Utilization of Nanoparticles to Enhance Hydrocarbon Recovery*

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Abstract

There is a drive in the oil and gas industry to improve recovery from petroleum reservoirs. Current techniques of surfactant flooding which is typically used to improve sweep efficiency in tight areas can be supplemented with nanoparticles (Schlumberger, 2017). A mechanism by which nanoparticles can improve sweep efficiency is through assemblage and formation of a wedge at the fringes between the oil and rock contact. The disjoining pressure exerted by the wedge-like compact nanoparticles reduces the capillary pressure needed to sweep the oil from the pore throats of the reservoir.

A benefit of using nanotechnology in flooding is their convenient particle sizes. This size allows them to create conglomerates of large surface areas, which allows the fluids containing them to sweep oil more efficiently (El-Diasty and Aly, 2015). Recent measures show that nano-fluid injection has not only reduced the required capillary pressure, but also significantly reduce residual oil saturation, making the process more profitable (Srinivasan and Shah, 2014).

The aim of this research is to determine the effects of various types of nanoparticles on the effectiveness of conventional surfactants in enhancing oil recovery. In particular, a dozen nanoparticle-surfactant mixtures were tested. This research is divided into two phases: Phase 1: Nanoparticle-Surfactant Mixture Screening through Contact Angle Measurement and Phase 2: Permeability Analysis through Nanoparticle-Surfactant Core Flooding.

Method

Phase 1: Nanoparticle-Surfactant Mixture Screening through Contact Angle Measurement

This first part begins with screening all the possible nanoparticle-surfactant mixtures to find the best performing mixtures. The mixtures with the best results will be further tested in phase 2 to analyze its ability to improve oil relative permeability. The performance of a nanoparticle-surfactant mixture will be gauged by its ability to alter the oil wettability of a rock surface (i.e. by observing changes in the contact angle of a placed droplet of crude oil on the surface before and after the surface is exposed to the mixture). A Rame-Hart Goniometer, pictured in Figure 1, along with its accompanying software was used.

In the conducted trial run, four surfactants were used: Distilled Water, Brine (20 g/L), Ethanol, and Diesel. In addition, at the time, three nanoparticles were available for testing: Aluminum Oxide with a size range of 30-60 nm, Copper Oxide with a range of 0-50 nm and Silica sized at 2 nm. All 12 possible nanoparticle-surfactant mixtures were created and 12 different slices of core sample were wetted with the different mixtures. Each mixture was 4% nanoparticle solid by weight. The core samples used in this phase were obtained by cutting a carbonate core sample into circular slices 2 inches in diameter and 0.5 inches thick. Each slice was then submerged in 250 mL of each nanoparticle-surfactant mixture for 24 hours.

After submersion, the core samples were removed from their respective mixture and the contact angle of oil-rock were measured with the goniometer. In addition, the contact angle of a droplet of oil dropped on a dry slice of sample was recorded in order to find the changes in contact angles due to the mixtures. An example of the interface of the Rame-Hart software being used to measure the contact angle can be found in Figure 2.

Phase 2: Permeability Analysis through Nanoparticle-Surfactant Core Flooding

Once the best nanoparticle-surfactant mixtures are identified from phase 1, these mixture will then be used to flood core samples (of the same type of carbonate rocks used in phase 1) for core flood analysis. Each core sample will first be flooded and saturated with brine. The core sample will then be flooded with oil. The relative permeability of oil at this point can also be found using the pressures at the inlet and outlet while the core is being flooded. A nanoparticle-surfactant mixture can then be used to flood the core, and the amount of oil recovered can then be found with the amount of oil remaining in the core. Improvements in the oil relative permeability and recovery can then be examined and compared.

Results

The obtained measurements and contact angle percent increases due to the mixtures are presented in Table 1. As seen from Table 1, immersing the rock sample in a solution of Silica and Ethanol resulted in the highest contact angle increase of 1520%. Hence, the Silica and Ethanol mixture showed the most promise in reducing oil wettability. Rock samples immersed in Copper Oxide and brine and Silica and Diesel expressed almost no increase at all. The rest of the nanoparticle + surfactant mixtures at least doubled the contact angles, which indicates satisfactory effectiveness in reducing oil wettability.

In addition, all rock samples remained oil-wet, although their oil wettability decreased after emulsion, except for those immersed in Copper Oxide and brine and Silica and Diesel. It was recognized earlier that the destabilization of the nanoparticle-surfactant emulsions as the rocks were immersed in them for a day during this experiment would undoubtedly affect the effectiveness of such mixtures in altering contact angles and oil wettabilities, and thus cause errors in the contact angle measurements. Hence, another trial of this phase will be performed, with the applications of a sonicator as a mixer and acid to increase the mixture's pH in order to better stabilize the emulsions.

Conclusions

Based on this phase of the research a number of areas of the procedure requiring improvement were identified. First, it was found that even after a couple of hours the nanoparticle solids would quickly settle and separate from the surfactant. The following two improvements would be implemented in the next stage of this research;

1) Use an ultrasonic machine to thoroughly mix the mixture
2) Add acid to the mixture to decrease the overall pH of the solution. The goal is to decrease the pH level below the isoelectric point of the nanoparticle in question, thus charging the particles and preventing them from coming to close contact with each other.

Ultrasonication along with a low pH will ensure the mixture remains stable for the entire period of core sample submersion. Results revealed that Silica and Ethanol mixture were most effective in reducing oil wettability, while the Copper Oxide and brine and Silica and Diesel mixtures had almost no effect at all. All the nanoparticle-surfactant mixtures except the latter two may then be qualified for the next phase of the research.

Acknowledgments

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Figure 1. Rame-Hart Goniometer (Rame Hart Instrument Company).

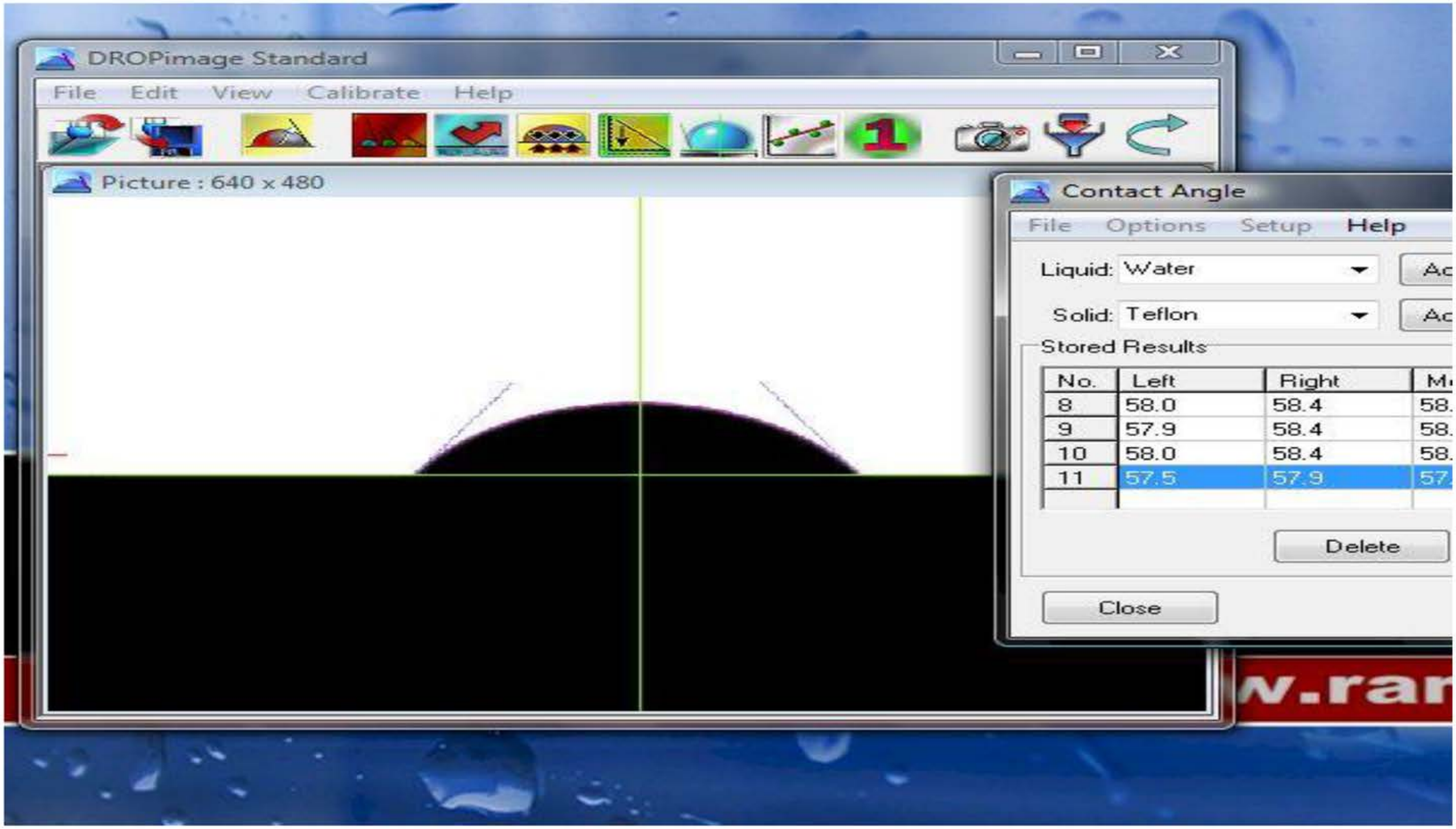

Figure 2. Interface of the Rame-Hart software used to measure the contact angle.

Rock Sample	Immersed in solution of	Initial Contact Angle (degrees)	Contact Angle after immersion (degrees)	Percent Increase (%)
1	Aluminum Oxide and distilled water	5	10.75	115
2	Copper Oxide and distilled water	5	29.6	492
3	Silica and distilled water	5	10	100
4	Aluminum Oxide and brine	5	10.5	110
5	Copper Oxide and brine	5	5	0
6	Silica and brine	5	11.1	122
7	Aluminum Oxide and Ethanol	5	12.5	150
8	Copper Oxide and Ethanol	5	28.4	468
9	Silica and Ethanol	5	81	1520
10	Aluminum Oxide and Diesel	5	15.6	212
11	Copper Oxide and Diesel	5	15.3	206
12	Silica and Diesel	5	5	0

Table 1. Experimental results for contact angle percent increases.