

Effect of Electromagnetic Waves on Petroleum in Porous Media with High Pressure and Temperature Micro-Model

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Abstract: The main extensively used technique of thermal oil recovery is by injecting steam into the reservoir. A well-designed steam injection project is extremely efficient in recovering oil. However its applicability is restricted in many conditions. Experimental studies have exposed that for low infectivity reservoirs, small depth of the oil-bearing zone, and reservoir heterogeneity restrictions the performance of steam injection. This essay discusses methods of transferring heat to oil reservoirs, based on electromagnetic waves. We show the applicability of electromagnetic heating in high pressure and temperature micro-model for first time (reservoir condition) with magnetic feeders in the radio frequency region. The transmitter was developed to focus the 3 electromagnetic feeders in water-tank occupied with brine at 30 % salinity. The EM waves emitted by the transmitter with 3 magnetic feeders were able to achieve an average displacement rate of 1.6% (of image) per minute for non-electromagnetic case. In other words, in every minute 1.6% of the pores were occupied by water. When electromagnetic comes into play, the average rate goes up to around 3.6% per minute.

Key words: electromagnetic waves, high pressure and temperature micro-model, displacement, oil.

INTRODUCTION

Major challenge for oil industry is to progress the oil recovery from the reservoir. There are lots of methods for the oil recovery such as thermal EOR, chemical EOR and electromagnetic EOR etc. (Hamouda and Karousi, 2008).

One of the famous methods for oil recovery is steam injection EOR; steam injection method is not possible for Low permeability formation reservoir heterogeneity (Sahni, *et al.*, 2000)

In EM waves in radio frequency and microwave region are uses for enhanced oil recovery. The energy from the EM waves transfers to the resistive materials in the form of heat and decrease the fluid viscosity which enhance the mobility of the oil. The electromagnetic heating in the reservoir can be produce by Radio, microwave and low frequency. In Radio and microwave, heating take place due to the support movement of dipole of the molecules with EM waves. The power dissipated due to high frequency EM is $P = \sigma E^2$. When electrical energy in low frequency (50Hz) EM waves are use resistive heating take place and power dissolute is $P = I^2 R$ (Chhetri and Islam, 2008; Vermeulen and McGee, 2000).

Some studies have been done in theory and experimental by many researches apply the EM method for improved oil recovery. A mathematical model for EM heating of the oil shale was developed by (Javris and Inguva, 1988).

In this form, temperature, pressure, saturation, chemical reactions, mass conversation and basis terms equations was used for the recovery of oil. A model for development of oil stream by microwave heating was presented (Soliman, 1997).

Sresy use analytical and numerical model for microwave heating and EM waves were used to produce oil from tar-sand deposits when experiments were done in laboratory and field scale (Sresy, *et al.*, 1986). They also showed that the method was efficient.

An EM beating laboratory was developed for recovery of oil from thin pay zone by (Chakma and Jha, 1992) When they combine gas injection with, they understand that heat losses can be obtained when electromagnetic heating was confined to oil zone. They study Effect of porous media parameters such as salinity, oil viscosity, pressure, frequency, temperature on the oil recovery. They recovered oil more than 45% when combined with gas injection.

By using Maxwell's equations the simplified term for average power dissipated in a volume V is given by (Sahni, *et al.*, 2000).

The objective of this work is to develop an EM transmitter that can be to spotlight the EM waves to improve oil from core sample (M. Kashif, *et al.*, 2011). They study effect of electromagnetic on core and study

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oil recovery with electromagnetic they use 3 electromagnetic feeders that feed with function generator and use electromagnetic field for oil recovery.

Section Formatting:

Visualization with 2-D glass models gives us a general approaching into immiscible displacement of oil by water. But to understand the process at pore scale, micro-model studies are needed. For this purpose, a glass etched micro-model was built at high pressure and high temperature glass facilities at the University of Science and Research Branch for first time in Iran that is differ from past micro models. A series of experiments were performed on this model to capture the pore-scale physics of the displacement process under EM waves.

Micro-model Preparation:

A. Fabrication:

Micro fluidic devices are generally two dimensional microchips enclosing small volumes and are usually used to study the fluid behavior at micro scale. In petroleum reservoir studies, micro-models are employed to represent the porous media. To produce a micro-model, one first designs the pattern and makes a new holding that design which is needed to etch silicon or glass. Our model is a glass scribed with laser model and its fabrication consists of a few steps as detailed below:

1) Design: The design is done using COREL DRAW software with design the micro model and get out line with it and reduction error, outline .1 mm we can reduction error. (Fig1)

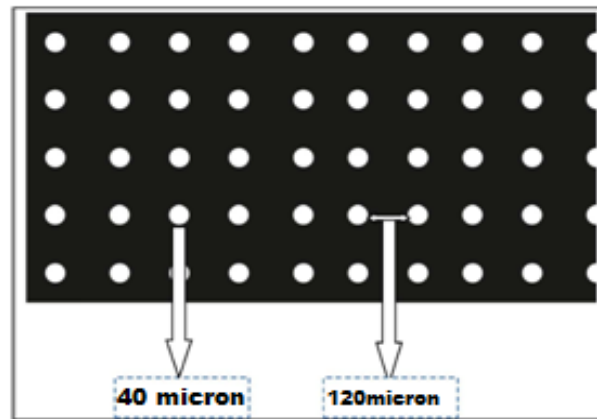


Fig. 1: Design micro model design with COREL DRAW black.

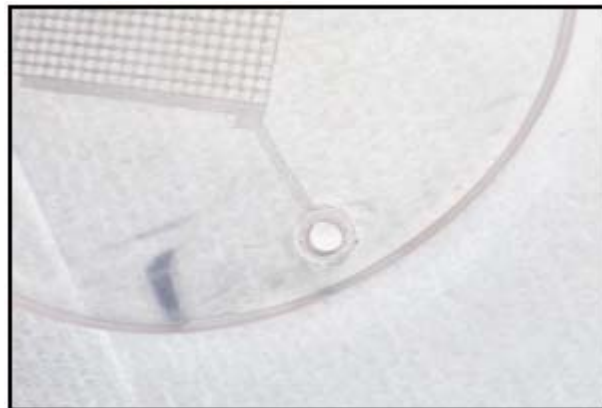


Fig. 2: Drilling glass after etched with laser.

2) Glass: Glass choice that base of flat glass (that used in mirror) the base of micro-model where pattern and the whole model will be scribed with laser on it. Because the work is done at nano scale, a tiny particle could cause a great damage to model so the substrate should be very clean.

3) Drilling glass: after scribed glass use glass bit for drilled glass. (Fig 2)

Micro-model specification:

We designed a simple homogenous model consisting of circles of around 40 micron diameters as grains and empty space among them as pores. Fig 3 shows the glass substrate of micro-model from top. Fig 1 shows the design of micro-model.

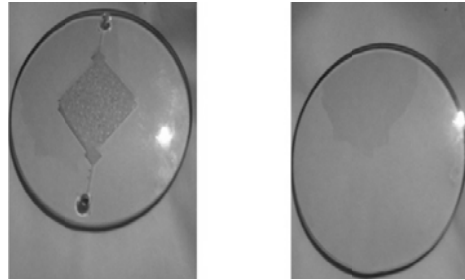


Fig. 3: Micro model.

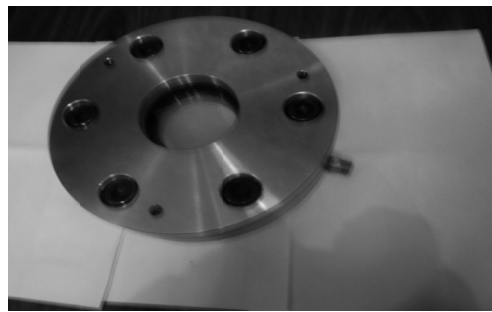


Fig. 4: High pressure and temperature Micro-model.

Electromagnetic Setup:

The magnetic field strength of EM transmitter with magnetic 3 feeders that use as number of feeders increase electromagnetic field that increase as number of magnetic field strength field also increase. For feeders use Toroid Core with 5 cm diameter in the form of 20 turns of copper wire (Fig5). The wire connected with function generator with sinusoidal waves at 1 kHz and peak to peak voltage of 20 V both for transmitter and magnetic feeders.

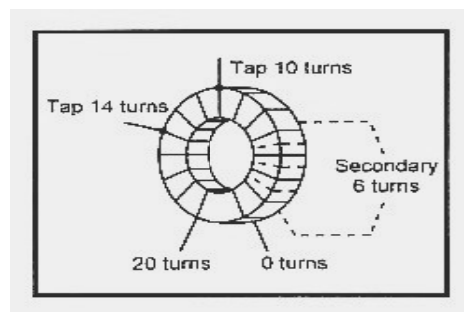


Fig. 5: Toroid core with kind of turns.

Experimental-Setup:

High pressure and temperature Micro-model (Fig 6) was attached to a glass base on which two holes were drilled. The holes were aligned on dawn of the micro-model ports and were sealed around with O-RING. These holes were connected to two valves which control the flow in and out of the model. This unit was then immersed into a bath filled with water displace with oil in high pressure and high temperature to make a suitable environment for electromagnetic application. A digital microscope was focused at the pore scale. The microscope mounted on the laboratory system sent images to a PC. For the electromagnetic cases, function generator, which is able to produce EM waves at frequency of 20 V to peak of 1 kHz, was used. The micro-

model was first saturated with water to make it wet and then vacuum-injected kerosene until it fully displaced water and saturated the model. A small amount of water saturation left inside. (Fig 6).

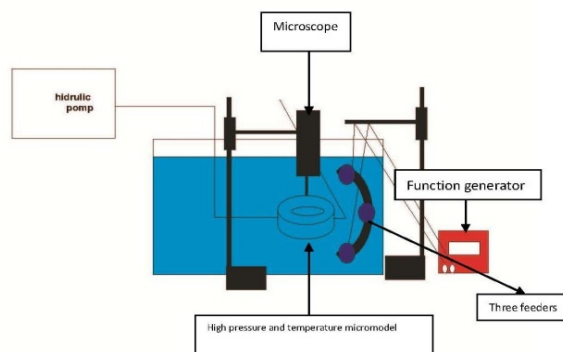


Fig. 6: Experimental-setup.

Results:

It is significant to find the area to be zoomed during the experiments to capture the images describing the process. The growth of the displacement front however, cannot be easily predicted. Therefore, the focus was kept on the injection front. Experiments at dissimilar rates were conducted with and without EM exposure. A selection of acquired images is presented in this section.

Fig. 7 shows the snapshots of the experiment with the injection rate of 0.1 ml/hr in 2000psi and 100°C, with and without EM radiation. The experiment was started without electromagnetic energy. Without varying the zoomed area, the electromagnetic generator was switched on at 25 minute. Therefore, the patterns shown in Fig. 7(c) are the maintenance of Fig. 7(b) with the only difference of EM energy existence. Represent kerosene and water was indicated by white color.

Non-electromagnet incase is slow in the beginning but becomes slowly faster. Note that injection rate is steady during the experiment and the change in the area swept could be due the front movement to this direction. In fact, the front movement was not uniform in all directions. After switching the EM energy, it was observed that the water diffusion was enhanced. Even though our evaluation is qualitative based on a chain of pictures and video clips generated from them, we also attempted to obtain a more quantitative evaluation of the imposed effects of EM radiation. With the theory of a linear trend of displacement, we obtained an average displacement rate of 1.6% (of image) per minute for non-electromagnetic case. In other words, in each minute 1.6% of the pores were occupied by water.

When electromagnetic comes into play, the average rate goes up to around 3.6% per minute. The electromagnetic feeders are located on the up side of the model and the flow in this direction could be enhanced. One observes a steady progress of water displacement and more compact cluster is obtained under electromagnetic waves. As observed here and also in the sand pack visualization experiments, the efficiency of EM energy on immiscible displacement is dependent on injection rate. A more general estimate can be done using the capillary number. (Hamida, 2006) related the cluster (displacement pattern) characteristics (fractal dimension) to the capillary number.

The capillary number is a dimensionless number representing the ratio of viscous forces to capillary forces and is defined by Eq.4.

One observes a good sweep resulting in a packed in cluster. Looking at another part of the model after switching the electromagnetic energy, one observes that less packed in but more branched displacement pattern. The sweep is not as good as the non-electromagnetic case and finger type branches are quite obvious.

The capillary number is a dimensionless number representing the ratio of viscous forces to capillary forces and is defined by Eq. 4:

$$N_{ca} = \frac{v\mu}{\sigma \cos \theta} \quad (4)$$

Where v is displacing fluid velocity, μ is displacing fluid viscosity, σ is interfacial tension (IFT) between displacing and displaced phases and θ is the contact angle. Commonly (also in our experiments), the displacing fluid is water and the displaced fluid is oil. Hence, Eq.5 can be re-written as follows:

$$N_{ca} = \frac{v_{ow}\mu}{\sigma_{ow} \cos \theta} \quad (5)$$

The residual oil saturation is dependent on the capillary number, as well as wettability characteristics and pore structure of the porous medium. When capillary number increases, residual oil saturation decreases. (Klins 1984; Green and Willhite, 1998). When the rate is slow, the capillary forces such as the wettability and IFT dominate the process.

Back to our experiments, in non-electromagnetic case (or normal case without external influence imposing on the system), the capillary number is directly related to injection rate. Thus, at higher rates, i.e. Higher capillary number; the less residual oil will be remained in the system after displacement. For the electromagnetic cases, at low injection rates, the acoustic energy reduces the interfacial tension and thus increases the capillary number and makes a better sweep than the identical case without electromagnetic radiation.

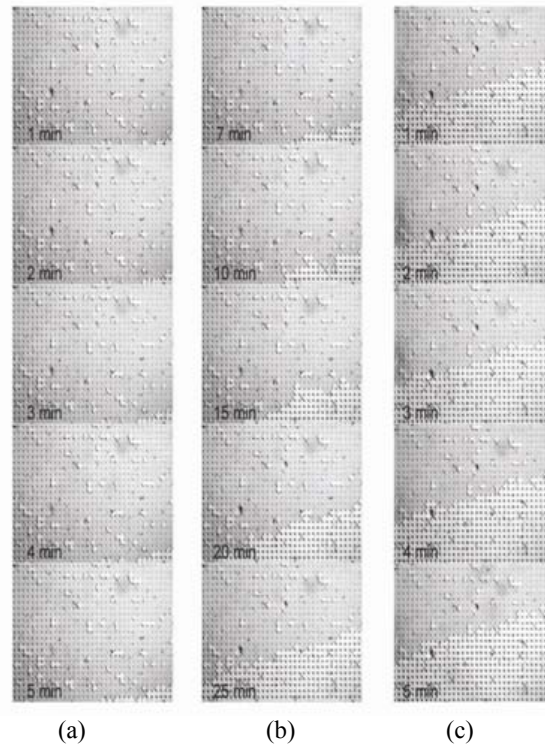


Fig. 7: Experiment at the rate of 0.1 ml/hr: (a), (b) without electromagnetic waves and (c) continuing the same experiment with electromagnetic waves exposure (lighter color (white) corresponds to water–displacing phase).

Conclusions:

We performed a few experiments in a homogeneous micro-model with and without electromagnetic energy at. For injection, a positive effect of electromagnetic energy creating a better sweep and displacement was observed. With the theory of a linear trend of displacement, we obtained an average displacement rate of 1.6% (of image) per minute for non-electromagnetic case. In other words, in each minute 1.6% of the pores were occupied by water. When electromagnetic comes into play, the average rate goes up to around 3.6% per minute. However giving a decisive theory needs more experiments in a wider range of injection rates, various wettabilities, and different designs of pore characteristics (heterogeneous micro-models).

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