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IMPROVING OIL RECOVERY USING Fe_2O_3 NANOPARTICLES FLOODING

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Abstract

Both primary and conventional secondary recovery methods can approximately produce 35% of the original oil in place (OOIP). Application of nanotechnology in the petroleum industry has already drawn attention for its great potential of enhancing oil recovery. In the last few years, some publications have already addressed this topic, but its mechanism to enhance oil recovery has not been released very clearly. The main objective of this paper is to investigate the effect of Fe_2O_3 nanoparticles to improve oil recovery. This paper also aims to investigate the reason behind this improvement in oil recovery. A series of sandpack flooding runs were conducted to study the effect of Fe_2O_3 nanoparticles concentration in the displacing brine on wettability alteration, oil viscosity, interfacial tension, and finally the ultimate recovery factor. Fe_2O_3 nanoparticles were prepared in four different concentrations (0.005, 0.01, 0.1 and 1 wt. %) using sonication method. Then Fe_2O_3 nanoparticles used for flooding in a sand pack model after saturation of brine and crude oil respectively. The crude oil supplied from the western desert in Egypt with API= 30.749º. All nanoparticles have the same size of 5.0 nm. The base run was performed using conventional water flooding. The ultimate recovery factor by water flooding was 50.4 % of the OOIP. Results have proved an enormous improvement in the recovery factor that reaches 70 % of the OOIP by using Fe_2O_3 nanoparticles at a concentration of 0.01 wt%. Moreover, the effect of Fe_2O_3 nanoparticles on oil viscosity, interfacial tension, and wettability alteration was investigated. Finally, an economic study was conducted through a comparison between Fe_2O_3 nanoparticles flooding and conventional water flooding.

Keywords: *Fe_2O_3 nanoparticles; Improved oil recovery; Wettability alteration; Oil viscosity; Interfacial tension.*

1. Introduction

Currently, enhanced oil recovery through chemical flooding acquires incremental attention on both laboratory and field scale [1-7]. The remaining oil in place after applying primary and secondary oil recovery methods reaches in most oil fields, 65% of the original oil in place [8]. In the few past years, some changes were noticed in the way which crude oil is extracted all over the global market. As in Latin America, the production of crude oil was increased by approximately 4.4 MMbbl/day. About 1.0 MMbbl/day out of this production growth, was produced by the upgrading of crude oil properties from Venezuela [9]. Nanotechnology deals with various structures of materials having dimensions of what is called a nanoscale level, perhaps from 1 to l00 nm [10]]. One nanometer (nm) is one billionth of a meter, and it is 10,000 times smaller than the diameter of a human hair. A nanoelement compares to a basketball, like a basketball to the size of the earth. The promise and essence of the nanoscale science and technology are based on the demonstrated fact that materials at the nanoscale have distinct chemical, electrical, magnetic, mechanical and optical properties rather than the bulk materials [11]. Many researchers investigated the effect of some nanoparticles on improving oil recovery. They stated that the nanoparticles have the ability to penetrate the edge of the discontinuous phase and form a film between the oil and the rock, thus improves the oil recovery, as illustrated in figure 1. This mechanism is known as a joint mechanism [12-14].

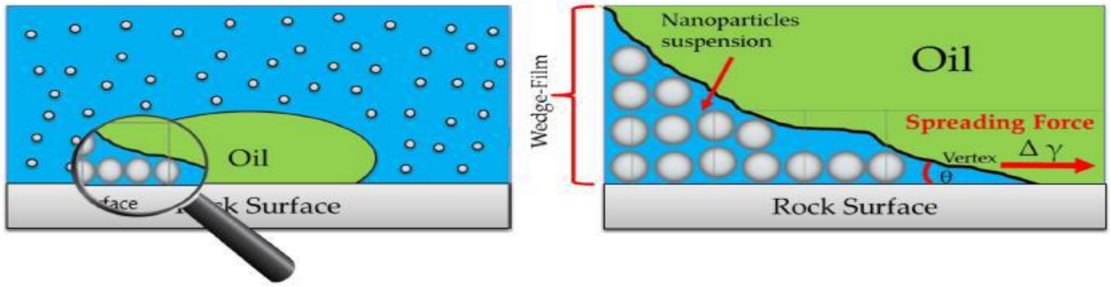


Fig. 1. Clarifying the joint mechanism due to the presence of nanoparticles in the injection fluid

Alomair *et al.* [15] and Alomair and Alajmi [16] have stated that there is a noticeable effect on interfacial tension of crude oil/ brine and oil viscosity through flooding of nano-SiO_2, NiO and tungsten trioxide. The nanoscale of any particle type has shown their ability in the change of its chemical and physical properties; due to the difference between the particles at their naturally occurring size, to the nanoscale size. In other words, nanoparticles of a certain material exhibit different behavior than the material in its original size [17]. Lower production from heavy oil reservoir can be a result of the high crude oil viscosity. Therefore, decreasing the viscosity of crude oil is the best way to deal with these reservoirs. When the oil viscosity decreases, the oil mobility increases, and then an increase in the oil recovery occurs. The main reason for increasing the viscosity of crude oil is the reactions between the clusters. These micelles like clusters are the product of the asphaltene molecules agglomeration inside the crude oil.

Reduction of crude oil viscosity can occur when the clusters reactions stop by breaking the agglomeration between asphaltene molecules. One of the recommended solutions is reducing the crude oil viscosity by adding kerosene to crude oil. By the way, it was widely assumed that kerosene does not break the asphaltene molecules agglomeration. However, kerosene has shown its role as an effective diluent [18]. Nano-sized particles have shown their ability to change the physical and chemical properties compared to the particles in their natural size. These nanoparticles have also proved the ability to break down the agglomeration between the asphaltene molecules, so the interactions between clusters stop and the oil viscosity decreases [19]. Clark *et al.* [20] concluded that increasing the reservoir temperature is not the only way that decreases the oil viscosity. A series of chemical reactions have shown also a noticeable performance for decreasing the crude oil viscosity. The addition of nanometals to the process of thermal hydrocarbon recovery can guarantee a more reduction in the oil viscosity when it is compared with steam injection only. However, there is not a possible way to combine these nanoparticles with the steam injection until now [21]. Accordingly, this research suggests that the best applicable method to investigate the effect of nanoparticles on the crude oil viscosity through measuring the oil viscosity after being exposed to nanofluid flooding. In addition, another method was used to study the effect of adding nanoparticles at different concentrations on crude oil at 200 ºF that represents the actual reservoir temperature.

Wettability alteration or the change of the formation surface from oil wet to water wet has approved its ability to show a great enhancement to the oil recovery. Wettability alteration affects the relative permeability, fluid distribution, and fluid flow behavior [22]. Some nanoparticles have proved their ability to change the surface from hydrophobic to hydrophilic. In other words, some of the nanoparticles can change the surface properties from repelling water, to attract water and repelling oil instead. Accordingly, the electrostatic repulsion between oil and formation is noticed to be much higher during the existence of some nanoparticles. Then, a higher oil recovery occurs [22]. The probability of exploring new huge hydrocarbon fields is not that high as the way it was before. On the other hand, exploring small oil fields is not economical because of its highly expensive costs [23]. Therefore, the most economical solution is to produce trapped oil inside the previously developed field. Surfactant flooding and nano flooding displacement are the two common methods that are used from enhanced hydrocarbon methods, to produce this trapped oil and to increase the oil recovery [24]. The use of nanotechnology was commonly needed in the downstream industry [25]. However, there are researches that have proved the great impact of using nanoparticles inside the reservoirs, where an enhancement of viscosity, interfacial tension, and wettability alteration occur [26].

For the optimum nanofluid displacement, the concentration of nanoparticles has to exceed the critical micelle concentration, to decrease the interfacial tension and to increase the oil recovery [27]. Giraldo *et al.* [28] used SiO_2 nanoparticles-based nanofluid and NiO/SiO_2 nanoparticles-based nanofluid at a concentration of 100 mg/L and size of 116.5 nm. The researchers stated that the IFT in the absence of nanoparticles has a value of 26.2 mN/m. When nanoparticles are added to the system, the IFT decreases with both nanoparticles and is lower for the NiO/SiO_2 nanoparticles regarding the SiO_2 nanoparticles for the whole range of concentration evaluated. A minimum of the interfacial tension is observed at 100 mg/L for both SiO_2 and NiO/SiO_2 nanoparticles with values of 20.5 mN/m and 17 mN/m, respectively. However, they stated that SiO_2 did not show an increase in oil recovery regarding the one obtained in the water flooding step. Meanwhile, the NiO/SiO_2 nanoparticles at the same concentration showed an increase in oil recovery up to 50%. Sayed and Mohamed [29] investigated the effect of silica nanoparticles on enhanced oil recovery. They found that the ultimate recovery factor has been increased at a certain size and concentration. They indicated that the enhanced oil recovery in this situation results from the wettability alteration. Sayed, Adel, and Mohamed [29-30] investigated the effect of alumina (Al_2O_3) nanoparticles on enhanced oil recovery. They found that the ultimate recovery factor of 81.13% is achieved at 10 g/L. of Al_2O_3. They indicated that the enhanced oil recovery in this situation results from the wettability alteration. Moreover, they have addressed the importance of some nanoparticles in reducing crude oil viscosity and enhanced oil recovery.

This research serves to investigate the effect of Fe_2O_3 nanoparticles flooding on oil recovery. Four different concentrations of (0.005, 0.01, 0.1 & 1 wt.%) with size of <50 nm will be used. Conventional water flooding case was considered as the base run. Then the Fe_2O_3 nanoparticles will be sonicated in brine and used as a secondary recovery method. The crude oil viscosity and interfacial tension are measured before and after adding Fe_2O_3 nanoparticles. The effect of Fe_2O_3 nanoparticles on wettability alteration and improving oil recovery were investigated.

2. Experimental work

2.1. Materials and chemicals

Fe_2O_3 nanoparticles are iron(III) oxide, CAS no. 1309-37-1, with a size of less than 50nm, purchased from Sigma Aldrich.

2.2. Preparation of brine

Sodium chloride (NaCl) was used for preparing brine with a concentration of 35,000 ppm. This brine was then used for saturating sand pack, then soaked by crude oil to retrieve the initial reservoir conditions. Moreover, brine was used for preparing the nanofluid solution, which is then undergoing a sonication process.

2.3. Determining fluid properties

Pycnometer was used to measure the density of the fluids. While Chandler rolling ball viscometer was used to measure the fluid's viscosity. Finally, Tensiometer was used to measure the interfacial tension. The density of crude oil was measured to be 0.87 g/cc (API= 30.7º). The interfacial tension between crude oil and brine was 37.9 dyne/cm. While the measured crude oil viscosity = 9 cp.

2.4. Sandpack model

Average porosity is 28%, and the average absolute permeability is 832 mD. Sand pack inner diameter was 6 cm, and the length is 15 cm. Bulk volume is equal to 425 cc. Figure 2 illustrates a schematic representation of the flooding apparatus.

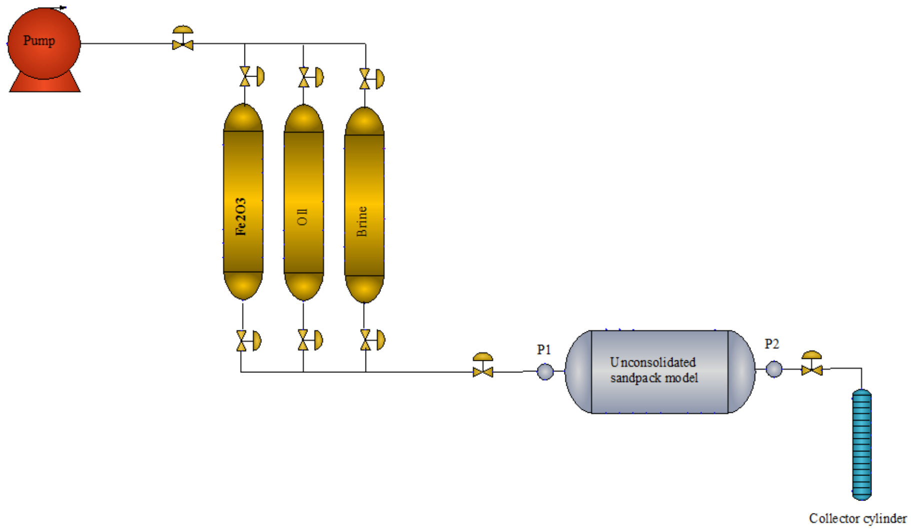


Figure 2. Schematic representation of displacement apparatus.

2.5. Sand pack initiation

Nanoparticles were prepared by the required concentrations in the previously prepared brine. Then this solution undergoes the sonication process inside a sonicator for 2-3 hours to make all nanoparticles suspended inside the solution or nanofluid.

2.6. Flooding operation

First, the sand pack is filled with sand while considering packing the sand well. Then brine is injected to the sandpack till the sandpack is fully saturated with brine. Then, inject oil to displace the existing brine. Not all the brine is displaced by the oil. Accordingly, the amount of displaced brine is the same amount of the initial oil in place for this case, and by subtracting the amount of brine displaced by oil from the total amount of brine that was initially injected to saturate the sand pack, now the calculated amount of un-displaced brine can represent the connate water saturation. Thus, it is possible to have the sand pack conditions like initial reservoir conditions.

2.7. Water flooding

In the base run case, brine was injected to displace the oil, and this case represents the conventional water flooding scenario. The amount of oil displaced by brine was measured to determine the oil recovery factor. Then, viscosity and interfacial tension of the displaced oil was measured. Relative permeability curve was constructed to determine if the sand pack is oil wet or water wet. This case was considered as a reference case for each following case, where the results of each nanofluid case were compared to this case of the conventional water flooding.

2.8. Injection of nanofluids

After constructing the conventional water flooding as a reference case, Fe_2O_3 nanofluid was injected in four different concentrations (0.005, 0.01, 0.1, 1.0 wt%). The oil recovery of each case was determined, along with measuring viscosity, interfacial tension, and wettability alteration. Accordingly, the reason behind the change (whether enhancement or reduction) in oil recovery for each case, was identified (due to change in oil viscosity, interfacial tension, and wettability). The experimental procedure was performed as follow:

1. Fill the sand pack with sand and consider packing the sand well. Then, determination of its dry weight.
2. Inject brine until the sand pack is fully saturated; calculate absolute permeability from Darcy equation. Then, measuring the sand pack weight at its saturated condition.
3. Subtract dry weight from saturated weight and then divide the result by brine density to calculate the pore volume.
4. Inject oil to displace the existing brine, where the amount of displaced brine is the same amount of the initial oil in place for this case. By subtracting the amount of brine displaced by oil from the total amount of brine that was initially injected to saturate the sand pack, now the calculated amount of un-displaced brine can represent the connate water saturation. The sand pack then simulates the reservoir having original oil in place and connate water.
5. Inject brine to displace the oil. For each fraction of the pore volume injected, the amount of injected brine is measured and the time is determined to calculate flow rate, then by substituting in Darcy equation, effective permeability is easily calculated.
6. Measure the amount of oil extracted to determine the oil recovery percentage.
7. Construct a relative permeability curve using absolute and effective permeability to determine the change in wettability.
8. Measure the viscosity of the extracted crude oil.
9. Measure the interfacial tension between the extracted crude oil with the injected solution.

To construct other cases than the conventional one, in step five, inject the prepared nanofluid instead of brine. Then, compare the results to the conventional water-flooding scenario.

3. Results and discussion

3.1. Wettability alteration

3.1.1. Base run: Conventional water flooding

Relative permeability curve, as shown in Figure 3 for conventional water-flooding, depicts that the intersection of both curves occurs at water saturation of 0.36. Accordingly, the formation is strong oil wet. Then, any noticeable alteration in the wettability will decrease the residual oil saturation and increases oil recovery. The ultimate recovery factor reaches up to 50% of the original oil in place, as shown in Figure 4.

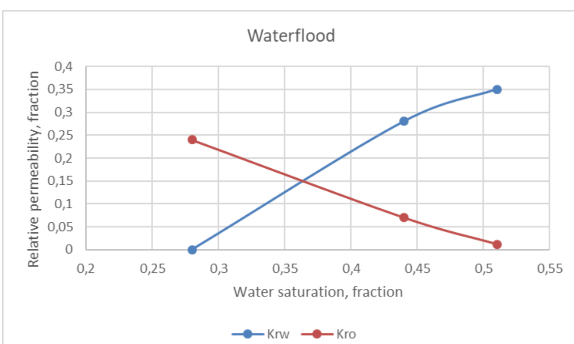


Fig. 3. Relative permeability curve for conventional water flooding

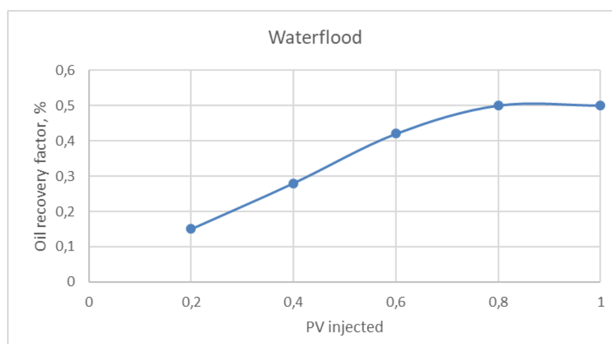


Fig. 4: Effect of conventional water flooding on oil recovery

3.1.2. Fe_2O_3 flooding (Case 1)

The Fe_2O_3 is added to brine in concentrations of 0.005 wt %. After sonication, the nanofluids were injected to the core sample to displace the oil. Relative permeability curve, as shown in figure 5. The intersection of both curves occurs at water saturation of 0.38, that means that formation is now slightly more water wet than the conventional water-flooding case. The oil recovery factor is 48 % of the original oil in place, as shown in figure 6.

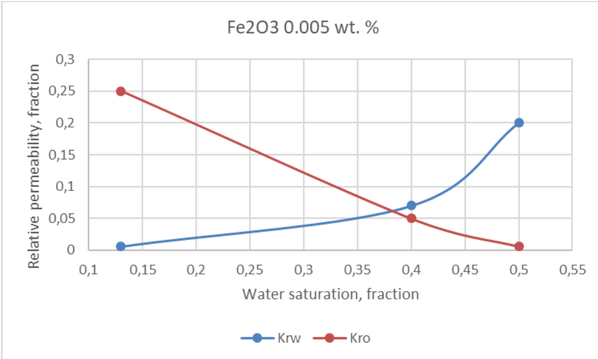


Fig. 5. Relative permeability curve at 0.005 wt % Fe_2O_3

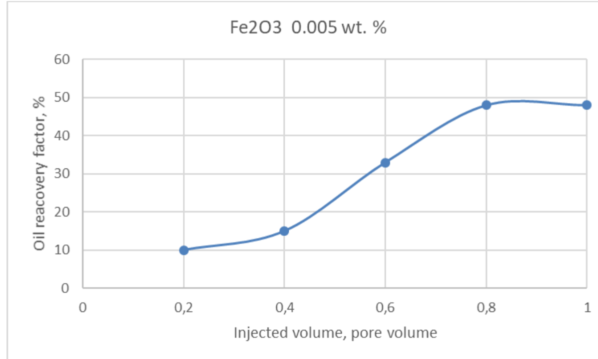


Fig. 6. Effect of 0.005 wt. % Fe_2O_3 on oil recovery

3.1.3. Fe_2O_3 flooding (Case 2)

The Fe_2O_3 is added to brine in concentrations of 0.01 wt. %. After sonication, the nanofluids were injected to the core sample to displace the oil. Relative permeability curve, as shown in Figure 7. The intersection of both curves occurs at water saturation of 0.42, that means that formation is more water wet than the conventional water-flooding case. The oil recovery factor is 80 % of the original oil in place, as shown in Figure 8.

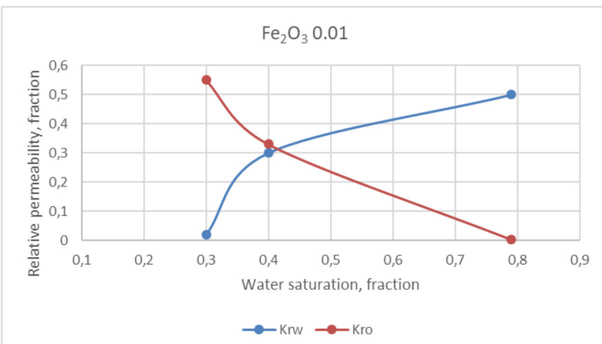


Fig. 7. Relative permeability curve at 0.01 wt % Fe_2O_3

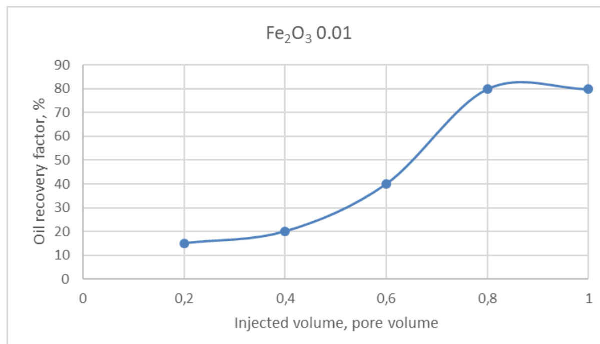


Fig. 8. Effect of 0.01 wt % Fe_2O_3 on oil recovery

3.1.4. Fe_2O_3 flooding (Case 3)

The Fe_2O_3 is added to brine in concentrations of 0.1 wt %. After sonication, the nanofluids were injected to the core sample to displace the oil. Relative permeability curve, as shown in Figure 9. The intersection of both curves occurs at water saturation of 0.43 that means that formation is more water wet than the conventional water-flooding case but less than a case of 0.01. The oil recovery factor is 50 % of the original oil in place, as shown in Figure 10.

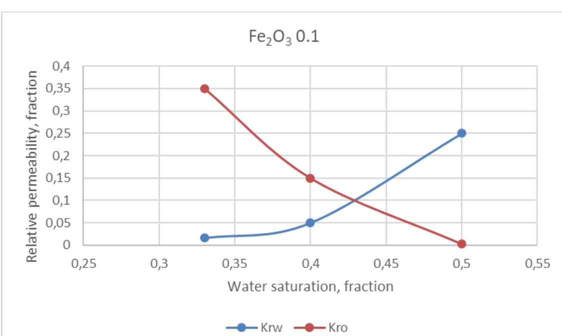


Fig. 9. Relative permeability curve at 0.1 wt. % Fe_2O_3

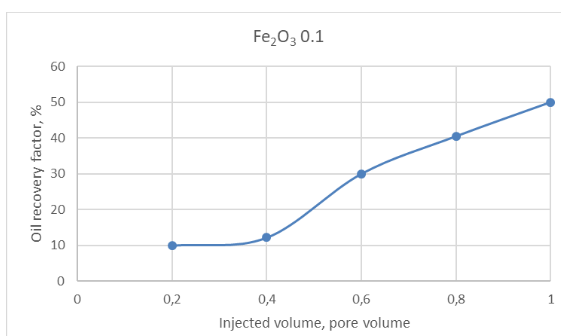
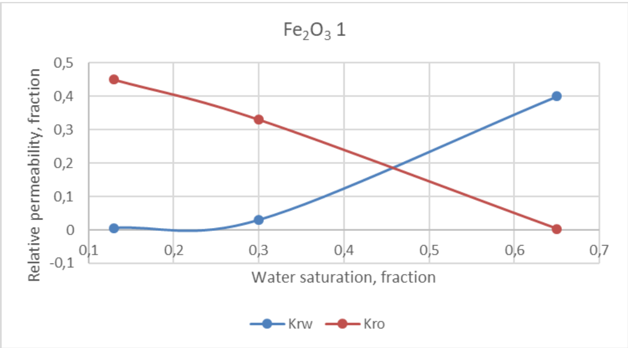


Fig. 10. Effect of 0.1 wt. % Fe_2O_3 on oil recovery

3.1.5. Fe_2O_3 flooding (Case 4)

The Fe_2O_3 is added to brine in concentrations of 1 wt. %. After sonication, the nanofluids were injected to the core sample to displace the oil. Relative permeability curve, as shown in Figure 11. The intersection of both curves occurs at water saturation of 0.46, that means that formation is now slightly more water wet than the conventional water-flooding case. The oil recovery factor is 45 % of the original oil in place, as shown in Figure 12.



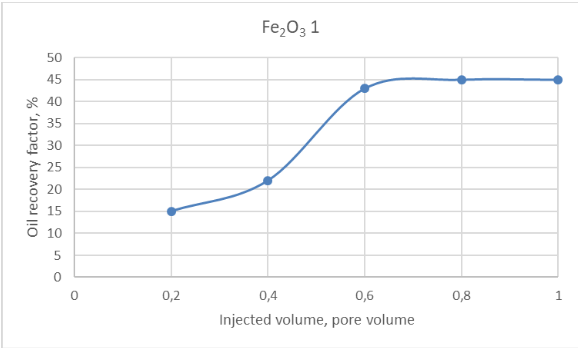


Fig. 11. Relative permeability curve at 1 wt. % Fe_2O_3

Fig. 12. Effect of 1 wt. % Fe_2O_3 on oil recovery

4. Reduction of crude oil viscosity

Fe_2O_3 nanoparticles with four concentrations (0.005, 0.01, 0.1 and 1 wt. %) are added to the crude oil. The mixture is sonicated. Then, the crude oil viscosity is measured using rolling ball viscometer at 200 ºF that represents the actual reservoir temperature. Figure 13 shows the effect of each concentration of Fe_2O_3 nanoparticles on crude oil viscosity. When the concentration of Fe_2O_3 nanoparticles increases the crude oil viscosity decreases.

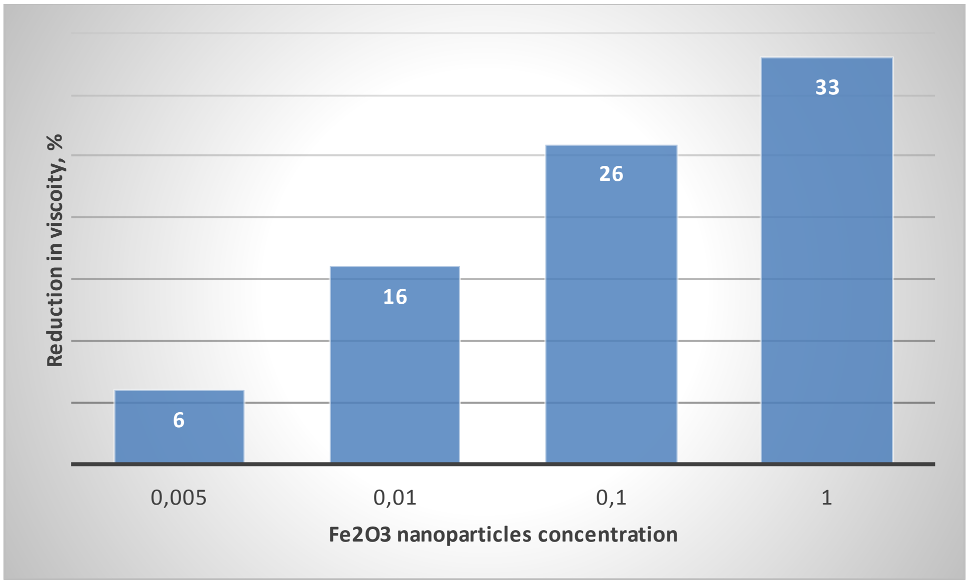


Figure 14. Effect of Fe_2O_3 nanoparticle on crude oil viscosity

5. Reducing interfacial tension between crude oil & flooding fluid

Fe_2O_3 nanoparticles with four concentrations (0.005, 0.01, 0.1 and 1 wt. %) are added to the crude oil. The mixture is sonicated. Then, the interfacial tension is measured by using Tensiometer. Figure 15 shows the effect of each concentration of Fe_2O_3 nanoparticles on interfacial tension. When the concentration of Fe_2O_3 nanoparticles increases the interfacial tension decreases.

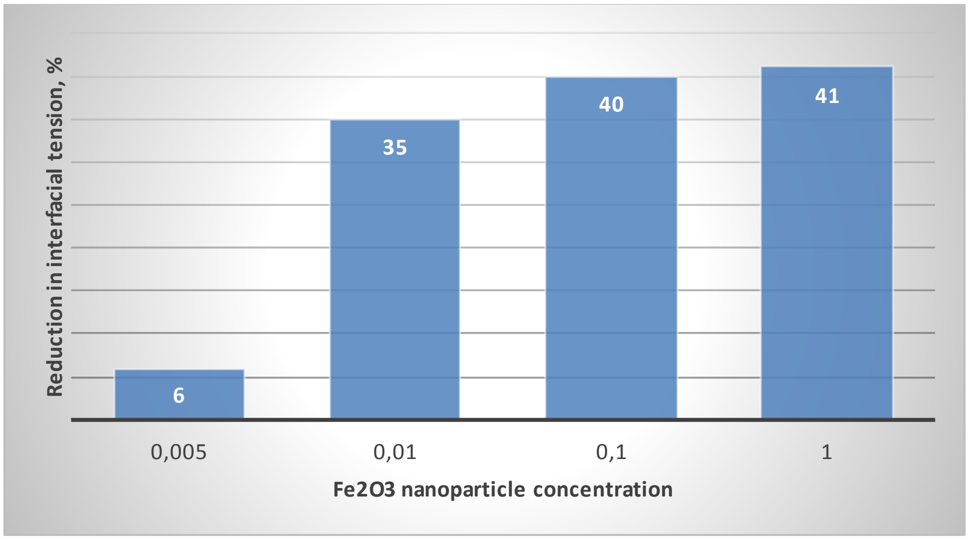


Figure 15. Effect of Fe_2O_3 nanoparticle on interfacial tension

6. Economic profile

To find whether the need for this recovery mechanism is applicable or not. The net present value for the total project has been estimated. Firstly, the initial oil in place for a field is assumed to be 100 MM STB, and the field comprises four production wells with the same decline rate. Also, the number of years for production is assumed to be 10 years. Moreover, drilling and production operational cost is assumed to be 25 million dollars considering the cost of flooding operations. More and more, a discount factor of 10% is also assumed. All the previous assumptions were applied to all the cases. However, the only variable now is the nano cost. The net present value for the water flood case is shown in Figure 16, and the net present value for the Fe_2O_3 nanoparticles flooding of concentration 0.01 wt. % is shown in Figure 17. It is clear from the figures that the net present value in case of using the Fe_2O_3 nanoparticles is more than that of the conventional water-flooding case.

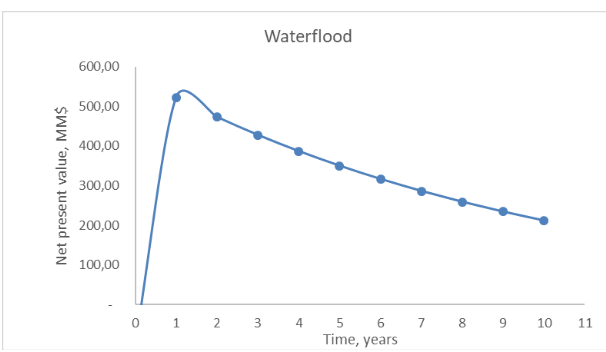


Fig. 16. Net present value for waterflood scenario

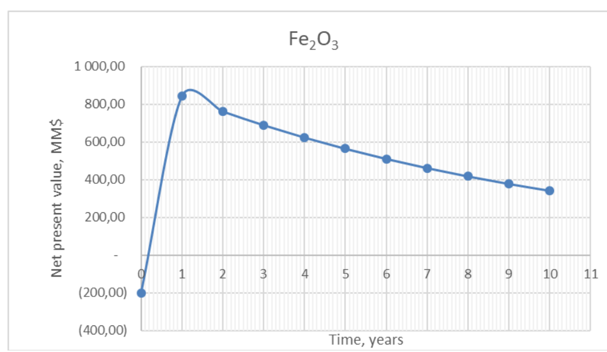


Fig. 17. Net present value for Fe_2O_3 nanoparticles 0.01 wt. % scenario

7. Conclusion

The effect of Fe_2O_3 nanoparticles with four different concentrations (0.005, 0.01, 0.1, 1 wt.%) on crude oil viscosity, interfacial tension, wettability alteration, and oil recovery factor was investigated. Flooding of Fe_2O_3 nanoparticles as a secondary recovery has proved its ability to reduce interfacial tension, crude oil viscosity, alter formation wettability, thus increase oil recovery. The oil recovery factor is 50 % of the original oil in place by conventional water flooding and increased to 80 % by using Fe_2O_3 nanoparticles with a concentration of 0.01 wt.

%. This work proved the ability of Fe_2O_3 nanoparticles to alter the formation to more water wet. Moreover, Fe_2O_3 nanoparticles can reduce oil viscosity and interfacial tension.

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