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Field Application of Nanoparticles-assisted Water Flooding

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Abstract

Nanotechnology has recently emerged to remove barriers in front of oil reserves that other methods cannot produce. Nanoparticles with a size of 1-100 nanometers are capable of causing changes in some properties that have a positive impact on oil recovery from reservoirs. The role of nanotechnology in increasing oil production is still limited to laboratory experiments. These laboratory experiments have proven the ability of these nanoparticles to make a difference in the extracted oil. This paper will present a practical case to apply nanotechnology in two different Egyptian fields. The first field is a sandstone reservoir and the second field is a limestone reservoir.

Keywords: *Nanotechnology; Nanoparticles; Pilot test; Water flooding.*

1. Introduction

Nanoparticles can change the properties of rocks, such as their wettability, whether these rocks are sandstone or limestone. Nanoparticles can change the wettability of rocks from oil-wet to water-wet and from water-wet to strongly water-wet. Changing the wettability pushes the oil into the large pores, increasing its relative permeability and thus reducing its residual saturation [1-2]. Nanoparticles can also change surface properties, such as the interfacial tension between the injected fluid and the displaced fluid. Nanoparticles can reduce the interfacial tension between them, which helps in improving the displacement efficiency [3-4]. Nanoparticles can change the properties of the injected liquid by increasing its viscosity and thus reducing fingering and early breakthroughs.

2. First oil field – sandstone formation

2.1. Field history

The first well was drilled in 2002 when production started. The drilling continued and reached twelve wells in 2011. In 2017, twenty producers were achieved. Three production wells were converted into injection wells in 2018 when a water flooding project started.

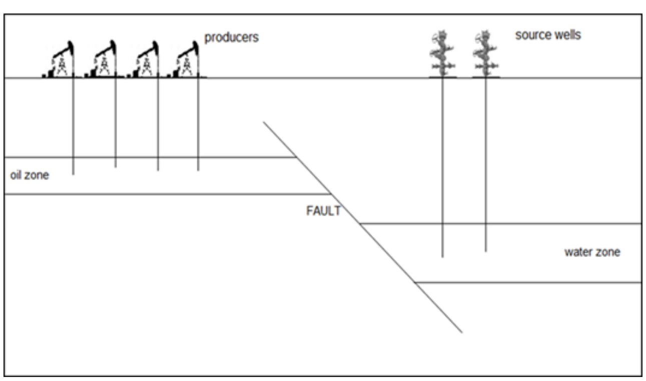

Figure 1. Fault Section in the reservoir (Sd)

The water source is from two source wells completed in a water-bearing formation that is not in contact with the depleted oil-bearing zone because of a fault, so the reservoir is a depletion drive reservoir, as shown in Figure 1. The production started in 2002 and increased with time to reach its peak in 2011, then began to decline. As shown in Figure 2, field pressure decreased with time before water injection. From Figure 2, pressure decline was stable with time, forming a linear relationship. Figure 3 depicts the field production rate before water injection. It is observed from the relationship that the rate started to increase due to the development of the field by drilling new wells, and then the production rate began to decline with time owing to the reservoir pressure reduction.

The proposed new wells in the drilling plan were few, so secondary recovery was started. Cumulative production before water injection is also shown in Figure 4. Water injection was needed to displace oil from the reservoir. The source of water was the water-bearing formation. The water was treated at the surface and then injected into the oil-bearing formation through the injection wells.

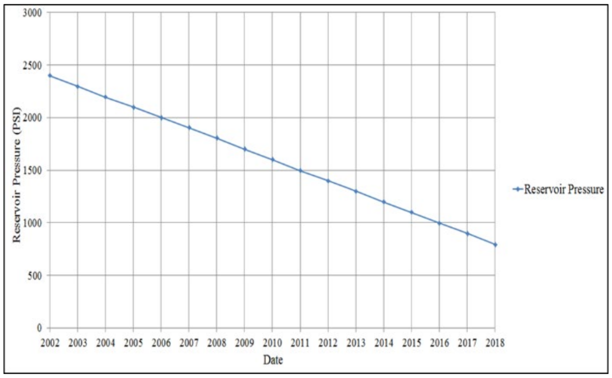

Figure 2. Reservoir pressure versus time (Sd)

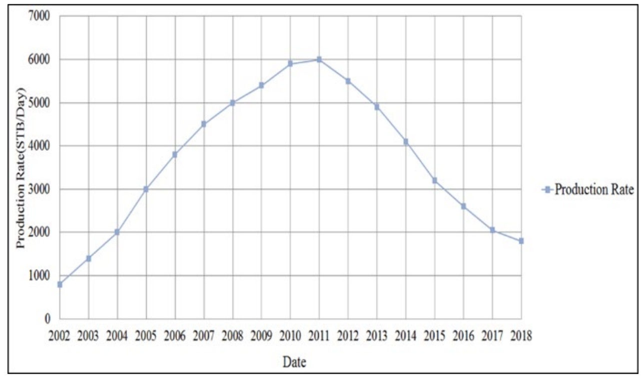

Figure 3. Field oil production rate versus time (Sd)

2.2. Reservoir characteristics

According to well logging data, the lithology is sandstone, the bay zone thickness is 18 feet, and the porosity is 14%. From well test data, the initial reservoir pressure is 2400 psi, and the permeability is 25 md. From PVT analysis, the API of crude oil is 40°, the viscosity of crude oil is 2.2 cp at 25°C, and the reservoir is undersaturated. According to the special core analysis, the sandstone rock is oil-wet using the Amott test.

2.3. Pilot test

The flooding project consists of three injectors and ten producers in three five-spot patterns because there are two producers in common in the three five-spot patterns, as shown in Figure 5. Wells O8 and O13 are shared in two five-spot patterns. Well V1 was drilled as a water source well when the flooding project was started, and then well V2 was drilled a year later. The nanoparticles-assisted water flooding pilot test was applied in well A3, while wells A1 and A2 are for conventional water flooding. The three patterns, A1, A2, and A3, indicated that the A3 pattern had the highest oil production, as shown in Figure 6. Silica nanoparticles were used as an additive with a 0.5 wt.% in the A3 injector [5]. Water injection started in October 2018, but its effect didn't appear until April 2019. At this time, the production rate began to increase due to conventional flooding in patterns A1 and A2 and Nano-flooding in pattern A3. The pilot test had a high production rate due to the effect of nanoparticles. Nanoparticles changed the rock wettability from oil-wet to water-wet, reduced the interfacial tension, improved the relative permeability to oil, and delayed water breakthrough. In Figure 7, the water cut for each pattern is plotted against time, and it is seen that the breakthrough was delayed due to the effect of nanoparticles in the Nano-flooding pattern. The project is still working today, and the results indicate that the project is successful. The results also show that the pilot test is better at recovering oil than the conventional water flooding method.

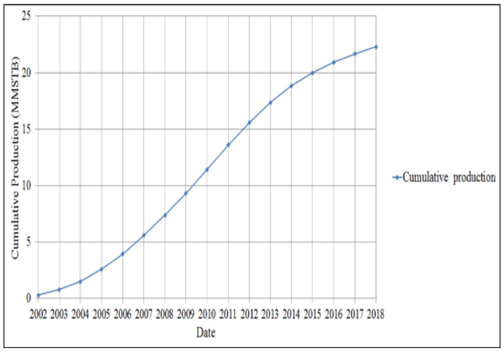

Figure 4. Field cumulative oil production versus time (Sd)

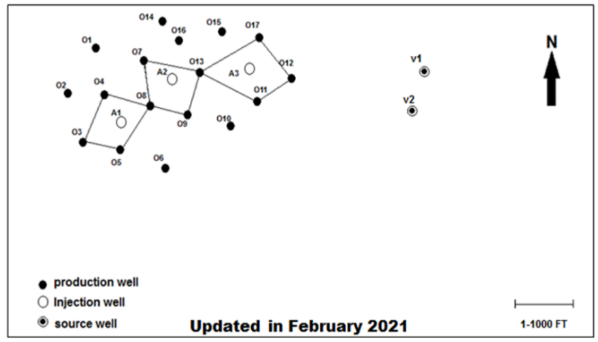

Figure 5. Water flooding patterns (Sd)

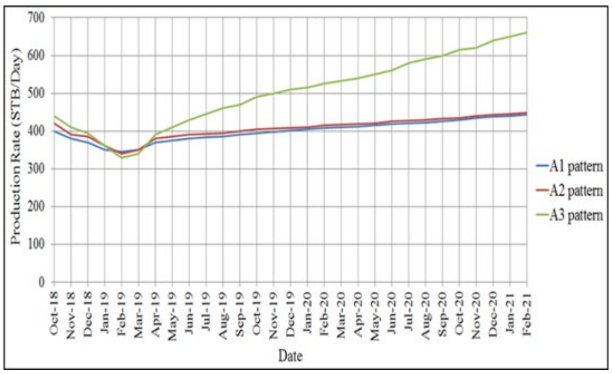

Figure 6. Production rate of the three patterns (Sd)

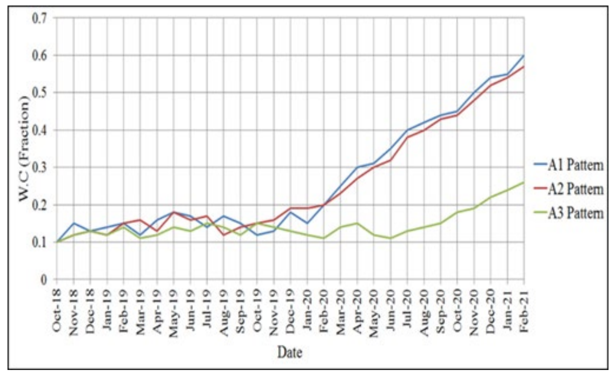

Figure 7. Water cut for the three patterns (Sd)

3. Second oil field – limestone formation

3.1. Field History

According to the drilling plan, the first well was drilled in 2008, and because two drilling rigs were working simultaneously, fourteen producers were reached in 2012. The drilling continued, and twenty-eight producers were reached in 2016. The water flooding project commenced in 2019 by converting four producers into injectors to displace oil left after primary recovery. The five-spot pattern was used in the flooding project. The water source was from a water-bearing formation under an oil-bearing formation separated by a thick shale zone, as shown in Figure 8. The reservoir was a fold trap, and the drive mechanism was a depletion drive mechanism. The pressure of the reservoir started to decrease with the beginning of production, which reached its minimum value in 2019 and then became stable with water flooding. Production rate increased with increasing the drilling of new wells. Reservoir pressure, field oil production rate, and field cumulative oil production are plotted versus time in Figures 9, 10, and 11, respectively. The clues appeared that water flooding was essential to drive residual oil toward producing wells. The clues were the reservoir pressure decline and the production rate decline. The primary reserve was about to cease, so secondary recovery was needed. About 35% of the oil in place was produced with the natural energy of reservoir and artificial lift methods, so secondary and tertiary methods were essential to be commenced. Nano-flooding was used as a pilot test to increase recovery from flooding operations.

3.2. Reservoir characteristics

From well logging data, the lithology is limestone, the average thickness of the bay zone is 20 ft, and the porosity is 16%. From the well test data, the initial reservoir pressure is 2200 psi, and the permeability is 30 md. From PVT analysis, the API of crude oil is 42°, the viscosity of crude oil is 2.1 cP at 25°C, and the reservoir is undersaturated. From special core analysis, the wettability of limestone rock is oil-wet using the Amott test.

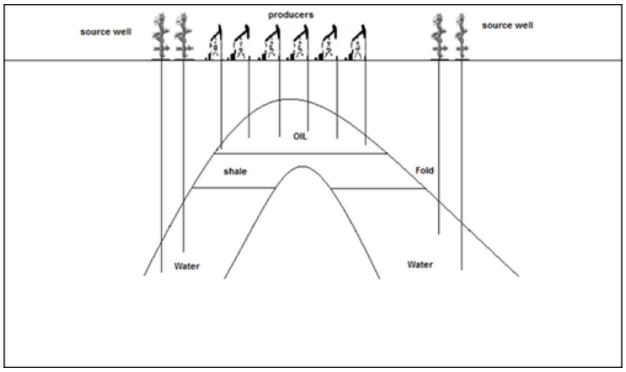

Figure 8. Fold section in the reservoir (Lm)

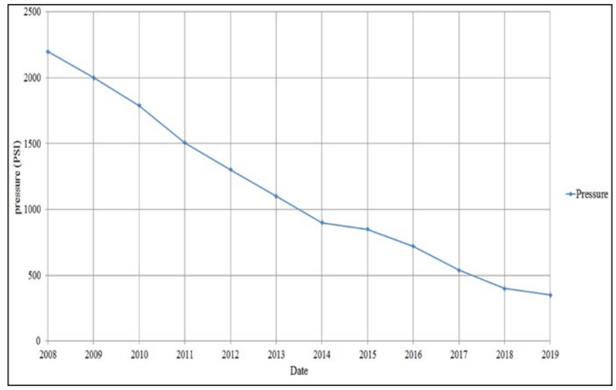

Figure 9. Reservoir pressure versus time (Lm)

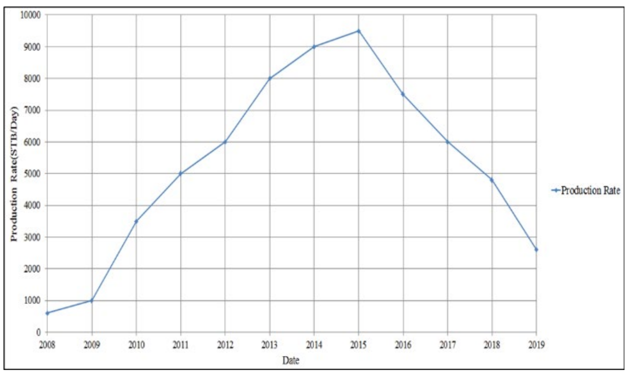

Figure 10. Field oil production rate versus time (Lm)

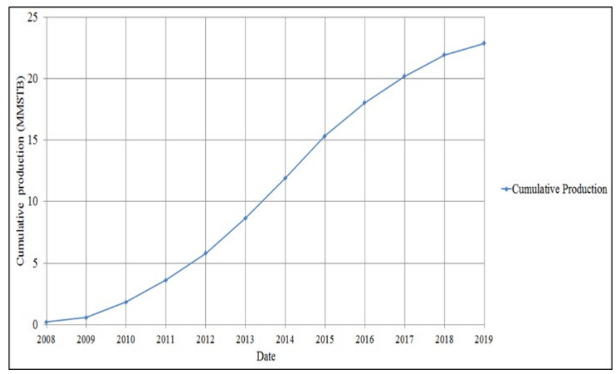

Figure 11. Field cumulative oil production versus time (Lm)

3.3. Pilot test

The project started in 2019 when four producers were converted into injectors, and the source wells were completed. The flooding project consisted of four five-spot patterns, which were Q1, Q2, Q3, and Q4, as shown in Figure 12.

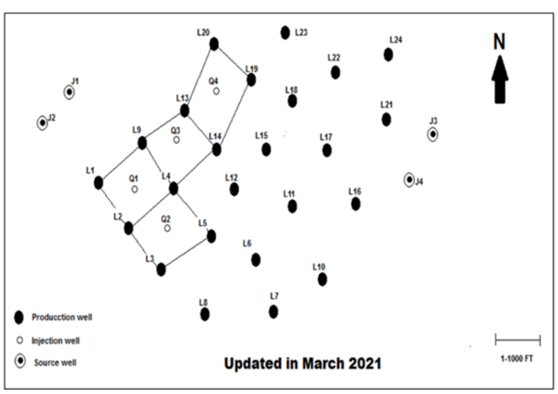

Figure 12. Water flooding patterns (Lm)

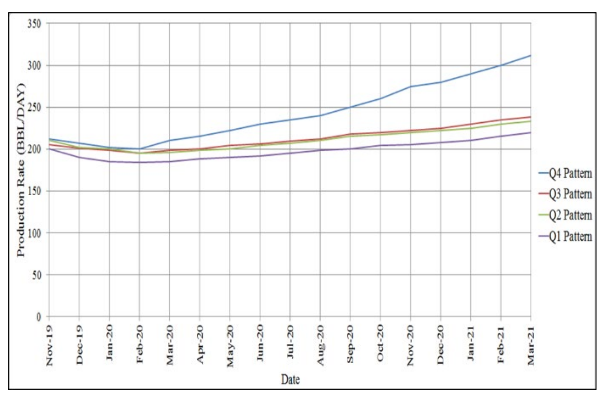

Figure 13. Production rate of the three patterns (Lm)

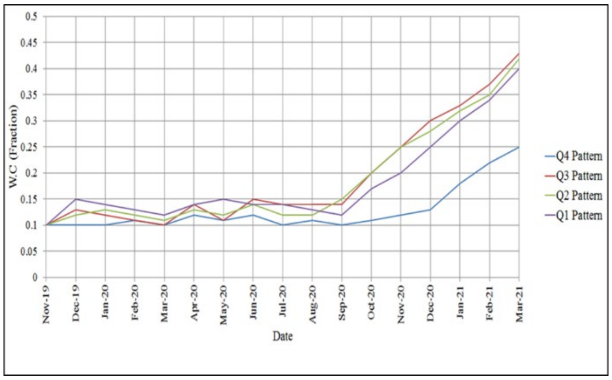

Figure 14. Water cut for the three patterns (Lm)

Silica nanoparticles with a concentration of 0.5 wt. % were used in the nanoparticles-assisted water flooding project [5]. Results are shown in Figures 13 and 14 for oil production rate and water cut for the three patterns, respectively. As seen from the figures, the production rate for the four patterns continued to decrease because the effect of water flooding took time due to gas compression, then it began to increase. Nano-flooding had a much more significant impact on oil recovery than conventional water flooding. The water cut from the pilot Nano-flooding pattern was less than the other patterns.

4. Conclusions

Nano-Flooding is a promising technique for improving oil recovery. It increases oil production, improves sweep efficiency, and displacement efficiency, and delays water breakthrough. There have been successful field applications, demonstrating that silica nanoparticles are suitable for Nano-Flooding applications.

Abbreviations

Sd: Sandstone;   Lm: Limestone

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