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Enhancement of Heavy Oil Recovery by Nanoparticle/Microwave Application

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Abstract

The primary heavy oil recovery is low due to the high viscosity and low mobility; hence, conventional thermal enhanced oil recovery methods such as steam flooding are widely applied to increase the oil production. New unconventional method such as microwave assisted gravity drainage (MWAGD) is under study the change the viscosity of the oil by microwave radiation. Different challenges such as heat loss and low efficiency are faced in unconventional thermal recovery methods especially in deep reservoirs. To improve the performance of unconventional methods, nanotechnology can play an important role. Nanomaterials due to their high surface to volume ratio, more heat absorbance, and more conductivity can be used in a novel approach called nanomaterial/microwave thermal oil recovery. In this work, several nanofluids prepared from nanoparticles such as γ-Alumina (γ-Al_2O_3), Titanium (IV) oxide (TiO_2), MgO, and Fe_3O_4 were used to enhance the oil viscosity reduction in the porous media under MWAGD mechanism. Our tests showed that adding nanoparticles can increase the absorption of microwave radiation in the oil/water system in the porous media. The magnitude of this increase is related to the type, particle size distribution in base fluid and, concentration of nanoparticles. Aluminum oxide nanoparticle was found to have the greatest effect on thermal properties of water. For example, only 0.05 wt.% of this nanoparticle, improves the alteration in temperature of water for around 100%. This change can affect the oil recovery and changed it from 37% to more than 40% under MWAGD. Hence, our experiments showed that besides other applications of nanotechnology in enhance oil recovery, heavy oil recovery can also be affected by nanomaterials.

1. Introduction

Nanotechnology is the study materials at the range of 1 nm to 100 nm size. Due to the specific properties at this range, different applications have been introduced in branches of science such as medicine, electronic, space and information, science and engineering [1–12]. Different properties of materials at the nano scale such as large surface area makes them attractive to use in fluid/solid interactions and modifications of material surfaces.

During the last decade, petroleum researchers have also been attracted by nanotechnology to overcome their problems in producing oil and improving recovery from oil reservoirs. Generally after primary and secondary oil recovery stages in an oil field, noticeable amount of oil remains in the porous media as a discontinuous phase in the form of oil drops trapped by capillary forces. Enhanced oil recovery (EOR) methods are needed to affect the forces in the porous media and overcome this capillary force to produce the residual oil. Different applications of nanotechnology to improve the performance of EOR methods have been reported in the literature, mostly at lab scale study. Different laboratory studies show that nanofluids are able to recover trapped oil from reservoir efficiently [13–16]. In most of the cases nanoparticles are used to enhance the fluid property and change the rock/oil/brine interactions to make the oil in the porous media mobile. For example, applications of nanoparticles may affect wettability of the rock or

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interfacial tension of oil and brine which can reduce the capillary force in pore spaces. There are several literature reviews on applications of nanotechnology in difference disciplines of petroleum engineering and especially in EOR which shows the importance of this technology in the oil industry [12, 17].

One of the main approaches to improve oil recovery by EOR methods is to increase the ratio of viscous to capillary forces to make the oil mobile. In many cases such as heavy oil reservoirs due to the high viscosity of the oil, movement of drops is more difficult and requires EOR approaches such as thermal methods. The main idea of conventional thermal processes is to improve the oil viscosity, oil mobility, and well productivity by increasing the reservoir temperature by injecting hot fluid or producing a hot zone. The most popular ones are steam flooding, in situ combustion, steam assisted gravity drainage (SAGD), and cyclic steam injection (CSS) [18]. Due to the high heat loss to the surrounding formations and operational problems, there is a new trend to use unconventional thermal methods to improve the oil recovery especially in deep thin reservoirs. In these methods, fluids in the formation are heated by waves or electricity by electromagnetic heating. Hence, the medium is heated more uniformly as the heat is generated inside it instead of being brought from the outside.

Electromagnetic heating is a thermal EOR method that utilizes microwave and radio frequency to heat reservoir fluids. The primary heating mechanism in this technique is dielectric heating. This mechanism, also known as high-frequency heating, is a process in which high frequency waves heat a dielectric material by dipole rotation. As the electromagnetic field alternates, polar molecules in dielectric materials continuously try to align themselves in the field. Rotating molecules push, pull and collide with other molecules and because of friction, the dielectric materials are heated tremendously as seen in domestic microwave ovens [19]. In the unconventional methods, electromagnetic heating can be used to heat up the target area more efficiently with lower heat losses than with the conventional thermal process. This method is considered as a green technology for thermal oil recovery.

In electromagnetic heating, two horizontal wells are drilled and completed parallel to each other as the upper injection well and lower producer. By microwave radiation, the residual oil in the porous media close to the injector is heated and drained to producer due to the gravity. The heated oil is produced to the surface. There are a few publications in this area to study the possibility of microwave assisted gravity drainage (MWAGD) at the lab scale [20–22].

Unfortunately, there are also another challenges with these unconventional methods such as low penetration in the porous media. Hence, it is critical to make the heat absorption more efficient in the formation. To overcome this challenge, nanotechnology can be used. It is possible to improve the performance of microwave heating in the formation by a preflush of nanofluid to the area around the injector. By improving the heating, viscosity reduction and oil drainage are enhanced which affects the productivity of the well. In this paper the possibility of nanotechnology application to enhance the capability of the formation fluid to absorb prior to employment of the MWAGD method is studied to develop a new EOR method in this field.

2. Experimental

2.1. Experimental setup

The experimental setup consists of a microwave oven system with fixed power and variable time settings, a glass container, a Perspex plastic filter, and glass beads. This setup is used to study the effect of water saturation, to compare the conventional thermal methods with unconventional thermal methods, and to study the effect of nanoparticles. The container was filled with a homogeneous mixture of heavy oil (API _ 19), water, and glass beads to mimic the sandstone formation. After packing the mixture, the porous media was left to produce oil by the gravity drainage in the primary recovery stage. After completion of this stage and when there is no more oil recovery, the container was put under the microwave radiation to study the incremental oil recovery by MWAGD process. Different parameters such as water saturation in the porous media and radiation duration affect the oil recovery. In this work to improve the production, flushes of different nanofluids were added to the water in the porous media to compare the performance of MWAGD and nano-MWAGD methods.

As the preliminary test, different mixtures of water and nanofluids were heated by conventional heating method and microwave radiation to investigate the possibility of enhancing the heating process.

MgO, Al_2O_3, SiO_2, and Fe_3O_4 nanoparticles were used in this study. Purity of all of them were higher that 99%. Average particle size of these materials were 20 nm, 10–20 nm, 10 nm, and 60 nm, respectively. Also, specific surface area of them were 40, 90–160, more than 600, and 55 m^2/g, respectively.

3. Results and discussion

3.1. Preliminary results

In order to evaluate the effects of nanoparticles type and concentration on thermal properties of water, different samples were prepared by mixing of deionized water and various concentrations of nanofluids. The sample was placed under the microwave radiation and the temperature was recorded after different times of microwave irradiations. The same experiment was done by deionized water as the base case to investigate the effect of nanofluids. Our experiments showed that the temperature of the nanofluids increased more than the de-ionized water. Figure 1 shows a sample of results which compares the increase in temperature after 75 sec of microwave irradiation for different types and concentrations of nanofluids. For more comprehensive results, reader is referred to [19]. This example shows a clear increase in nanofluids temperature compare to water. Hence, it proves the possibility of this new approach to improve the performance of MWAGD in heavy oil formations. Hence, Adding nanoparticles can increase the absorption of microwave radiation in de-ionized water. The magnitude of this increase is related to type, particle size distribution in base fluid and, concentration of nanoparticles.

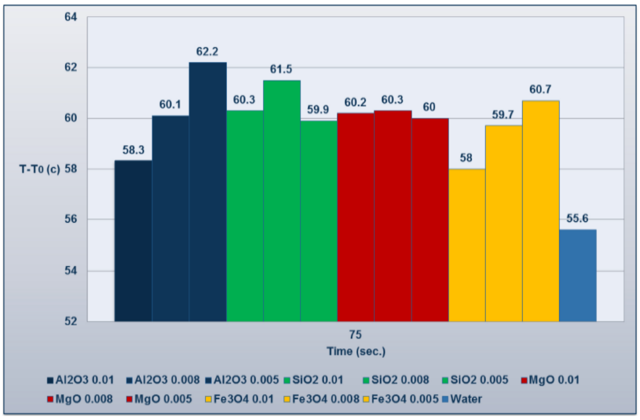

Fig. 1. Temperature alteration of deionized water and different water/nanofluid mixtures under microwave radiation

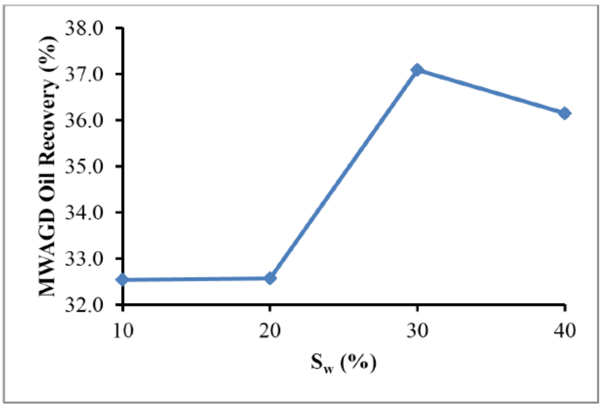

Fig. 2. Oil recovery under MWAGD for different initial water saturation in porous media.

3.2. Oil recovery in porous media

As mentioned, different parameters affect the heat absorption in the porous media under microwave radiation. Figure 2 shows the oil recovery by MWAGD for different water saturation in the porous media. It can be noticed that higher recoveries were obtained at higher water saturations with an optimum recovery at 30% water saturation. This can be explained by the more absorption of heat by water molecules in the system. At very high water saturation due to the formation of oil/water emulsions, the viscosity of the mixture increases which affects the capillary forces and reduces the oil recovery. At higher water saturation, the change in temperature is higher which changes the oil viscosity more. The lower the oil viscosity, the lower the capillary force. Hence, the gravity force can overcome the capillary force and mobilize oil droplets from pore spaces. A complete set of results for this study is presented at [18].

Oil recovery under gravity drainage improved due to the presence of nanoparticles and alteration in the emulsion viscosity and the thermal conductivity of the nanofluid. As shown in our preliminary tests, alumina has potential to improve the oil recovery. We examined alumina and different other nanomaterials to be used as the preflush to the porous media. After mixing them in the media, the system will be set under MWAGD. Figure 3 shows the average oil recovery by MWAGD for one case as an example. In this case, we used alumina as the additive. It can be noticed that the highest recovery with Al_2O_3 occurs between 0.1 and 0.5 wt.%. Our experiments showed that at this range, the oil/water emulsion breaks due to the presence of nanoparticles which reduces the emulsion viscosity.

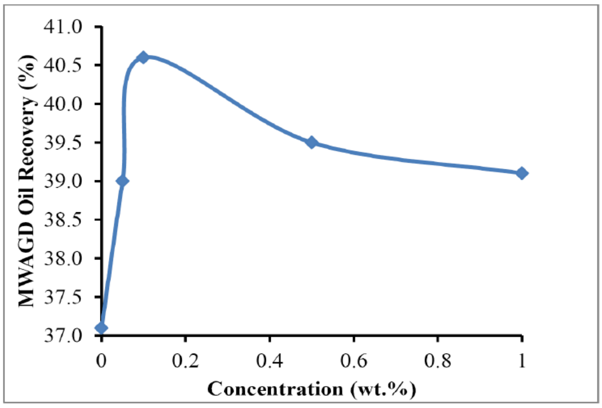

Fig. 3. Average oil recovery under MWAGD under microwave heating for Al_2O_3 nanoparticles.

Also we observe the higher thermal conductivity at this range. Hence, these two mechanisms reduces the oil viscosity and also emulsion viscosity which affects capillary force. At lower nanoparticle concentration, the recovery is lower due to the higher emulsion viscosity. Also, at high concentration, one reason for the lower recovery may be the agglomeration of nanoparticles and plugging of pore channels [23].

The nanoparticle effect on the emulsion viscosity at different temperatures were measured as shown in Fig. 4. At 80 °C and 0.05 wt.%, for example, Al_2O_3 nanofluid increases the emulsion viscosity by 1.98% compared to the emulsion without nanoparticles. At 0.1 wt.%, Al_2O_3 nanofluid has almost no effect on the emulsion viscosity and the emulsion viscosity increases by about 0.4% compared to the emulsion without nanoparticles. That means the specific surface area of Al_2O_3 still does not reach its critical point where it can reduce the viscosity. From the figure, it can be noticed that the trend of Al_2O_3 nanofluid is changing between 0.1 wt.% and 0.5 wt.% that means its viscosity critical reduction point is located between these two concentrations. At 0.5 wt.%, Al_2O_3 nanofluid shows the maximum declining in emulsion viscosity by 5.95% compared to the base case, which is without nanoparticles. Ogolo et al. found that Al_2O_3 nanoparticles have the ability to reduce the oil viscosity when used with distilled water and brine as dispersing fluids [24]. As the concentration of nanofluid rises, the specific surface area value will be less that will reduce the effect on the emulsion viscosity.

In this section, the improvement of water thermal conductivity is discussed by studying the change in nanofluid temperature (the difference in temperature of the nanofluid after and before the microwave heating) (T-To). Figure 5 shows the change in nanofluid temperature for different concentrations and for different microwave heating periods. At 0.05 wt.%, the change in temperature for Al_2O_3 nanofluid reaches up to 44 °C that is around 100% change in temperature compared it to the base case (water without nanofluid). At 0.5 wt.%, the change in temperature for Al_2O_3

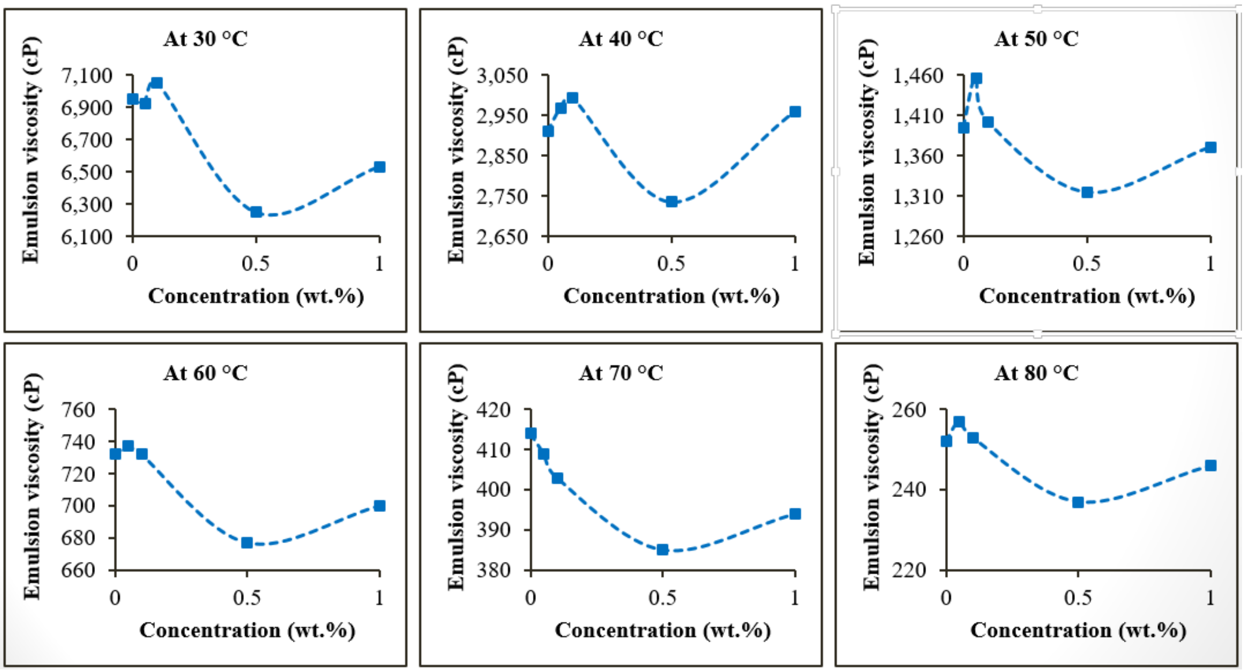

Fig. 4. Effect of nanofluid on emulsion viscosity.

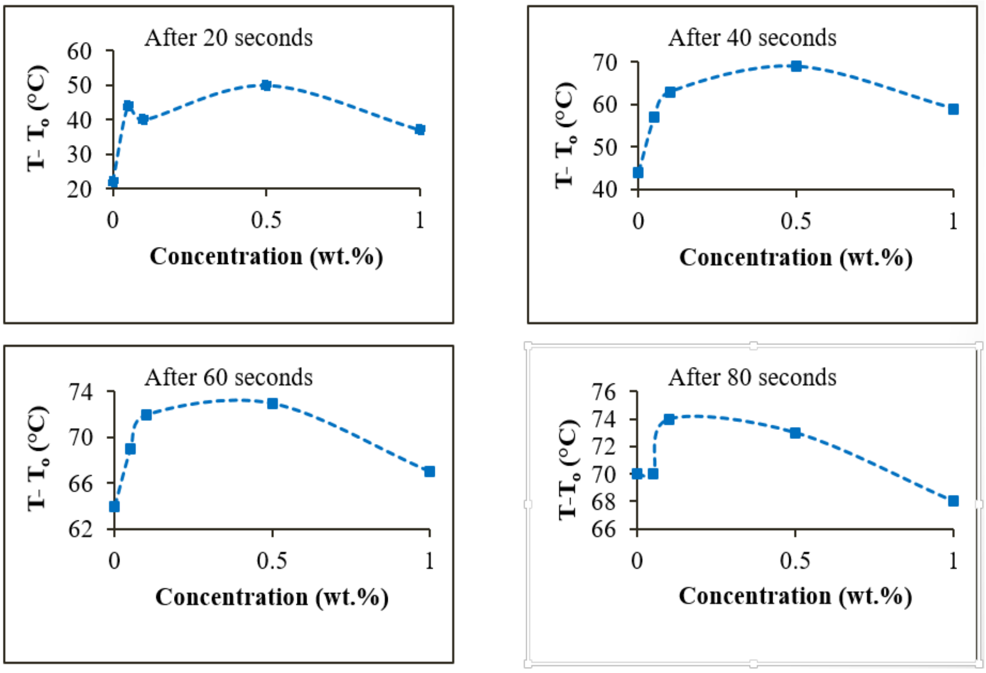

Fig. 5. Effect of nanofluid on thermal conductivity.

reaches a maximum value of 50 °C, which is an increase by 127% when comparing it to 0 wt.%. This can be explained by that, the specific surface area reaches its critical point.

Hence, adding nanoparticles to the water improves its thermal conductivity, increases the heat adsorption, reduces the heavy oil viscosity, and increases the recovery by MWAGD. Results for other nanoparticles are explained in details in [22].

4. Conclusions

Adding nanoparticles can increase the absorption of microwave radiation in formation water. The magnitude of this increase is related to type, particle size distribution in base fluid and, concentration of nanoparticles.

Adding nanoparticles to the water improves its thermal conductivity, increases the heat adsorption, reduces the heavy oil viscosity, and increases the recovery by MWAGD.

Nanotechnology can assist oil industry to improve oil recovery in thin deep heavy oil reservoirs by affecting the performance of MWAGD.

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