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## Effect of polysilicon nanoparticles on enhanced oil recovery in Iranian oil reservoir

### ABSTRACT

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Recovery Factor is an important parameter in determining commercial viability of the oil Reservoirs. Wettability is a major factor that affects oil Recovery. Therefore, changing rock wettability may enhance oil recovery. In this paper, the effect of polysilicon nanoparticles on wettability change of Iranian carbonate reservoir is investigated. To assess this, hydrophilic changes of carbonate rocks are studied by using the contact angle test. Our results show that with increasing nanoparticle concentration, the contact angle decreases. In the next stage, the effect of adding nanoparticles on water flooding is studied. Our experimental results demonstrated that increasing the nanoparticle concentration up to 0.1 percent increases the recovery but further increase to 0.5 reduces the effect on recovery.

**Keywords:** *Polysilicon nanoparticles; Water flooding; Wettability; Enhanced oil recovery; Carbonate reservoirs.*

### INTRODUCTION

More than 85% of Iranian oil reserves are held in carbonate rocks. Many unfavorable parameters cause low oil recovery factor in these reservoirs. Oil-wet nature is one of these parameters. Therefore, the water flooding efficiency of these reservoirs is low. Nanoparticles are small enough to pass through pore throats in significant reservoirs and change the wettability of pores. In this paper, we improved the recovery efficiency by dissolving lipophobic-hydrophilic polysilicon nanoparticles (LHPN) in the injected water to alter the wettability of the reservoir rock to a more water-wet state. Carbonate surfaces are usually positively charged in neutral PH brine [1]. This attracts negatively charged compounds in crude oils, such as carboxylic acids. Therefore, carbonate formations are usually intermediate-wet to oil-wet [2]. According to Treiber et al., 84% of carbonate formations are oil-wet, while 8% are intermediate-wet, and 8% water-wet [3].

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The residual oil saturation in mixed-wet rock is lower than residual oil saturation in both oil wet and water wet rocks [4]. Experimental data have documented the change in residual oil saturation with changes in the Amott-Harvey wettability index in Berea sandstone [5] and other sandstones [6] and carbonate rocks [7]. The results showed that the residual oil saturation is the lowest when the wettability is nearest to neutral-wet or mixed-wet conditions corresponding to an index near zero [8]. Several studies have shown that intermediately wet formations yield more oil than water wet rocks. These results did not obtain from using nanoparticles.

Ju *et al.*, have reported that polysilicons in nano scale can change the wettability in the surface pores [9]. Binshan *et al.*, have used two types of polysilicons in nanoscale. They did their experiments on sandstone reservoirs and concluded that using polysilicons in flooding leads to enhanced oil recovery [10]. Onyekonwu *et al.*, have used three types of polysilicon nanoparticles. They did their experiments on water wet rocks [11].

Since a large portion of the reservoirs formation are low permeability carbonate formations and the few studies that have been done in this method have failed to cover these reservoirs we have designated this paper to study of carbonate formations. In this paper, we have investigated the effect of SiO<sub>2</sub> nanoparticles on oil wet carbonate rocks and the resulting changes in wettability and the consequent effect on enhancement oil recovery. The SiO<sub>2</sub> nanoparticle can be particularly relevant or our purpose sine it reduces the surface energy. Furthermore, the extremely small size of the particle allows it to easily penetrate in the reservoir pores. We have used the experimental method for our research.

## EXPERIMENTAL

### Polysilicon Nanofluids

The particle used was lipophobic-hydrophilic polysilicon nanoparticles (LHPN). It was bought from Aerosol Co. (Figure 1). Properties of each of this PSNP are presented in Table 1. These nanoparticles added to water so form a suspension. The device used to disturb the particles evenly was “ultrasonic jac 1200,” made by Kodo

CO. Korea. The resulting suspension was put in the device for 15-20 minutes. Therefore, the prepared suspension was stabilized, and the nanoparticles were not settled in the water during the experiment. This suspension was prepared in various concentrations.



Fig. 1. SiO<sub>2</sub> nanoparticles used in the experiments.

Table 1. Properties of PSNP used in this study

Nanoparticle type	LHPN
Average size (nm)	14
Color	White
PH in used	3.7-4.7
Melting point (°C)	1700
Density (g/cm <sup>3</sup> )	2.2
Smell	Odorless

### Core Plugs

The experiments were conducted using carbonate core plugs. Permeability and porosity of these plugs were measured by using the Key-Phi device manufactured by Vinci. Cores' properties are shown in Table 2.

**Table 2.** Properties of the core plugs used for flooding test

Core sample No.	Rock type	Length (cm)	Diameter (cm)	Porosity %	Permeability (md)	Pore volume (cm <sup>3</sup> )
C1	Carbonate	6.1	3.8	15	0.2	10.4
C2	Carbonate	6.2	3.8	15	0.2	10.5
C3	Carbonate	6.2	3.8	15	0.2	10.5
C4	Carbonate	6.2	3.8	15	0.2	10.5
C5	Carbonate	6.1	3.8	15	0.2	10.4

### Oil and Brine

All the oil used in the experiment was taken from “S” reservoir in Persian Gulf. The density of the oil was 897.101 kg/cm<sup>3</sup>. For saturation and flooding 200000 ppm and 42000 ppm brines were used respectively. The brine used for this experiment was prepared in the laboratory with the same salinity as the “S” Reservoir formation water.

### Core flooding Experiments

At first, core flooding study was conducted to investigate the impact of wettability alteration on oil recovery in water flooding.

### Core Flooding Apparatus

We used a core flooding device, commercially named the Capri device made by Vinci CO. France in this research. The device is made of two positive pumps, a core holder, oven, controlling pumps, two free pistons and pressure transducers. A schematic diagram of the core flooding apparatus is depicted in Figure 2. The experiments were done in the room temperature. The overburden pressure was first set to 1000 psi and gradually a pressure difference of 400 psi was achieved.

### Measurements of oil recovery

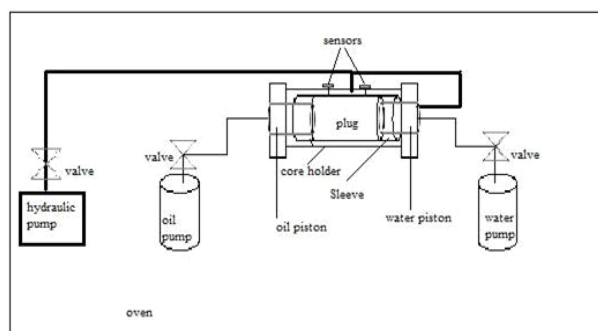
First, the core was saturated by brine (200000 ppm salinity).

Then the core was saturated by oil with a 0.1 cc/min flow rate. The injection was continued

until no more water came out of the core. Then the total water recovered from the core was measured using graduated cylinder and based on this  $S_{WC}$  was calculated.

Next, the core was flooded by 42000 ppm brine with a 0.1 cc/min flow rate. The water injection was continued until no more oil came out. The total amount of recovered oil was measured. The injection was done with 15 PV.

In this step, after saturating the core with oil and water it was flooded using 10pv of nanoparticles suspension with different concentration: 0.01, 0.05, 0.1 and 0.5 followed by 5 PV of brine with 0.1 cc/min flow rate. Then the recovery was measured using the explained method. The nanoparticles suspension also contained 42000 ppm NaCl. No precipitates were observed in the effluents during the water flooding process.

**Fig. 2.** Schematic of the Capri apparatus used in flooding experiments.

### Measurements of contact angle

At the second step, the hydrophilic changes of cores were studied by using the contact angle test. To measure the contact angle, 1cm slices cut from the cores and the tests were done on them. The SEM image of the carbonate core after and before injecting with nanoparticles is shown in Figures 3a and b. The pictures are taken with 10000 magnifications.

The results of contact angle tests can be seen in Table 3. The result showed the initial

contact angle of 124 degrees. Thereafter, it could be said that the cores were weakly oil-wet. As expected, after flooding core with LHPN, contact angle decreased from  $124^{\circ}$  to  $0^{\circ}$ , which indicates the wettability alteration of the surface. The contact angle decreases with increasing nanoparticle concentration. It means that hydrophilic property is increased and core becomes more water-wet. The contact angle measurements were performed with an 'OCA 15 plus' instrument.

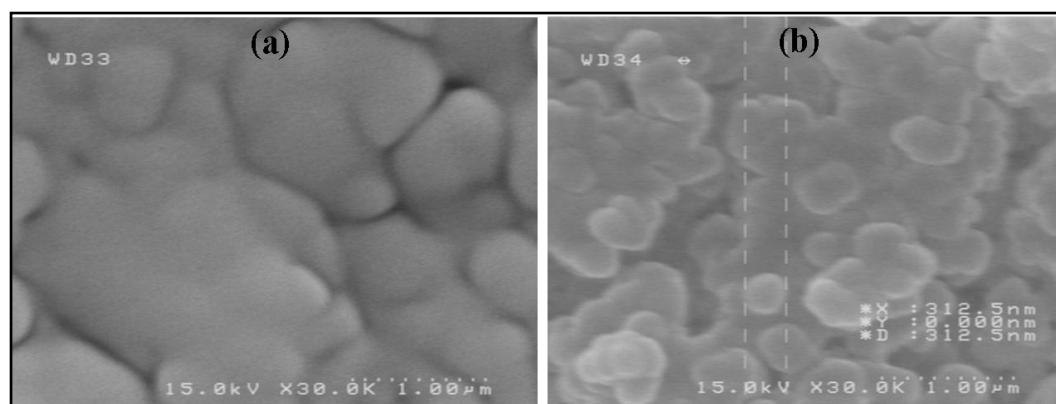


Fig. 3. (a). SEM images of carbonate cores before injecting with nanoparticles suspension, (b). SEM images of carbonate cores after injecting with nanoparticles suspension

Table 3. Results of contact angle test in carbonate cores that injected with different concentrations of nanoparticle suspensions

Nanoparticles concentration (%wt)	0	0.01	0.05	0.1	0.5
Core no.	C1	C2	C3	C4	C5
Contact angle	123.7	96.6	48.6	30.2	0.00
Wettability Type	Weakly oil-wet	Neutral wet	Weakly water-wet	Waekly Water-wet	Water-wet

## RESULTS AND DISCUSSION

### Core Flooding test

Results from the flooding are seen in Figure 4. The figure shows that when the flooding was done with brine, the recovery factor was only 44% while with adding nanoparticles in later stages in weight percentages of 0.01, 0.05, 0.1, and 0.5 the recovery has respectively increased by 5.8%, 9.1%, 20.3 % and 6.5%. The results confirm that neutral-wet and weakly water-wet rocks yield more oil than water wet rocks. Furthermore, to clarify the results enhanced recovery per nanoparticle concentration is depicted in Figure 5.

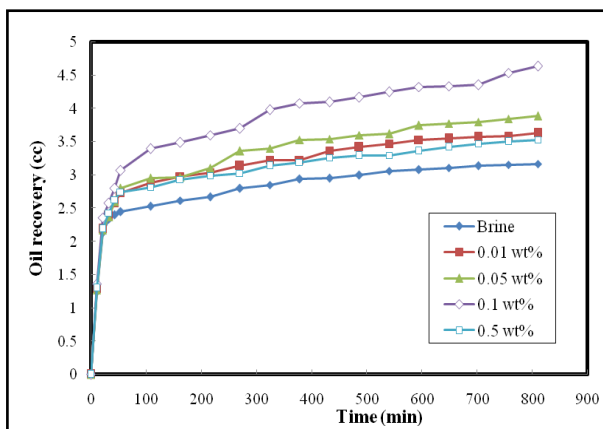


Fig. 4. Oil recovery vs. time in various nanoparticle concentrations

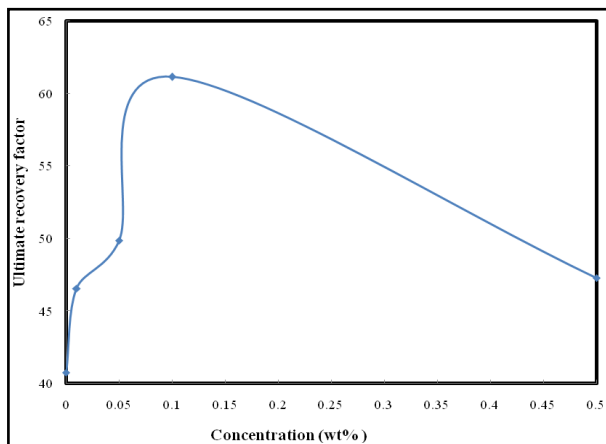


Fig. 5. Ultimate oil recovery VS. nanoparticles concentration

$S_{wc}$  reached from each core are presented in Table 4. The results show that the final step of increasing the concentration to 0.5% has led to a

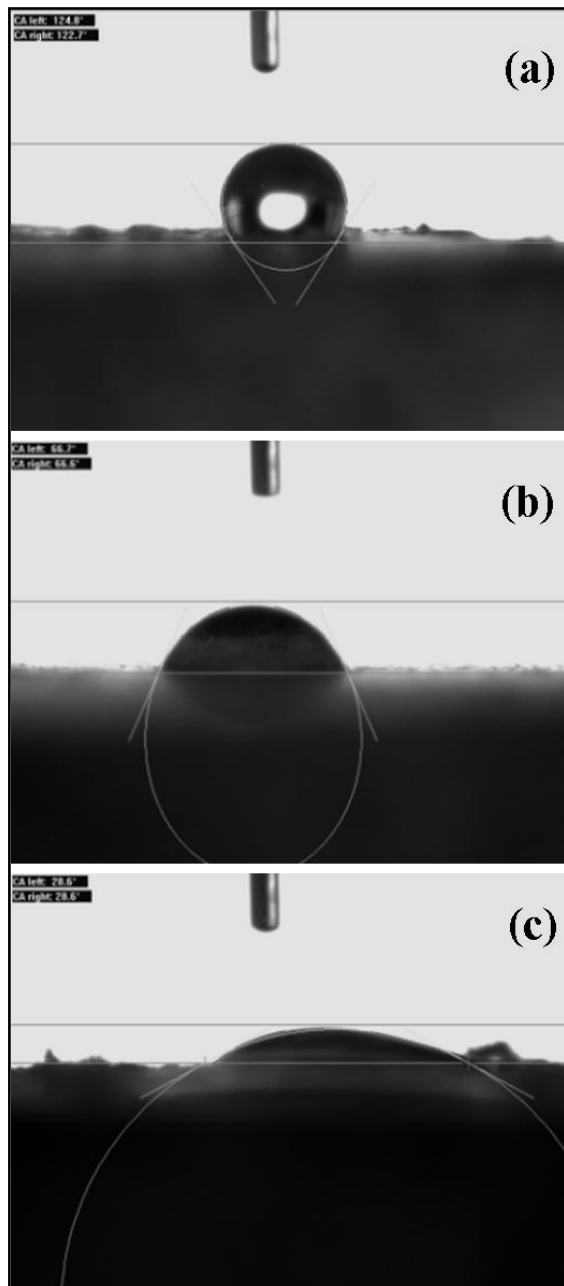
decrease in recovery. To explain this we should note that there are two regions in rocks; region 1 contains: small pores, throats and nooks and region 2 contain: large pores. In oil-wet rocks, oil exists in the region 1 and water exists in the region 2, therefore oil is trapped because of the capillary force. Unlike this, in water-wet rocks oil exists in the region 2 and water exists in the region 1, therefore narrow pore throat hinders movement of oil and oil is trapped. In neutral wet rocks, oil and water exist in both region and capillary pressure in very low, so we have lower residual oil saturation. Because of nanoparticles adsorbed during water flooding, contact angle changes continuously, and a dynamic wettability alteration occurs. We measured the final contact angle. It means that average contact angle is higher than these results. Therefore, the oil recovery curve has a stepwise shape. Furthermore, pore plug may have occurred because of the nanoparticles accumulation in the pore throat.

Table 4. SWC in various steps

Nanoparticles concentration (% wt)	0	0.01	0.05	0.1	0.5
Core no.	C1	C2	C2	C3	C4
$S_{wc}$	0.281	0.26	0.264	0.213	0.25

### Contact angle test

At the second step, the hydrophilic changes of cores were studied by using the contact angle test. The results of contact angle test on the cores can be seen in table 3. The result shows the initial angle of 124 degrees, and it could be said that the cores were weakly oil-wet. As expected, after flooding core with LHPN, contact angle decreased from 124° to 0°, which indicates the wettability alteration of the surface. The contact angle decreases with increasing nanoparticle concentration. It means that hydrophilicity is increased and core becomes more water-wet. The images of water drops are shown in Figure 6 a, b and c.



**Fig. 6.** (a). Core image when injected brine only,  
 (b). Core image when injected with 0.05% suspension  
 (c). Core image when injected with 0.1% suspension.

## CONCLUSIONS

Based on the experimental tests, the following results achieved:

Water wettability increases with higher concentration of LHPN.

The results showed that the maximum recovery factor occurred when the wettability is nearest to neutral-wet or weakly water-wet conditions.

It can be concluded that optimal nanoparticle concentration is 0.1.

## Nomenclature

$S_{WC}$ : Non recoverable water, the water that remains in the core

$S_o$ : Oil saturation percentage at each moment

$S_w$ : water saturation percentage at each moment

PV: pore volume, cc

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