VISUALIZATION OF OIL DISPLACEMENT BY WATER AND OIL-WATER EMULSION INJECTION

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Abstract. *Water injection is a common method to improve reservoir sweep and maintain its pressure. The efficiency of oil recovery in the case of heavy oils is limited by the high mobility ratio between the injected water and oil. Different enhanced oil recovery methods are being developed and studied as more efficient alternatives to water flooding.*
Dispersion injection, in particular oil-water emulsion injection, has been tried with relative success as an enhanced oil recovery method, but the techniques are not fully developed or understood. If emulsion injection proves to be an effective EOR method, its use would bring the add benefit of disposing produced water with small oil content, that could be modified to form the injected oil-water emulsion. The use of such methods requires a complete analysis of the different flow regimes of emulsions inside the porous space of a reservoir. Most analyses of flow of emulsion in a porous media use a macroscopic description. This approach is only valid for dilute emulsion in which the size of the disperse phase features is smaller than the pore throat. If the drop size of the disperse phase is of the same order of magnitude of the pore size, the drops may agglomerate and partially block the flow through pores. This flow regime may be used to control the mobility of the injected liquid, leading to higher recovery factor.
We have shown in recent experiments of oil displacement in a sandstone core that by alternating water and emulsion injection, the oil recovery factor could be raised from approximately 40 %, obtained with water injection only, up to approximately 75 %. Although these results clearly show the improvement on the recovery factor, the mechanisms responsible for the phenomenon are not clear. In this work, the displacement of mineral oil from a non-consolidated, planar and transparent porous media by water and emulsion injection is visualized to elucidate the mobility change due to emulsion injection.

Keywords*: Porous media, emulsion, oil displacement, recovery factor, enhanced oil recovery*.

1. INTRODUCTION

Water flooding is a conventional secondary oil recovery method, often used in field development plans, whether for pressure maintenance or oil displacement. Pressure maintenance is a way to assist insufficient primary water drive by injecting water into the edges of the oil column (edge aquifer) or in the bottom aquifer. In its well-patterned strategy (displacement), the method basically consists of injecting water through injection wells to drive the oil towards production wells. The application of this method is responsible for more than half of the world oil production, but the process has limited sweep efficiency, often leaving a considerable amount of oil in the reservoir. This is the result of an unfavorable mobility ratio between oil and water and the action of interfacial tension between the two liquid phases. Waterflooding is also affected by reservoir heterogeneity, which is typically linked to large contrasts in absolute permeability, such as the so-called “thieves-zones”, i.e. high permeability layers between injectors and producers that leave lower permeability layers unswept. When the water injection becomes uneconomic, this situation can be mitigated with the use of blocking agents. These agents increase the effectiveness of injection fluids in sweeping low permeability zones, hence helping to recover some of the remaining oil. Emulsions can be used to selectively block porous media, and consequently improve the efficiency of displacing fronts.

Several laboratory studies have been carried out to understand emulsion flow in porous media. McAuliffe (1973) determined properties of oil-in-water emulsions and studied their flow through porous media, to show that emulsions could be used as selective blocking agents for oil recovery in waterflooding experiments. He also showed that oil–in-water emulsions displace oil more efficiently than water alone. Later, Soo e Radke (1984) studied the flow of dilute emulsions through porous media and determined the final reduction in permeability. They measured droplet size distributions, both at the outlet and at the inlet of the porous sample and determined how the distribution changed as a result of filtering. They used a glass micro-model to prove that permeability reduction is caused by a capture mechanism similar to that observed in particle filtration processes. Kambharatana (1993) mentions the lack of good physical and mathematical descriptions for the flow of emulsions through porous media. In his work, he observed that viscosity changes of emulsions in porous media have a similar behavior trend as that seen in the viscosimeter, for the shearing rates of interest. Kambharatana confirmed that emulsion drops were captured according to a filtration process.

Emulsion injection as an alternative chemical recovery method is not a mature technology, but has been used successfully in some field trials. In the recovery of heavy oil, emulsions may provide an effective mobility control when the oil is displaced through the porous media (Bragg, 1999). In case this proves technically viable, the use of emulsions would bring some advantages relative to polymer injection. The cost of production of emulsions would be much smaller than the cost of polymer solutions and, because the emulsions could be prepared with native liquids from the reservoirs, the fluid-rock interaction could be minimized.

One of the difficulties in developing emulsion injection technologies for EOR relates to the lack of fundamental knowledge about the flow of emulsions through porous media. Blockage of the pores by the discontinuous phase, as one of the controlling mechanisms, is a function of several parameters involved in the physics of the flow. In this sense, it is important to find a rational way to establish a relationship between pressure drop and flow rate, depending upon variables such as emulsion viscosity, viscosity ratio between the continuous and discontinuous phase and mean droplet size/mean pore-throat size ratio. A detailed observation of these phenomena at the microscopic scale was presented by Cobos et al. (2006).

In a previous paper (Guillén et al. 2007), we showed the efficiency of emulsions to improve the oil recovery. The goal of work was to study the recovery of oil in a sandstone plug by the injection of water and different emulsions in coreflooding experiments. The oil recovery factor and the injection pressure were recorded during the experiments for different fluid displacement protocols. At final stage of water and emulsion injection, the recovery factor was raised from 40% (just with water injection) to approximately 75% of the initial oil in place, Although these results clearly show the improvement on the recovery factor, the mechanisms responsible for the phenomenon are not clear.

So, the goal of this paper is visualize oil displacement process by water and emulsion injection in a non-consolidated transparent porous media and help to clear the mechanisms responsible for the higher recovery factor obtained with emulsion injection.

2. EXPERIMENTAL PROCEDURE

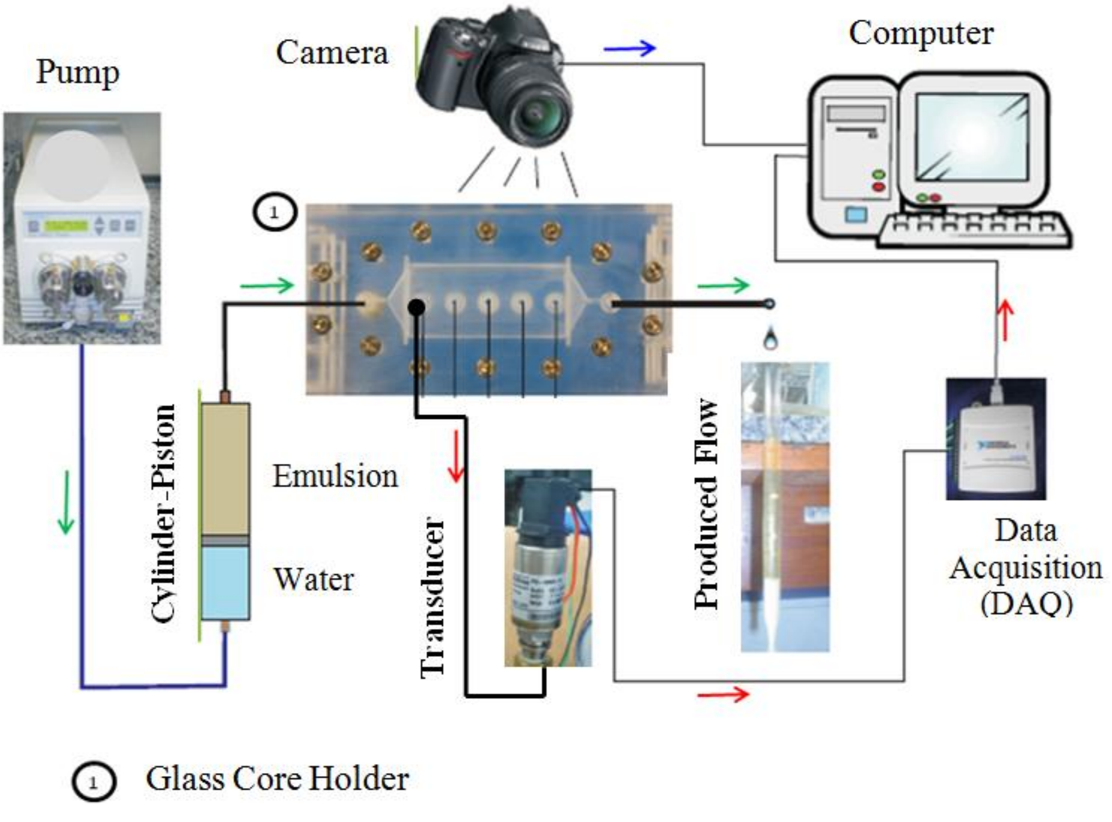

Figure 1. Schematic representation of experimental setup.

The experimental setup used in the analysis is sketched in Fig.1. Two different types of injection liquids were used, water and emulsions. A positive displacement pump controlled the flow rate fed into the porous media. To reduce the wear of the pump, only water flew through it. The water drives a piston installed in the storage cylinder to drive the injection liquid into the porous media, as indicated in Fig.1. The porous media considered a non-consolidated pack of glass spheres that were placed inside a rectangular cavity machined in a plexiglass plate. A pressure tap connected to a transducer was installed in the entrance of the porous media to measure the injection pressure during the experiments. A camera was mounted to look the transparent porous media from above and visualize the displacement process.

The porous media was first fully saturated with water in order to measure the pore volume and permeability. The properties of the non-consolidated porous sample used in the experiments are shown in Table 1. Mineral oil (μ = 410 cP) was then injected into the porous media displacing the water until the irreducible water saturation was obtained. Them, the porous sample was submitted to alternated injection of water and emulsion to displace the oil. As in our previous work, the produced liquid was weighted on a scale to determinate the oil fraction recovered during the entire experiment:

Table 1. Properties of the porous media used in the experiments.

POROUS MEDIA		
Glass Spheres	Common Glass	
Height	3	mm
Wide	35	mm
Long	75	mm
Porosity	35	%
Permeability	2,1	D
Pore Volume	2980	mm^3

(1) : measured at 23°C.

The properties of the oils used to saturate the porous media and to prepare the emulsions are shown in Tab.2. A 30% oil-in-water emulsion was prepared as the injection liquid. Its properties are presented in Tab.3. The emulsion has an average drop diameter of 70 μm. The emulsion presented a shear-thinning, as indicated in Fig.2. The viscosity value presented in Tab.3 represents the viscosity at a characteristic shear rate.

Table 2. Properties of the oil used to saturate the porous media and the oils used.

Oils	Viscosity (mPa-s)	Density (g/ml)
Mineral Oil (Saturate to Rock)	410[1]	0.9101
Synthetic Oil (Emulsion Prepare)	1000[1]	0.998

(1) : measured at 25°C.

Table 3. Properties of the emulsions used in the experiments.

EMULSION	Viscosity (mPa-s)	Density (g/ml)	Drops Diameter (μm)	Concentration (--)
Oil-in-Water	120[(1)]	0.9992	60	30/70

[(1)] : measured at 23 °C.

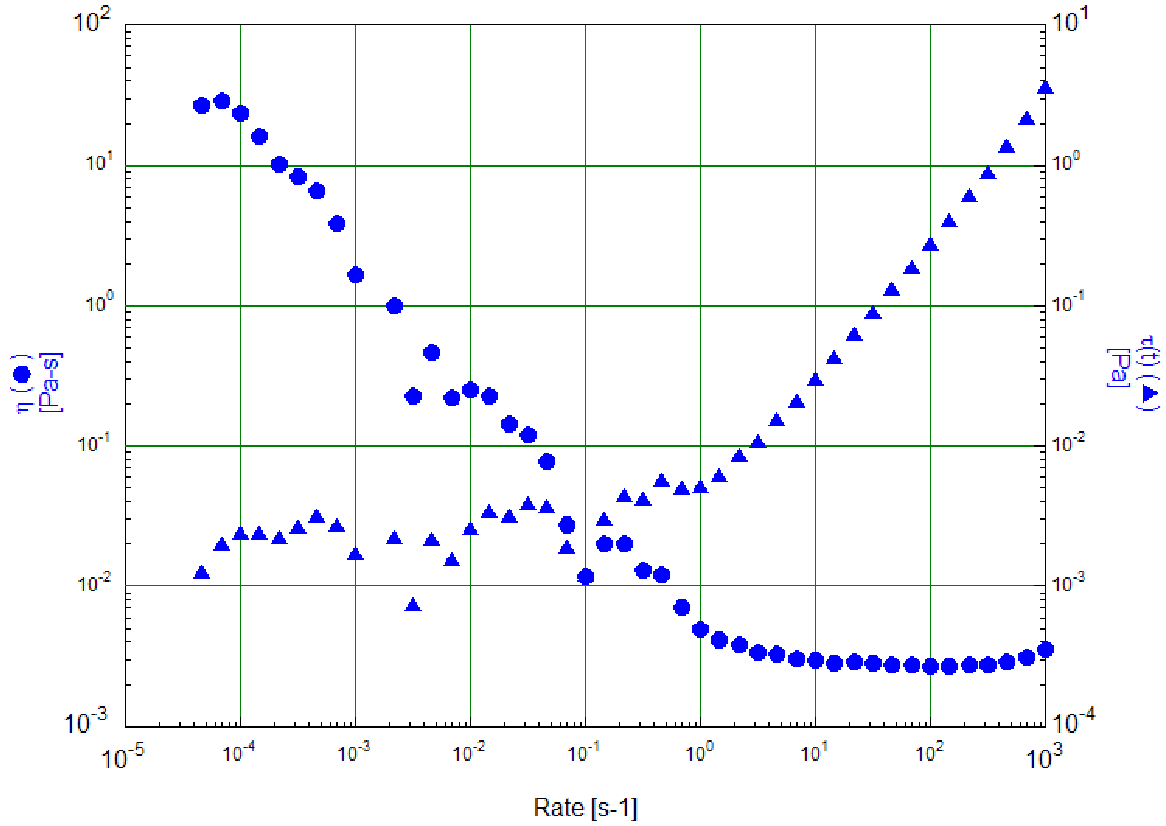

Figure 2. Variation of the viscosity with respect to the shear rate for the emulsion

3. RESULTS

The amount of oil produced during the experiments is presented here as a recovery factor, defined as the ratio of volume of oil recovered to the volume of oil inside the porous space at the beginning of the experiment. To make a correct comparison, oil volumes ought to be compared at the same conditions. In the results presented here, the conditions of comparison were atmospheric pressure and room temperature (23°C).

In the experiments, the oil was displaced from the porous sample by alternate injection of water and oil-in-water emulsion, with an average drop diameter D = 70 μm. The experiment started with injection of approximately 10 Pore Volumes of water. The recovery factor had reached a plateau of approximately 41% and the injection pressure had also reached a relatively constant value of 0,3 psi. At this point, a volume of emulsion of 30% PV was injected, and after that, the injection of water was restarted. Just after the water injection has restarted, the recovery factor started increasing, until it reached a new plateau of approximately 48%. The injection pressure rises abruptly after the emulsion is injected. It keeps rising for a short while even after the water injection is resumed but starts falling just after that, until it reaches a new plateau of 0,4 psi. A second cycle of emulsion injection followed, with a volume of 60% of the porous volume. The recovery factor started rising just after the start of the emulsion injection. Immediately after the emulsion injection, the injection of water was resumed. It continued until the recovery factor reached a new plateau, now of approximately 57%. A third and final cycle of emulsion injection elevated the oil recovery factor to approximately 96% of the initial oil in place. During this final stage of emulsion injection, the inlet pressure increased to a value of approximately 3,5 psi.

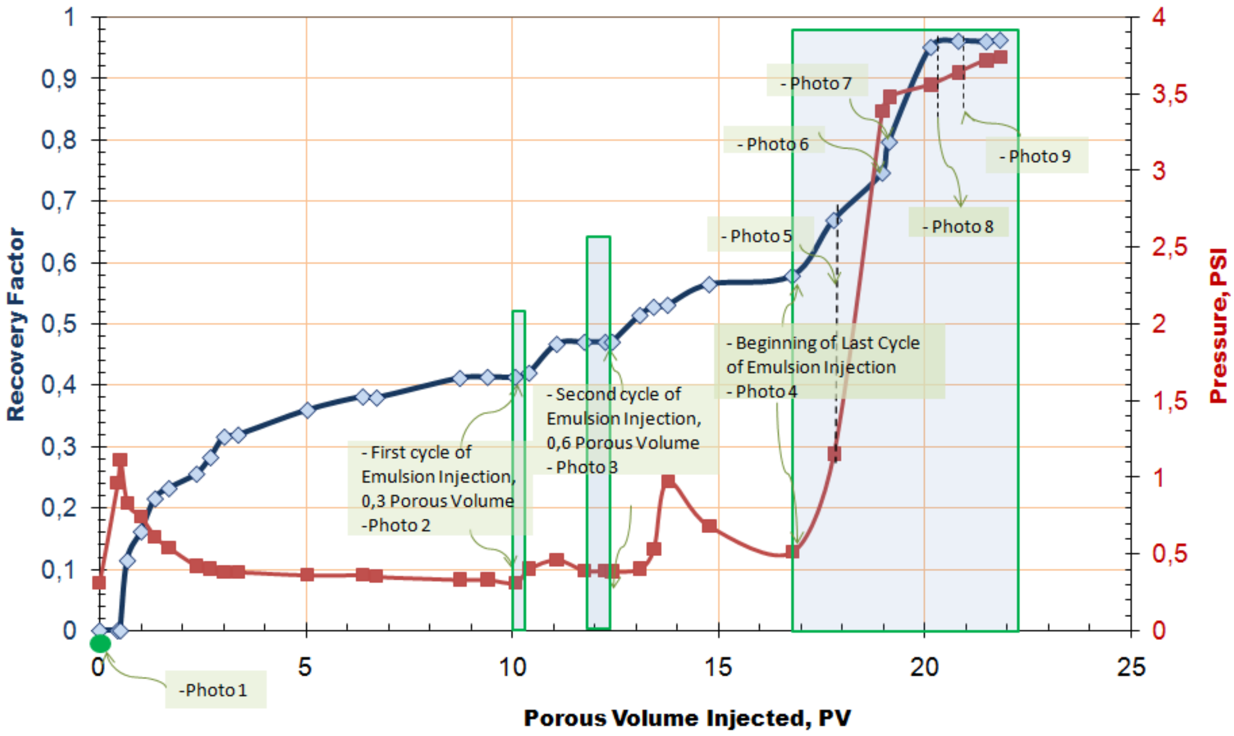

Figure 3. Recovery Factor through alternated water and emulsion injection in a glass spheres porous media.

The oil displacement process is showed by the photos presented in Fig.4. The instant that each photo was taken are indicated in Fig. 3 and summarized below:

- **Photo 1:** the porous media was saturated with oil until irreducible water saturation.
- **Photo 2:** End of the first batch of water injection and beginning of the first cycle of emulsion injection (FR ≈ 41%)
- **Photo 3:** End of the second batch of water injection and beginning of the second cycle of emulsion injection (FR ≈ 48%).
- **Photo 4:** End of third batch of water injection and beginning of last cycle of emulsion injection (FR≈ 57%).
- **Photo 5 to 9:** Emulsion injection.

The water was colored with a blue die in order to visualize the areas swept by water injection. In photos 2 and 3 we can clearly see the areas where the oil was not displaced (yellow colour). In photo 4, we can clearly see that a bank of oil was formed inside the porous media. The continuous injection of emulsion pushed this bank downstream, leading to a high recovery factor.

During the experiments, photos with high magnification were also taken to observe the details on a pore level. An example is shown in Fig.5. This figure shows the oil-in-water emulsion blocking process in the pore throat. We observe that emulsion drops of the same magnitude of porous size can agglomerate in it and thus change the permeability of porous media.

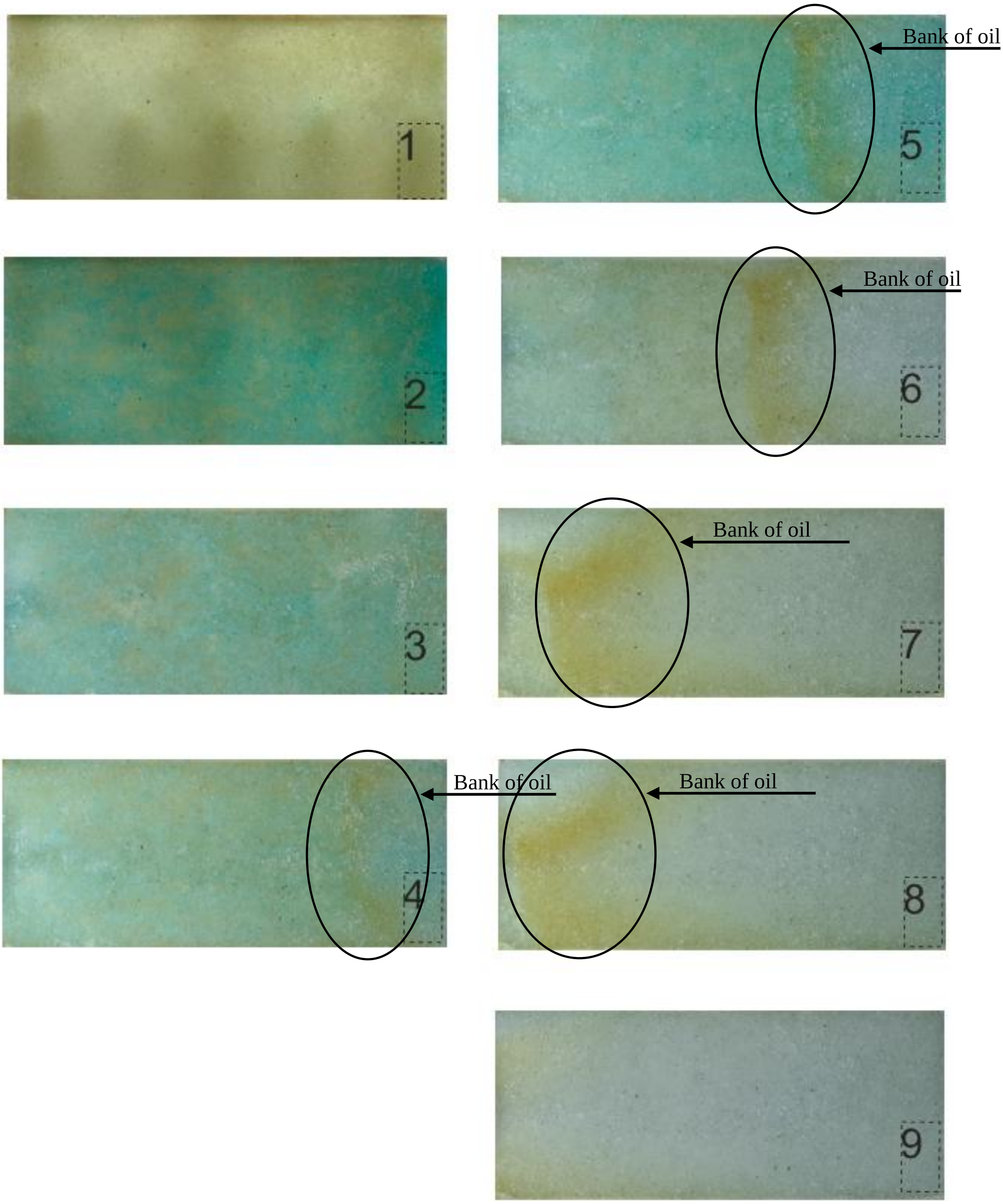

Figure 4. Oil displacement process in a glass sphere porous media.

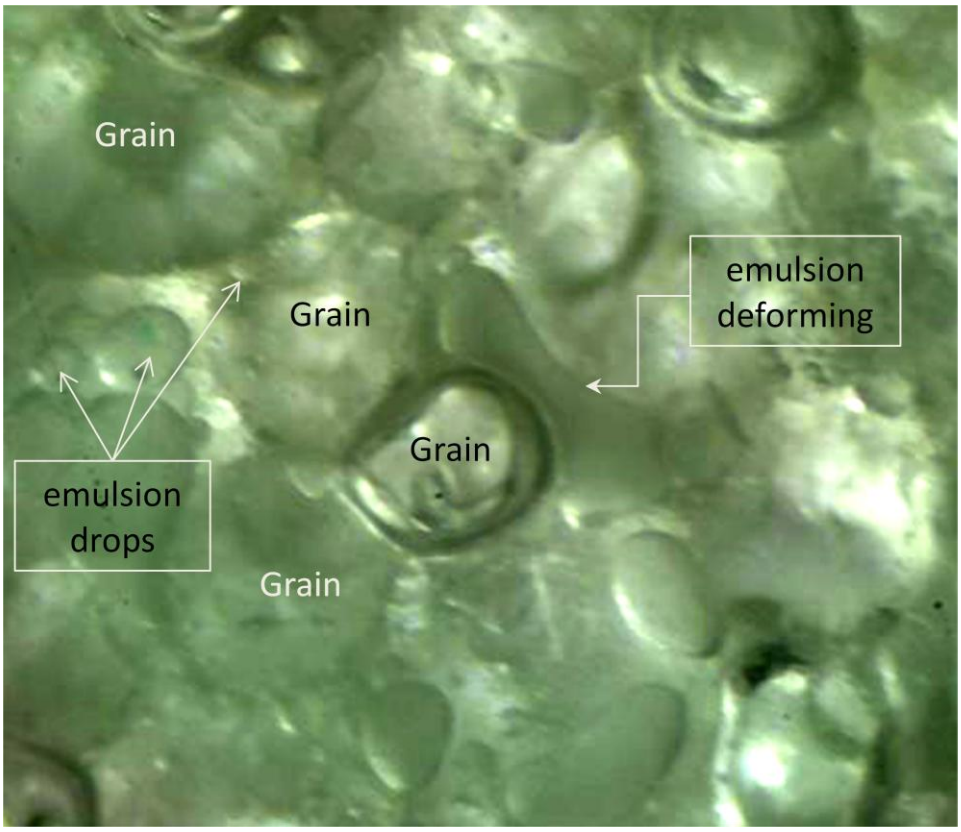

Figure 4. Emulsion agglomeration in porous throat.

4. ACKNOWLEDGEMENTS

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5. FINAL REMARKS

The experiments reported here illustrate the potential of emulsion injection as an EOR method. It raised the oil recovery factor from 40%, obtained by water injection, up to 55%, obtained with alternate water and emulsion injection.

The results also show that the mechanism responsible for the improvement on the recovery factor is not associated with the higher viscosity of the emulsion, but related to the pressure gradient necessary to flow an oil drop through a pore throat with a diameter of the same size of the drop.

The emulsion that is going to be injected has to have the appropriate micro structural properties in order to block the desired regions of the porous space. Pore visualization showed how oil drops of the same size to pore size can partially block the constricted passages. A question that we need to be addressed is the stability of the emulsions.

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