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The effect of gas-wetting nano-particle on the fluid flowing behavior in porous media

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HIGHLIGHTS

- Nano-silica particle is functionally modified by fluorosurfactant.
- The wettability is dominated by the morphology of adsorption layer on core.
- Wettability alteration can facilitate enhanced oil recovery.
- The mobility of fluids trapped in porous media can be improved.

GRAPHICAL ABSTRACT

The influence of gas-wetting alteration on the flow and distribution of fluids in porous media was studied with visualization flooding on a transparent glass micromodel whose original wettability is liquid-wetting. The glass model was first saturated with brine before gas-flooding to simulate the liquid-blocking effect near the wellbore region, as can be seen from Fig. 1a. As a result, severe liquid-blocking regions within the core did not allow gas passing through the outlet end of the micromodel (Fig. 1b). Fig. 1c shows how the liquid trapped in the outlet end of the micromodel is mostly removed after a certain amount of FG40-NP solution was injected. The red arrows in Fig. 1b show flow paths formed by the displaced. The liquid saturation in visualized flooding was calculated using MATLAB, which shows a sharp decline in liquid saturation after gas-wetting alteration, as shown in Fig. 1(g)–(i). If the initial liquid saturation in the micromodel is considered as 100%, the liquid saturation after gas-flooding is 33.23%. A liquid-blocking region can be observed in the top right corner of Fig. 1(h). Fig. 1(i) shows the liquid in the liquid-blocking region scattering as discontinuous phase after gas-wetting alteration, the liquid saturation declines to 20.77% in this stage. Hence, the flow path for fluids in porous media can be seen clearly. The amount of trapping liquid in micromodel decreased sharply after gas-wetting alteration. Therefore, the novel gas-wetting alteration agent can be applied to solve the liquid-blocking effect near wellbore region on the gas-condensate reservoir.

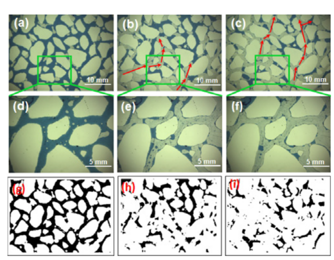

Fig. 1. Visualization flooding: (a) before gas-flooding, (b) gas-flooding until liquid-blocking, and (c) gas-flooding after gas-wetting alteration. Figs. 1(d), 1(e), and 1(f) are magnified areas of Figs. 1(a), 1(b), and 1(c). As shown in Figs. 1(g), 1(h), and 1 (i), the liquid saturations in Figs. 1 (a), (b), and (c) are 100%, 33.23%, and 20.77%, respectively. The liquid saturation significantly decreased from 100% to approximately 20.77% after treatment; hence, a clear flow path in model can be observed. The black region represents liquid in porous media, the white region corresponds to the flow path and rock.

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ABSTRACT

The effect of gas-wetting on the liquid-blocking effect near a wellbore region is significant. Here, we functionally modified nano-silica particles with a size of approximately 40 nm each by using a fluorosurfactant and obtained a super gas-wetting nano-silica particles, which could improve the contact angles of

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brine and hexadecane from 23° and 0° to 152° and 140°, respectively, and decrease the surface free energy of rock surface from 72 to 1.6 mN/m. The decrease in the gas displacement was approximately 30%. FT-IR, SEM and EDS were employed to determine the morphological change in the rock surface before and after gas-wetting alteration. Results indicate that when the fluorosurfactant molecules are joined to the nano-silica surface, and C—F bond is recognized. The grape-like particles forming a multi-adsorption on the rock surface, which play an important role in super gas-wetting by decreasing surface free energy and increasing roughness on the rock surface. The data of EDS was consistent with the results of FT-IR and SEM. To further understand the influence of gas-wetting alteration on the flow and distribution of fluids in porous media, visualization flooding was conducted. The results show that the initial liquid saturation in the micromodel decreased sharply from 33.23% to 20.77% after the gas-wetting treatment, and the contact angle of isolated brine droplet on the treated pore-wall was approximately 125°, which also verifies that pore wettability can be altered to gas-wetting. The analytical data of the oil displacement experiment demonstrates that the substantial decrease in oil saturation may contributes to enhancing oil recovery. Furthermore, the mobility of oil trapped in micro channels can also be enhanced significantly after gas-wetting alteration due to the presence of methane.

1. Introduction

The pressure of gas-condensate reservoir declines isothermally during the primary production. When the reservoir pressure decreases to the dew point, gas will condensate into liquid near the wellbore region, leading to an increase in liquid saturation and decrease in flow efficiency of fluids. Consequently, gas-deliverability will be killed instead of having gas evolution. This so-called liquid-blocking effect is one of the most serious threats to a low-permeability reservoir [1–3]. Wettability alteration has been well known as one of the most efficient approaches to mitigate the liquid-blocking effect and improve liquid distribution in porous media [4,5]. Li and Firoozabadi [6,7] reported that gas-well productivity could be enhanced significantly if the rock wettability near the liquid-blocking region is altered from liquid-wetting to gas-wetting in a gas-condensate reservoir; Estimates of gas deliverability are conducted by measuring the flow rate, inflow performance curve or gas-backpressure curve. Gas-wetting alteration can effectively improve gas deliverability by improving the flow rate of liquid in porous media. Wu and Firoozabadi [8] demonstrated that rock wettability can be permanently altered to intermediate gas-wetting by fluorosurfactants at a temperature of 90 °C. Wang et al. [9] found that flow efficiency of fluids in the liquid-blocking region can be improved by approximately 25% compared to that of fluids before gas-wetting alteration at an elevated temperature of 120 °C. The improved flow efficiency was reported to become even more pronounced with rising temperatures. Elsharafi and Bai investigated the effect of particle size on the permeability and wettability of reservoir was that small-sized particle could decrease oil production by blocking porous media in high-permeability reservoir [10–12].

Mousavi et al. [13] recently observed that fluorinated silica nanoparticles with an average diameter of 80 nm can alter the rock wettability from preferential liquid-wetting to intermediate gas-wetting, and the amount of liquid trapped in pore media can also be efficiently reduced by this gas-wetting alteration. Jin et al. [14] suggested that super gas-wetting rock can be achieved by using nano-silica particles which were functionally modified by fluorochemicals. As a results of the fluorochemicals intervention, the contact angles of brine and hexadecane on the modified rock surface can be increased from 23° and 0° to 150° and 140°, respectively.

Wettability alteration can also play a vital role in enhanced oil recovery (EOR). Anderson [15] found that more oil could be recovered from the preferential water-wet reservoir than from an oil-wet reservoir in the primary production. Newcombe and McGhee [16] indicated that oil recovery from the cores of intermediate wettability might be greater than that from more strongly water-wet cores. Investigations in recent years have shown that oil displacement efficiency in porous media improved by approximately 32% after enhanced oil recovery (EOR) [4,5,17,18]. This also presents a new challenge of finding ways to extract the remaining two-thirds of oil in place. Thus, it will be very interesting to see if oil recovery will show a greater increase if the wettability of porous media is altered from liquid-wetting to gas-wetting. However, conventional EOR methods, such as surfactant flooding and polymer flooding, still have the limitations of high doses, low efficiency, and heavy pollution. Therefore, a more efficient approach to enhanced oil recovery is needed.

Jiang et al. [19] investigated the effect of gas-wetting alteration on the flow behavior and distribution of fluids in micromodels with different wettability levels. They found the displacement front could be transformed from concave to convex when liquid wettability was replaced by gas-wetting. Seyyedi et al. [20] observed that discontinuous water phase in an oil-wet micromodel tends to appear as an isolated droplet on the core wall after a long water injection duration. Hou et al. [21] found oil-wet sandstone could be altered to water-wet by the adsorption of surfactants on the core surface, and the neutral-wet micromodel performed the highest oil recovery by waterflooding. However, few research has covered visualization flooding by gas-wetting nano-silica solutions, and the mechanism of flow behavior in the presence of gas-wetting nano-silica particles in porous media is not yet fully understood.

In this article, the research attempts to bridge the information gaps that prevents utilization of the modification mechanism between fluorochemicals and nano-silica particles. Another great challenge is to delineate the flow behavior of fluids in the trapping region after gas-wetting alteration in porous media. To address this challenge, we are presenting experimental evidence showing the effect of the presence of gas-wetting nano-silica particles at increasing concentrations on rock wettability and imbibition. We also perform a visualization flooding with a liquid-blocking effect, which explains the decreasing amount of liquid trapped in porous media by gas-wetting nano-silica particles.

2. Materials and experimental methods

2.1. Surface modification of silica nanoparticle with fluorosurfactant

Silica nanoparticles with the mean diameter of approximately 40 nm were prepared in our laboratory by the advanced Stöber method [22]. Fluorosurfactants exhibit extraordinary properties such as good gas-wettability and thermostability, thus being