of 60˚C by soaking the medium in a water bath placed over a temperature regulator. The impact of concentration was studied by injecting three different concentrations (0.01, 0.05, 0.10 wt. %) of MWCNTs in distilled water, independently. The experiments procedures was conducted as follows: firstly, Brine was injected into the weighed medium at an injection rate of 1.0 mL/min, then Heavy Arab crude oil was injected into the medium at an injection rate of 0.8 mL/min until it was totally saturated. Afterwards, brine was injected again at flow rate of 1.0 mL/min so as to attain 2nd oil recovery. Extra brine was continuously injected into the medium until it reached the point where no more oil came out. EOR or 3rd stage of oil extraction from the reservoir (EOR) was carried out by injecting 2 pore volumes (PV) of MWCNTs with a specific concentration and flow rate into the porous medium. Thereafter, brine was injected into the porous medium again as a drive solution until no more oil came out. Mobility reduction factor (MRF) was calculated using equation (1) to understand fluid mobility in the medium:

$$MRF = \frac{\Delta P_2}{\Delta P_1} \tag{1}$$

Where; ΔP_1 is the difference in the pressure after water flooding stage. ΔP_2 is the difference in the pressure before water flooding stage (EOR stage).

3. Results and discussion

3.1. Characterization of MWCNTs powder

High Resolution Transmission Electron Microscope (HRTEM) was used to observe the morphology of the MWCNTs sample (Fig.2.a). The HRTEM confirms that the samples are multiwall carbon nanotubes (MWCNTs) with mean diameter of 20nm. The sessile drop method was used to measure the contact angle between the MWCNTs plate and water drop. The contact angle was found to be 136˚, which proves the hydrophobicity nature of MWCNTs (Fig.2.b). The surface area of the MWCNTs was also measured using BET method to be 30m^2/g.

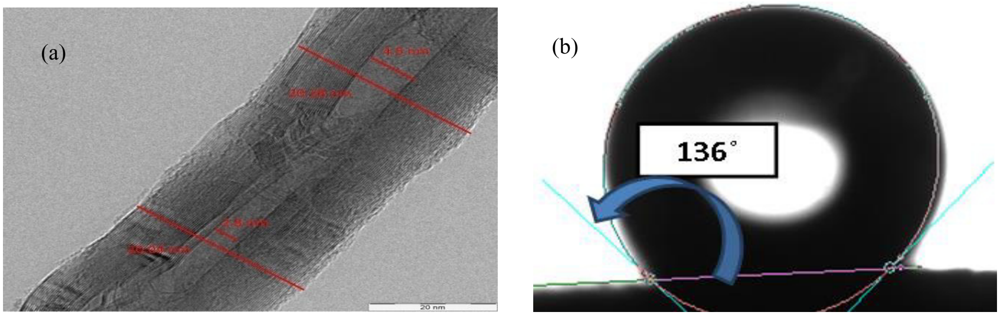


Fig.2. (a) HRTEM of MWCNTs; (b) contact angle between water droplet and plate of MWCNTs

3.2. MWCNTs fluid as an EOR agent

In this study, 3 different concentrations of MWCNTs in the fluid were injected independently into the porous medium in 3rd stage of oil recovery to study their impact on the fluid mobility and recovery efficiency in the porous medium. As observed in Fig.3.a, the highest recovery efficiency 31.8% ROIP was achieved with a concentration of 0.05wt. % while the other concentrations, 0.01 and 0.10wt. % demonstrated recovery efficiency of 29.2 and 23.0% ROIP respectively.

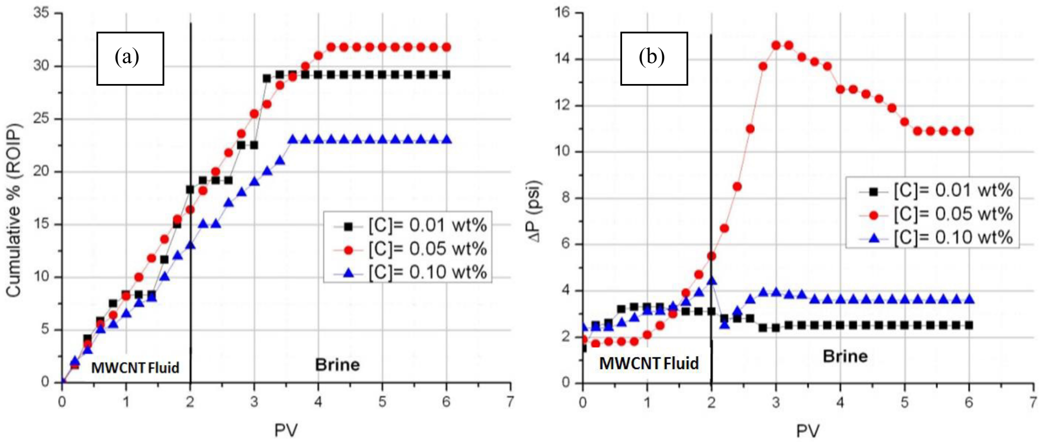


Fig.3. Comparison of the (a) recovery efficiency; (b) pressure versus pore volume of MWCNTs fluid and brine when different concentration of MWCNTs in the fluid were injected in EOR stage

The values of MRF for the concentrations 0.01, 0.05 and 0.10 wt. % were calculated from Fig.3.b to be 1.6, 10, and 1.7 respectively. It is an evident that these values are random and indirectly proportional to concentration, which indicates that the behavior of hydrophobic material in hydrophilic fluid and porous medium is not predictable. This implies that MWCNTs materials subjected to log-gamming effect due to their hydrophobic nature. Furthermore, it is apparent that the transportation of MWCNTs in the porous medium depends on the distribution of the pores, and the presence of trapped oil formed when particles adhere to the pore walls due to their oleophilic nature. This is demonstrated by the highest recovery efficiency 0.05wt.%, where flooding is enhanced when the blockage of channels or pore throats is nucleated in specific regions. This enhancement in flooding also increases the fluid velocity through some channels and pore throats containing trapped oil, and overcome the capillary pressure that traps oil. As a result, some additional oil might be mobilized and extracted. In addition, MWCNTs tend to form a thin film at the oil/water interface which adsorbs nanoparticles there by performing the role of surfactant by reducing the interfacial tension or surface energy [9, 10]. Moreover, Brownian motion will ensure MWCNTs are redistributed at oil/water interface. Thus, the surface energy or interfacial tension will be lowered because Brownian motion will work on reducing the cohesive energy at the interface to the lowest value [11].

4. Conclusion

TEM confirmed that the sample used in the experiment was in fact multiwall carbon nanotubes (MWCNTs). The active surface area measured with BET was $30m^2/g$. The measured contact was found 136˚ which proved the hydrophobic nature of MWCNTs. The study demonstrated that hydrophobic MWCNTs fluid has the ability to extract 31.8%ROIP of heavy Arab crude oil during EOR stage. Increasing fluid velocity through the channels which has trapped oil and reduction the interfacial tension between oil and water is the main reason back of recovery increment.

Acknowledgements

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