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Research Paper

Investigation of Ultrasonic Waves' Function in Improving Oil Production Capacity Using Water-Flooding Experiments

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Abstract: One way to improve oil production capacity is to use ultrasonic waves. Series of straight and ultrasonic stimulated water–flooding experiments were conducted on a long unconsolidated sand-pack using ultrasonic transducers because of a limited understanding of the mechanisms involved in applying ultrasonic waves as an enhanced oil recovery method. Kerosene and vaseline were used as non-wet phases in the system with a viscosity of 0.99 and 22 cp, respectively. Moreover, fluid flow and temperature rise experiments were conducted using an ultrasonic bath to enhance contributing mechanisms. They were carried out to observe the effects of ultrasonic waves on oil recovery. As a result, the recovery of water-flooding increased by about 16%. Furthermore, three mechanisms of improving oil production capacity were recognized: emulsification, cavitation, and viscosity reduction. The changes in pressure and ultrasonic velocity were also simulated using Comsol software alongside the sand-pack. As a result of the function of ultrasonic waves, this study can help the contributing mechanisms for improving oil recovery.

Keywords: Oil production capacity, Ultrasonic waves, Water-flooding, Sand-pack, Comsol.

INTRODUCTION

The application of seismic and ultrasonic waves in different processes, such as gravitational depletion and water-flooding, has been studied by several authors [1-4]. Despite many published papers and some field tests on this issue, the exact mechanisms of ultrasonic waves have not been fully understood.

In this study, a series of water-flood processes (first saturated with oil and then water) were carried out directly and stimulated by ultrasonic transducers on an unconsolidated sand-pack. Moreover, some additional tests (e.g., fluid flow and temperature increase experiments) were carried out to study the details of ultrasonic waves, the simulation of pressure changes, and the speed of ultrasonic waves during a sand layer (using Comsol software). This study focuses on mechanisms that lead to an increase in oil recovery using the water-flooding process.

METHODOLOGY

Set-up

Two types of ultrasonic transducers were used for the experiments. The ultrasound generator of Crest is used with a frequency of 40 kHz and a power output of 100 to 500 Watts. A centrifugal pump was applied with a constant injection rate of 3 (mL/min) to inject fluids in all water-flood tests. A flow meter connected to the pump was applied to keep the flow rate.

Materials

Two types of brine were used for experiments: normal and deaerated 3% NaCl brine with a density of 1.05 g/cm^3. In comparison with water, vaseline and kerosene with moderate viscosity-high surface tension and very low viscosity-moderate surface tension, respectively, were used as non-wet phase systems in the experiments.

Porous media

5 cm^3 of 106-225 µm sub-angular to sub-rounded quartz sand grains were poured into a sand-pack. At first, the grains were carefully washed and then dried in a furnace. The porosity and permeability of sand-pack were measured as 33% and 4000 mD, respectively

Experimental Procedure

Two types of experiments were conducted, including studying one-phase flow and the temperature increase using the ultrasonic column. In the one-phase flow experiment, the core was saturated with normal and deaerated brine and then exposed to ultrasonic waves. Pressure changes were also recorded in the system.

RESULTS AND DISCUSSION

One-phase flow

According to the intensity of the waves, the pressure reached a peak and then reduced to lower values. A possible explanation is that "cavitation" is responsible for irregular behavior of pressure. In an environment with normal conditions, the fluid consists of tiny atoms with gas or non-dissolution vapor. By changing the environmental pressure of the fluid to steam pressure, these atoms become larger and exhibit cavities. In this case, due to the evaporation process, the inner pressure of cavities increases with the fluid's vapor pressure. Increasing the pressure through ultrasonic waves caused an explosive property in the cavities. As a result, oil production increases due to bubble movement and also cavitation. Therefore, cavitation can be calculated as one of the effective mechanisms in the application of ultrasonic waves.

Following what was discussed, increasing the temperature results in a decrease in viscosity because the pressure is proportional to the viscosity of the water, and any reduction in viscosity decreases the pressure drop to the same amount. Due to the cavitation, it is difficult to determine the amount of its effect as a result of aerated water. The results also show that the pressure reaches a small amount of its initial value, and this decrease is caused by a drop in the water viscosity [5].

In the second series of one-phase flow experiments, the deaerated salt of 3% NaCl was used to eliminate the cavitation effects. Similar to the procedure of normal brine, the pressure changes were recorded. When the ultrasonic waves were radiated, the pressure was decreased, and the pressure value was stabilized at the end of each experiment. Due to the results of the temperature effect and one-phase flow experiment, the reduction in the water viscosity is the leading cause of pressure drop observed in the one-phase flow experiment.

Temperature effect

The system with normal brine and saturated sand-pack temperature increased by 4, 12, and 16 °C for the corresponding power output of 100, 250, and 400 Watts, respectively. In the second part of the experiment, the temperature was measured for vaseline and kerosene in the ultrasonic bath. Based on the thermal conductivity for vaseline and kerosene, the temperature ascent is almost identical in both cases (Figure 1).

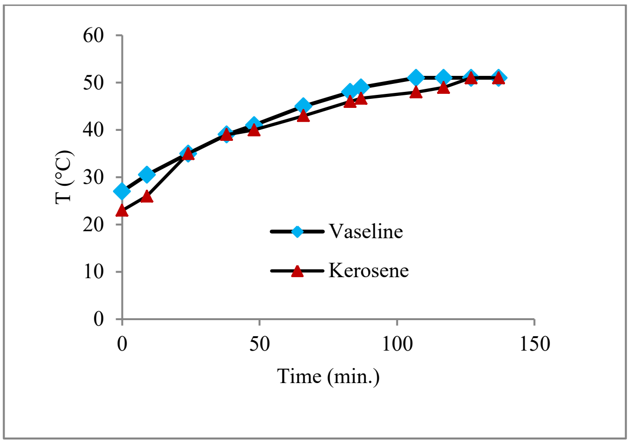

Figure 1. Temperature variations vs. time for both vaseline and kerosene

Table 1 shows the reduction of the surface tension in a system with vaseline-water and kerosene-water at different times calculated by Firozabadi and Ramey's equation [6].

Table 1. Changes of surface tension vs. time for vaseline-water and kerosene-water system

Kerosene (dyne/cm)	Vaseline (dyne/cm)	T (°C)
31	38	23
30.5	37.4	27
30	36.8	31
29.5	36.2	35
29	35.6	39
28.6	35	43
28.1	34.5	47
27.7	33.9	51

Although the surface tension for both vaseline-water and kerosene-water decreases, it is not high enough to significantly affect the capillary number; therefore, it cannot reduce the saturation of oil.

SIMULATION

Optimization of pressure and velocity variations in sand-pack have been done by Comsol software. In Figure 2, the pressure changes alongside the sand-pack are presented based on the Darcy equation. Because the porosity of the sand-pack is not high, the pressure on the sand-pack decreases gradually. This pressure decreases with decreasing fluid velocity (i.e., vaseline or kerosene) on the sand-pack.

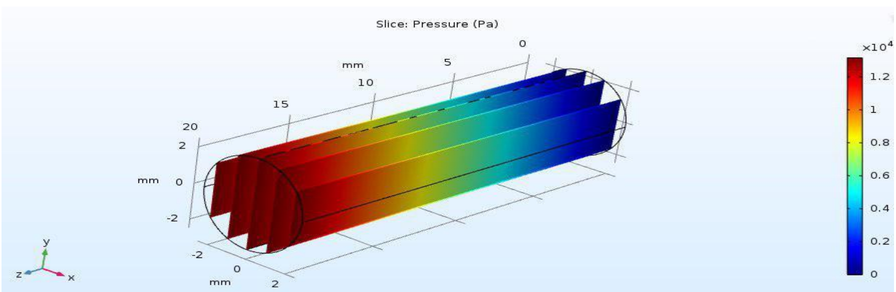

Figure 2. Slice countors regarding the pressure changes alongside the sand-pack

Figure 3 shows the speed of ultrasonic waves alongside the sand-pack. As shown in this figure, the speed of ultrasonic waves increases at the beginning of the sand-pack. However, it decreases gradually alongside the sand-pack due to the sharp drop of pressure and fluids (vaseline or kerosene) velocity at the end of the sand-pack.

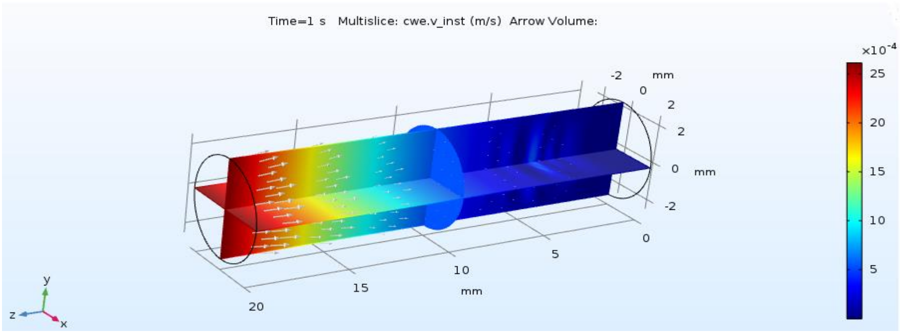

Figure 3. Changes the velocity of the ultrasonic waves alongside the sand-pack

CONCLUSIONS

Compared to deaerated brine, the use of normal brine caused more recovery of oil. This result can be explained by a space in the system when using normal brine. Besides, the increasing temperature is led to a decrease in the viscosity of fluids and their surface tension. Also, the one-phase flow experiment results show that increasing the initial pressure can be related to the Cavitation effect.

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