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REVIEW

Experimental application of ultrasound waves to improved oil recovery during waterflooding

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Abstract In oil reservoirs about 40% of the original oil in place is produced and the rest remains as residual oil after primary and secondary oil recovery due to geological and physical factors. Additional oil can be mobilized by applying some improved oil recovery methods. However, there is no universal IOR method to be implemented in any reservoir. Efforts are made to develop IOR methods with lower risk. One of these methods is the application of sound/ultrasound waves in the reservoirs to overcome the interfacial tension between oil and water, and reduce capillary pressure in the pores.

In this study, laboratory experiments on core samples were conducted to investigate the ability of ultrasound waves to mobilize additional oil. The core flooding was performed horizontally and vertically and the wave stimulation was applied at original oil in place and at residual oil saturation after performing initial waterflooding. Oil/water relative permeability was calculated to evaluate the flooding performance in the presence and the absence of wave stimulation and the rate of oil recovery was determined. In addition, water fractional flow curves were considered to determine the average water saturation after breakthrough in the presence and the absence of ultrasound waves. Moreover, the effect of wave stimulation on unconsolidated core samples was investigated.

Results show that the rate of oil displacement increases due to various identified mechanisms, and the interaction of the generated waves with the fluids in porous media causes changes in relative permeability and in water breakthrough. Wave stimulation at residual oil saturation was more effective than the case of original oil in place. Therefore, this method is advised to be used in depleted reservoirs. Moreover, wave stimulation on core sample with a compressive strength of < 150 psi (unconsolidated) is not recommended due to sand production.

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Contents

1. Introduction

The world oil reserves can be increased by employing new oil production methods to recover most of the oil found in pores between rock particles. The production history of a petroleum reservoir goes through several production stages. The first stage is primary recovery process, in which the reservoir pressure causes the fluid to flow into production wells and then to the surface. If the reservoir pressure is not significant to maintain fluid flow to the surface, down hole pumps or gas lift is used to raise the oil to the surface. The average primary recovery rate is around 10–15% of the original oil in place, depending on the oil and rock properties as well as drive mechanism. The second production stage known as secondary recovery methods includes gas and brine reinjection or water flooding. The injection of fluids is implemented to replace the produced reservoir fluid, thus, the reservoir pressure can be maintained, or to displace the oil directly into the production wells and then to the surface. The most common method involves flooding the reservoir with water. The ultimate recovery factor can be increased to about 40% by employing the secondary recovery method (Roger Hite et al., 2004; Lake et al., 1994; Chierici, 1994; Laherrere, 2001).

The main causes of the poor recovery of the first two production stages are the existence of the interfacial tension between oil and water (capillary forces), high mobility ratio, and the heterogeneities in the reservoir rock. Therefore, the remaining oil in the reservoir after the primary and secondary methods is the potential target of the third production stage, namely the tertiary recovery methods. The tertiary recovery method is often termed as Enhanced Oil Recovery (EOR). In order to recover some of the oil left in the reservoir, EOR-methods have to be applied to overcome the physical and geological effects.

The main goal of the EOR methods is one or more of the following (Lake et al., 1994; Littmann, 1997; Williams, 2003; Amro, 1994; Zhu et al., 2005; Gharabi, 2005):

- Reduction of the interfacial tension between oil and water, and reduce capillary pressure.
- Decrease of the mobility ratio between oil and water by increasing water viscosity.
- Injection of chemical solvents.

However, efforts are made to develop new techniques with lower application risk. One of these alternatives is the application of sound/ultrasound wave stimulation. This technique is promising as new well stimulation technology to enhance oil recovery and/or to remove formation damage around the wellbore. It is known that propagation of the applied waves depends on elasticity, grain size and density of the rock (Gharabi, 2005).

Ultrasound waves will create vibrations in the reservoir, which would facilitate the production by changing the capillary forces, adhesion between rocks and fluids and cause oil coalescence (Frederick, 1965; Kouznetsov, 1998; Hamida and Babadagli, 2005).

Generating elastic waves in the reservoir can cause an acceleration of gravitational segregation of gas, oil and water. International interest in developing elastic wave stimulation as an effective enhanced oil recovery technology is growing.

In Russia, China, Canada, USA and Norway, laboratory investigations have focused on elastic-wave vibration, pressure pulsing, vibro-seismic technology as new EOR techniques, to study the effect of these technologies on improving oil recovery and reducing water oil ration (Frederick, 1965; Kouznetsov, 1998; Hamida, 2005). Sound waves are generally used in the oil industry for exploration and appraisal during seismic and logging surveys and they are used in many other industrial applications to remove contaminants from other parts (Hamida and Babadagli, 2005; Westermark et al., 2001; Nikolaevskiy et al., 1996; Al-Homadhi et al., 2001).

Erfan et al. conducted an ultrasonic stimulated water-flooding experiment on unconsolidated sand pack. Kerosene, vaseline and engine oil were used as the non-wet phase in the system. A 3–16% increase in the recovery of water-flooding was observed. Emulsification and cavitations were identified as contributing mechanisms. These findings are expected to increase the insight into involving mechanisms which lead to improving the recovery of oil as a result of application of ultrasound waves (Mohammadian et al., 2013).

Khosrow and Tayfun use oil saturated cylindrical sandstone cores placed into imbibition cells, then oil recovery performances were tested with and without ultrasonic radiation. The ultrasonic frequency was 22 and 40 kHz. An increase in recovery was observed with ultrasonic energy in all cases. This change was more remarkable for the oil-wet medium. But the additional recovery with ultrasonic energy became lower as the oil viscosity increased (Naderi and Babadagli, 2010).

Tarek and Tayfun investigated the effect of ultrasound on flow through a capillary using the pendant drop method. Water was injected into a capillary tube submersed into several