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An Experimental Investigation of Multi-Phase Flow and the Effect of Fracture on Enhanced Oil Recovery in the Porous Medium

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ABSTRACT: Strategies for extracting residual oil in the reservoir are called enhanced oil recovery. One of the usual methods of enhanced oil recovery is the water alternating gas injection. The study of this injection method in a two-dimensional porous medium has been less considered. In this study, two porous media were made using a 3D printer. One is simple, and the other has a horizontal fracture. Nitrogen gas and water have been used in three different scenarios, in the form of a single injection of gas, water, and the water alternating gas injection, to increase the oil recovery. Then, the recovery of each injection scenario was calculated by processing the captured images. This study showed that the water alternating gas injection in the simple medium swept about 55% of the medium, which was more than 6 times the injection of gas and more than 2.5 times the injection of water. water alternating gas injection also swept about 38% of the fracture medium, which was 2.5 times more than the other two injection scenarios. The reason for the difference in recovery between the two media in water alternating gas injection is the negative impact of fracture. Also, the difference between water alternating gas injections and single injections can be found in the pressure drop diagram. The water alternating gas injection pressure drop consisted of separate injections of gas and water.

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1- Introduction

Fractured reservoirs are mostly carbonates that are located on land, and some offshore reservoirs, such as Siri Island, are sandstone reservoirs. The oil reservoir is inherently pressurized at the time of discovery, and as a result of this pressure, oil is easily extracted from it. This stage of oil extraction is called primary oil recovery. As the reservoir pressure decreases, the oil production rate decreases too, and fluids are injected into the reservoirs to maintain the pressure. Because these fluids are injected in the second phase of oil production, these methods are called secondary oil recovery. Conventional methods for recovering the oil in the second stage include methods such as immiscible gas or water injection. Even after the second stage, a large amount of oil remains in the reservoir. To extract this remaining oil, some novel methods are used, that is called Enhanced Oil Recovery (EOR), Such as Water Alternating Gas (WAG) injection [1, 2] and chemical injection [3-5].

2- Methodology

For this study, two porous mediums were printed with the 3D printer. One is Simple (S), and the other is similar to S in every aspect but it has a horizontal Fracture (F) in the middle. (Fig. 1)
Silicone oil was used as a displaced phase with a viscosity of 407 cP, also brine water (solution of distilled water with 2 gr of NaCl salt) and nitrogen gas with a purity of 99% (gas phase) are used as the flooding agent phase. For the WAG injection, a ratio of 1:1 (between water and gas) has been used.
This investigation includes studying two porous media in three different gas, water, and WAG injection scenarios. For this purpose, the porous mediums are first secured between two plates of Plexiglas, which contain pneumatic connections for the inlet and outlet. The oil is then injected into mediums from the outlet with a low flow rate until all the air is completely removed and filled with oil. In gas or water injection, the syringe pump injects the fluid into the medium at the rate of 4.3 ± 0.04 ml/hr, and it continues to inject until it reaches six times the Pore Volume (PV). It is necessary for WAG injection to inject equal volumes of water and gas into the medium at specific times. To achieve this goal, outlets of pumps are connected to solenoid valves, controlled by a timer, and set to alter the injection of each phase in 18 s. During the test, the inlet and outlet pressures are recorded at 0.5 Hz frequency by pressure sensors. The oil extraction process and the patterns created are also captured during the test. The recovered oil is drained into a container. After the experiment, the photos are processed using the image processing code.

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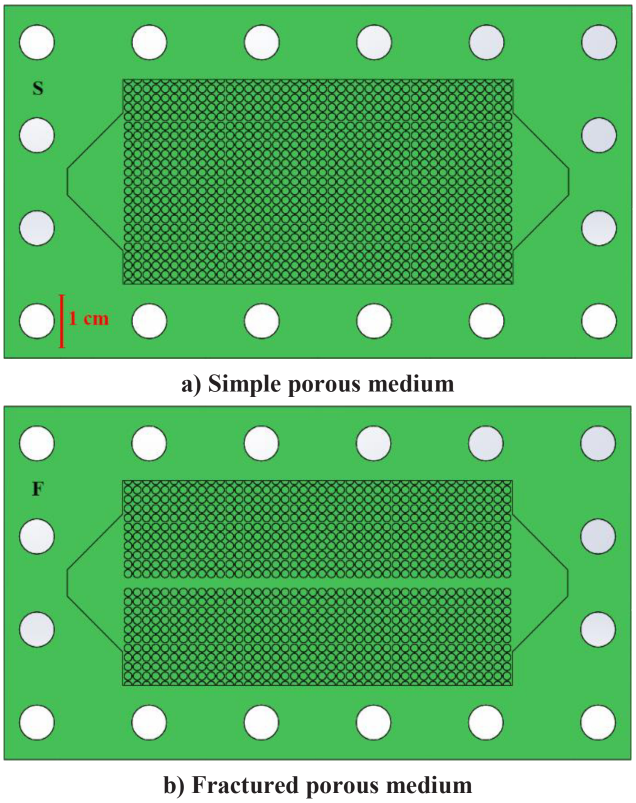

Fig. 1.The porous medium of this study

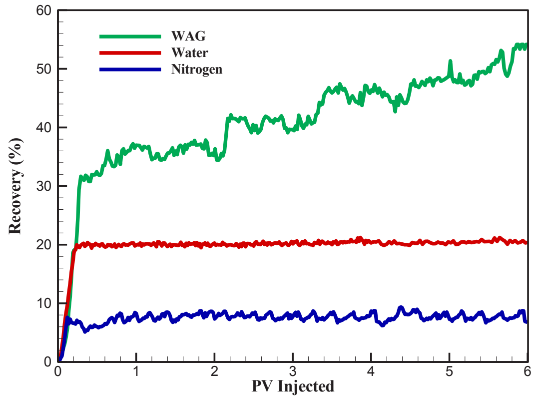

Fig. 2. Recovery vs PV injected in the S medium

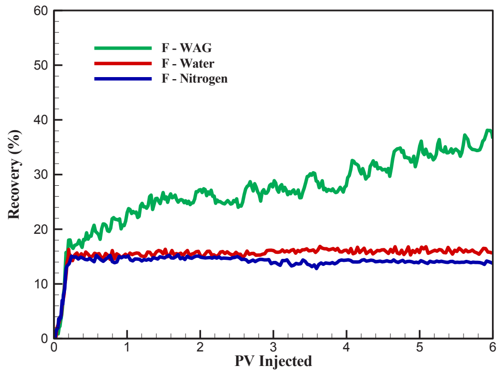

Fig. 3. Recovery vs PV injected in the F medium

3- Results and Discussion

Lenormand et al. [6] investigated the displacement of the wetting phase by the non-wetting phase (both phases are immiscible) in a horizontal porous medium without considering the effect of gravity. Their results showed that the displacement of two immiscible fluids in the porous medium is classified into three regimes: capillary finger, viscous finger, and stable displacement. The present study regime is located in the area of the viscous finger.

3- 1- Simple porous medium (S) results

The recovery vs. PV injected diagram was obtained by conducting the three scenarios in the S porous medium (Fig. 2). As can be seen in this diagram, the oil recovery rate in the gas injection scenario is about 8%, and in water, injection is about 20%. However, the recovery rate in the WAG injection is much higher at about 55%. In all three scenarios, the recovery increases linearly with the steep slope, and after the Breakthrough (BT), the slope of the graph decreases dramatically.

In gas injection, due to the low viscosity of the displacing phase, the mobility ratio is low, and this causes the rapid formation of the first finger of gas inside the oil phase. Because the medium has no fracture, the created finger must pass through the throat. Gas creates new and small fingers along its path, but with the BT of the first finger, an exit path is provided for the gas that reduces its pressure; thus, it does not create a new pass to the outlet, and the recovery rate remains almost constant.

In water injection, the formation of the first finger occurs later due to the water's greater mobility. In this way, water first enters the medium with a more stable front, and after sweeping some throat, it forms the first finger. As a result, the BT of water is delayed, resulting in more recovery. After the first finger of water reaches the outlet, the continued injection does not affect recovery and remains constant.

In WAG injection, it was observed that the recovery rate had increased significantly compared to the gas or water injection. It should be noted that WAG injection always begins with water invasion. The injection frequency creates successive queues of water and gas at the medium. Due to capillary pressure in the porous medium, the gas phase in the inlet is compressed. This compression goes so far as to overcome the capillary pressure of the environment, and the gas phase pushes water into the medium. The alternating injection of water and gas increases the pressure gradient, which causes local jumps in the recovery rate.

3- 2- Fractured porous medium (F) results

Like the S medium, three injection scenarios were also tested in the F medium, and the recovery vs. PV diagram was obtained (Fig. 3). This diagram shows that the recovery in gas and water injection has increased to about 14%. Also, the recovery in WAG injection is about 38%. Like the S medium, the recovery increases linearly and has a steep slope in all three scenarios until the BT, and the slope of the graph decreases after the BT. In WAG injection, due to the fracture, the recovery to BT is less than the recovery of this scenario in the S medium.

In the first scenario, gas was injected into the F medium. Due to the presence of fracture, which is a path with a very high permeability compared to other areas of the porous medium, the gas does not tend to enter areas with less permeability and flows in the fracture as soon as it enters the medium. Although the recovery has increased compared to the S medium, this increase is related to the width of the fracture, and even after the injection of six times of PV, it can be seen that the gas has only swept the fracture and has not penetrated low permeability areas. This experiment shows that in a porous medium with fractures, gas injection is not a suitable strategy for EOR.

In the second scenario, water was injected into the F medium, and its recovery result was similar to the gas injection and water has only been able to sweep the fracture. Due to the higher mobility of water, a few limited and small invasions happened, but it did not have much effect on the overall amount of recovery.

Although the recovery in WAG injection is more than gas or water injection, it has less recovery than the injection in S medium due to the fracture. Because, as mentioned before, the displacing phases enter the fracture alternately. As the injection continues, the pressure created by the gas condensation overcomes the capillary pressure of the throats, and eventually, they enter the porous medium around the fracture, which causes a jump in the recovery. During the test, like the water injection, some invasions (perpendicular to the fracture direction) are observed, but due to the pressure of the gas behind the water, these invasions expand and cause a noticeable increase in recovery.

4- Conclusions

As observed in this study, the recovery rate in WAG injection in both porous mediums was much higher than the injection of each fluid alone, which was explained by the pressure gradient diagram. In this way, the WAG injection pressure gradient diagram had a dual behavior and created local jumps in the recovery by creating local peaks in the pressure gradient. The study of fracture also showed that it hurts recovery significantly. In gas or water injection, the displacing phase chooses the high permeability path (fracture), and they were unable to penetrate the low permeability areas. In WAG injection, the displacing phase is less willing to penetrate into the low permeability area compared to the S medium, which significantly reduces the recovery.

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