Experimental Work of Nanoparticles-assisted Water Flooding

Ahmed Moawad Ahmed*, Egyptian General Petroleum Corporation, Cairo, Egypt

Abstract

The Nanoparticle is of great importance in enhancing oil extraction. The increasing oil demand pushed scientists to think of new technology to enhance oil recovery from oil reservoirs. The nanoparticle, which reaches a scale of 1-100 nanometers, is an influential element in maximizing oil production. Nanoparticles help recover crude oil by several mechanisms such as wettability alteration of the porous media, interfacial tension reduction, disjoining pressure, and mobility ratio reduction. This research introduces the effects of different nanoparticles such as silica, iron oxide, zinc oxide, and mixed nanoparticles on oil recovery. The results showed that nanoflooding improves oil recovery more than conventional water flooding.

Introduction

Nanotechnology has the potential to revolutionize the oil industry (Krishnamoorti 2006; Ahmed et al. 2023). Nanotechnology has been tried in exploration, drilling, production, and enhanced oil recovery. Nanotechnology appeared in chemical methods used to enhance oil recovery. Nanoparticles-assisted surfactants cause releasing of trapped oil in pores and throats. This release happens due to many factors such as reducing interfacial tension (IFT) between oil and water, spontaneous emulsion formation, wettability alteration of porous media, and modification of flow character, which ultimately increase oil recovery significantly. The observed reduction in interfacial tension and mobility ratio results from nanoparticles present at the interfacial layers. Different types of nanoparticles are used in oil recoveries, such as magnesium oxide, zinc oxide, iron oxide, titanium dioxide, tin dioxide, aluminium oxide, and zirconium oxide. Nanoemulsion can be used to enhance oil recovery (Odi 2018). Nanotechnology has been used to improve surfactant flooding (Wu et al. 2017), polymer flooding (Giraldo et al. 2017), as well as thermal recovery (Greff and Babadagli 2013). In drilling operations, nanotechnology improved the rheological properties of drilling mud, reduced filtration loss, and enhanced shale stability (Rafati et al. 2018).

Experimental Work

In this experimental work, nanoparticles were investigated as nanoagents in EOR methods. Ten core plugs were used in this experimental work. Five core plugs were sandstone core plugs, and the other five were limestone core plugs. Routine core analysis was made on the ten core plugs to determine their porosity and permeability. A special core analysis was made on the ten core plugs to determine their wettability. Flooding tests were made with formation water on two core plugs and with nanofluids on eight core plugs. Results were obtained from tests and presented graphically.

Core Plugs Analysis. The cores are all clean from shale. The cores are 100% oil-saturated. The porosity values are shown in **Table 1**. The permeability values are shown in **Table 2**. From Amott tests, all plugs are oil-wet.

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*Corresponding author: ahmedmoawad625@gmail.com

PVT Analysis. The specific gravity of the crude oil used in this experimental work is 0.825=40° API. The viscosity of the crude oil is 2cp at 25°C.

Table 1—Porosity of the core plugs.

Sandstone		Limestone	
Sample No	Porosity (%)	Sample No	Porosity (%)
1	18	6	17
2	18	7	19
3	17	8	17
4	18	9	19
5	19	10	18

Table 2—Permeability of the core plugs.

Sandstone		Limestone	
Sample No	Permeability(mD)	Sample No	Permeability (mD)
1	100	6	99
2	95	7	98
3	98	8	96
4	99	9	97
5	98	10	98

Flooding Tests. Ten core flooding runs were made to investigate the effect of nanoparticles on the oil recovery. Five core flooding runs were made in sandstone core plugs, and the other five core flooding runs were made in limestone core plugs. **Table 3** shows more details about these flooding runs. The flooding apparatus is shown in **Figure 1**.

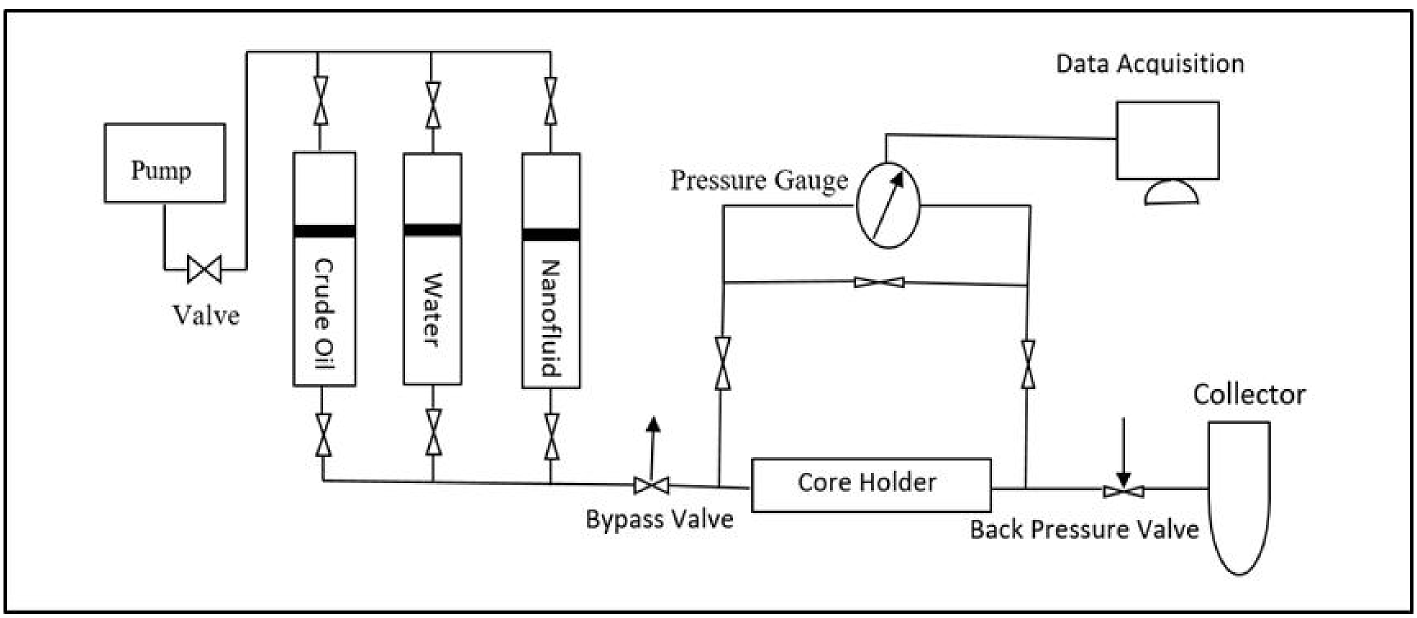

Figure 1—Schematic diagram of the flooding test setup.

Table 3—The flooding test runs.

No of Run	Fluid injected (nanoparticles/base fluid)	Lithology
1	Only formation water	Sandstone
2	0.1% wt. silica/formation water	Sandstone
3	0.1% wt. zinc oxide/formation water	Sandstone
4	0.1 % wt. iron oxide/formation water	Sandstone
5	0.05% wt. silica + 0.05% wt. iron oxide/formation water	Sandstone
6	Only formation water	Limestone
7	0.1% wt. silica/formation water	Limestone
8	0.1% wt. zinc oxide/formation water	Limestone
9	0.1 % wt. iron oxide/formation water	Limestone
10	0.05% wt. silica + 0.05% wt. iron oxide/formation water	Limestone

Results and Discussion

From the conventional water flooding and the nanoflooding tests, nanoflooding has a higher oil recovery factor than water flooding. As seen in **Figure 2**, the recovery factors in sandstone core plugs at the breakthrough for the water flooding (0.7 PV injected), the silica nanoflooding (0.9 PV injected), the iron oxide nanoflooding (0.9 PV injected), the zinc oxide nanoflooding (0.9 PV injected), and the mixed nanoflooding (0.9 PV injected) are 50%, 73%, 74%, 72%, and 69%, respectively.

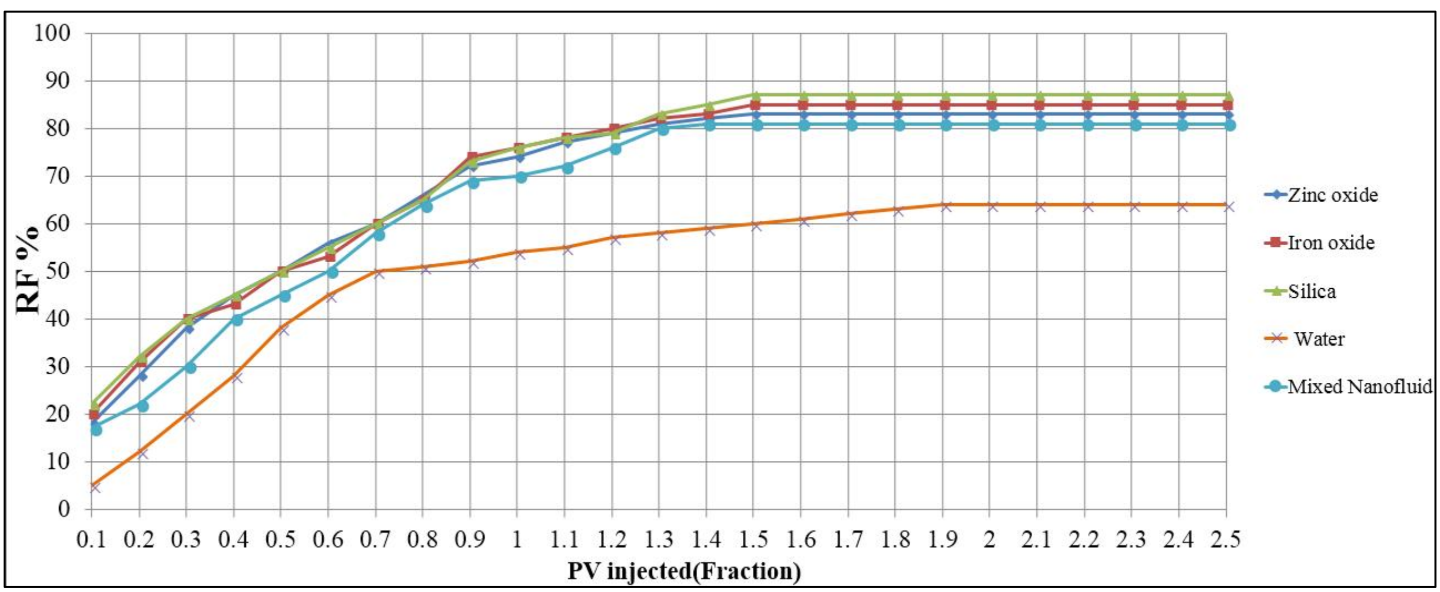

Figure 2—The flooding runs in the sandstone core plugs.

In **Figure 3**, the recovery factors in the limestone core plugs at the breakthrough for the water flooding (0.5 PV injected), the silica nanoflooding (0.7 PV injected), the iron oxide nanoflooding (0.7 PV injected), the zinc oxide nanoflooding (0.7 PV injected), and the mixed nanoflooding (0.7 PV injected) are 45%, 70%, 69%, and 68%, and 65%, respectively.

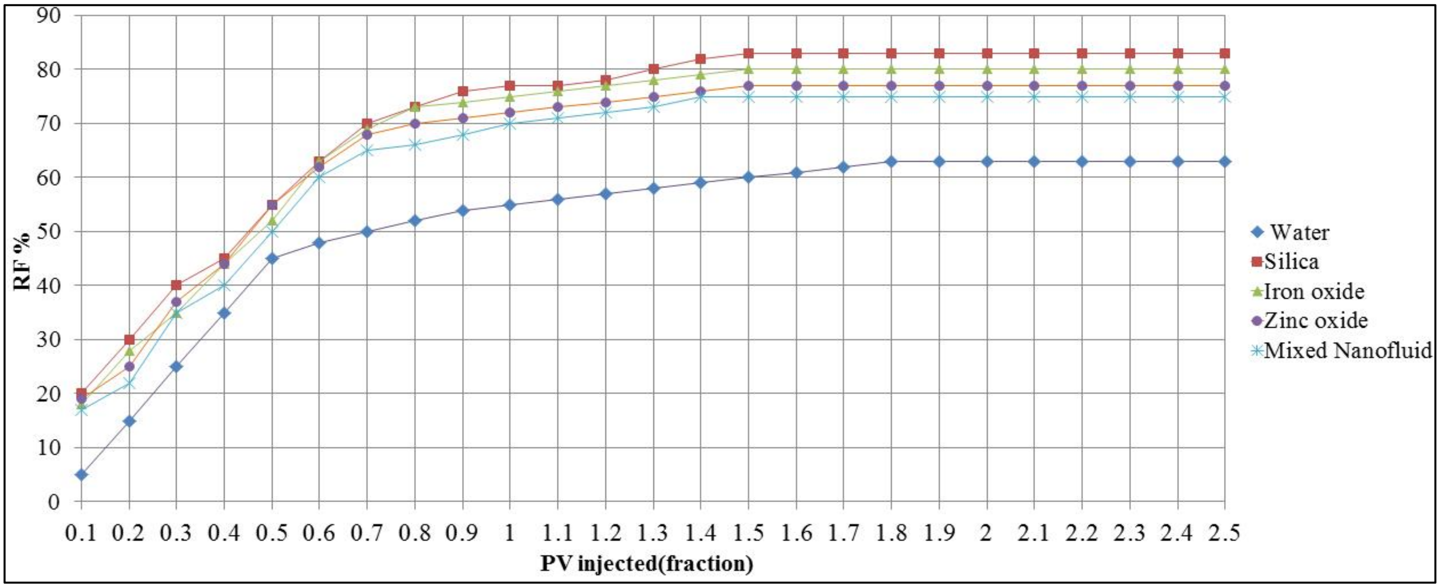

Figure 3—The flooding runs in the limestone core plugs.

This high recovery factor occurs due to the mechanisms performed by nanoparticles. Mechanisms of the nanoparticles to improve the recovery are the disjoining pressure, interfacial tension reduction, wettability alteration, and mobility ratio reduction (Negin et al. 2016). In the disjoining pressure mechanism, the nanoparticles present in the nanofluids tend to form a film that takes the shape of a wedge in contact with the oil phase. This wedge-like film acts to separate the oil droplets from the rock surface. In that way, more oil is recovered than previously possible when using conventional displacing fluids. In the interfacial tension reduction mechanism, the nanoparticles enter between the oil phase and the water phase acting as an agent for reducing the interfacial tension. Reduction in interfacial tension increases the capillary number. When the capillary number increases, residual oil saturation decreases. The hydrophilic nanoparticles are mainly used in enhanced oil recovery for strongly oil-wet reservoirs in the wettability alteration mechanism. The primary production mechanism of these nanoparticles is to alter wettability from oil-wet to neutral or water-wet. In the mobility ratio reduction mechanism, nanoparticles increase the viscosity of the displacing fluid dispersed in it. When the viscosity of the displacing fluid increases, its mobility decreases, and the mobility ratio decreases.

In recent years, active research efforts have been made on nanoparticles to obtain more precise information on reservoir rock and in-situ fluid properties and the dynamics of displaced and injected fluids. The trends of efforts are summarized in the following three points.

1. Addition of nanoparticles in the injected fluid bank, water flooding or EOR, and detecting remotely its location and movement through using super magnetic nanoparticles in the flooding bank. The super magnetic nanoparticles will be magnetized and generate an induced magnetic field around them by imposing an external magnetic field from the transmitter well. This induced magnetic field will be observed in the observation well. Once observed, the bank's location in the reservoir will be determined (Al-Shehri et al. 2013; Al-Ali et al. 2009).
2. Nanoparticles added to the injected fluids can detect specific properties of the reservoir rock and fluids. When the nanoparticles are produced, we can retrieve the data. The surface coating on the nanoparticles is designed to change its nature in a specific manner. When the nanoparticles are produced, the changes in their surface coating are investigated from which the desired reservoir property can be deduced (Berlin et al. 2011; Biederer et al. 2009).
3. Using nanoparticles-based sensing devices in reservoir formation for reservoir characterization. The biggest challenge for such applications will be how the tiny, fragile nanosensors can be protected from harsh downhole conditions to collect data properly (Bogue 2004; Shelley 2008).

Conclusions

Nanoflooding is a promising technique for improving oil recovery. It increases oil production, improves sweep and displacement efficiency, and delays breakthroughs. Excellent applications have proved that nanoparticles are potential candidates for enhancing oil recovery techniques. From the flooding test, the various types of nanoparticles show a better recovery factor than conventional water flooding. Also, nanoflooding delayed the breakthrough of injected fluid. The breakthrough occurred earlier in conventional waterflooding.

Conflicting Interests

The author(s) declare that they have no conflicting interests.

Abbreviations

EOR: Enhanced oil recovery
IFT: Interfacial tension
PV: Pore volume

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Ahmed Moawad Ahmed is a petroleum engineer at the Egyptian General Petroleum Corporation. Ahmed holds a bachelor's degree in petroleum engineering from the Faculty of Engineering- Cairo University. His main research area is in nanotechnology applications in the petroleum industry.