Experimental Study of Oil Recovery by Water Alternating Gas (WAG) process in Microporous media

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Abstract. Water alternating gas injection process (WAG) is a tertiary oil recovery technique commonly used to enhance the displacement efficiency of the residual oil which cannot be recovered during the primary and secondary recovery processes. In this study, experimental tests were conducted in a transparent water wet microporous model packed with glass beads and initially filled with crude oil. Alternate cycles of gas and water were injected to characterize the dynamics of three-phase flows and its associated oil recovery. The displacement of the residual oil at the end of each WAG injection cycle were studied in detail using the state of the art image processing techniques. It was observed that, the continuous cycles of WAG injection have helped the saturated residual oil to spread across the porous region and effectively displaced the residual oil that remained inside the water wet porous media after the initial water flooding. Obtained experimental results helps to understand the WAG process in detail and further it helps to validate future numerical models related to this process.

KEY WORDS
Micro-Porous Media, Glass Beads, Water Alternating Gas (WAG), Enhanced Oil Recovery (EOR)

1. Introduction
Enhanced oil recovery (EOR) processes have received a significant attention over the last years as the oil reserves are increasingly depleted [1,2]. The primarily method of acquiring oil from a reservoir is the water injection process, considered as the least favoured method because a remarkable amount of oil remains in the rocks. Later it was found that part of the remaining oil can be recovered if it is followed by gas injection process [3,4]. In addition, the recovery of the remaining oil can be improved by alternating injections of water and gas which is generally called as water alternating gas (WAG) technique [5-7]. With regards to several other recovery methods, WAG is considered as an improved oil recovery process (IOR) due to its dominance over the mobility ratio [4,7]. Most of the EOR processes includes the interaction of various fluids with the oil which in turn reacts and precipitates organic and inorganic compounds [9,10]. It is important to understand the recovery process of the crude oil by understanding its displacement mechanism for different fluids at varying injection rates [11,13]. Only few studies have been conducted so far dealing with the visualization of the crude oil and its dynamics for different flow conditions, especially WAG related studies in the porous media.
The objective of this study is to utilize the state-of-the-art visualization techniques to visualize and quantify the oil recovery by water alternating gas process in micro-porous media.

2. Experimental Setup
The experimental setup consists of a transparent micro-channel of area 50 x 20 mm$^2$, packed with glass beads of diameter 1.6 mm, a dual-drive syringe pump having two glass syringes, a collection tank and a digital microscope for flow visualization. The horizontal micro-channel has a depth of 1.7 mm.

![Figure 1. Schematic sketch of the experimental setup](image)

The schematic sketch of the experimental setup is shown in figure 1. The syringe pump (Cole-Parmer with 106.6 mL/min maximum flow rate) is used to generate a mixing working fluid flowing at a designed flow rate. The design specifications of the microchannel are presented in detail in Table 1.

| Length (mm) | Width (mm) | Depth (mm) | Porosity (%) | Pore Volume (ml) |
|------------|------------|------------|--------------|-----------------|
| 50         | 20         | 1.7        | ≈25          | 0.282           |

3. Experimental Test Conditions
Crude oil sample was prepared by centrifuging it at an rpm of 5000 for 20 minutes. The temperature and pressure of the working fluids were at a constant temperature of 21°C and standard atmospheric conditions respectively. The detailed experimental conditions are given in the Table 2.

| $Q_{\text{brine}}$ (PV/hr) | $Q_{\text{gas}}$ (PV/hr) | Total time of the experiment (minutes) |
|----------------------------|--------------------------|-------------------------------------|
| 0.05                       | 0.05                     | 180                                 |

The properties of the brine water used in this experiment are shown in the Table 3.
4. Image Acquisition & Analysis

The image acquisition consists of a microscope, a digital camera system to capture the real time image. Full-frame images of 1815×1151 pixels were acquired. The flow in the porous media was observed with a field of view 30 × 20 mm$^2$. An example of high-resolution image is presented in figure 2 showing clearly pore areas filled with crude oil, water or air. The acquired digital image shown in figure 2 is converted to grayscale image using MATLAB. An algorithm was programmed to convert the grayscale image to binary image. The binary images were then used to quantify the saturated crude oil.

![Figure 2](image)

Figure 2. High-resolution image showing the three fluids in the microporous media.

5. Experimental Results

Water-alternating-gas injection can potentially lead to an improved oil recovery and simultaneous cycles of alternating flooding improves the oil recovery to a greater extend. However, still there is an insufficient understanding of these processes in a micro-level and the need for comparative work is inevitable. Closely observing the pore-scale outcomes from each cycle, it was noticed that the fluids injected in the WAG process perceives new flow pathways in the porous medium which were different from those in the initial or previous cycles. Subsequently, alternate injection of water and gas forces the saturated oil to move through the newly formed pathways and more oil was recovered. The fluids used to study the effect of the WAG cycles were gas and brine water of salinity, C=0 ppm. Figure 3 depicts the comparison of first cycle water injection and third cycle gas injection images after a flooding period of 30 minutes. It is observed that the amount of residual oil present in the porous media after the third cycle gas flooding (figure 3-b) is less compared to the first cycle water flooding.
(figure 3-a) in terms of the initial oil saturation. Figure 4 represents the evolution of residual oil present in the porous media with time, after the first cycle of water flood and third cycle of gas flood.

![Figure 3](image1.png)

**Figure 3.** Images of three phases flow in micro-porous media (t= 30 minutes) for (a) first cycle of water injection, (b) third cycle of gas injection

The amount of crude oil present in the microporous media before the first cycle water flood was above 80% which declined gradually for 20 minutes when the flooding began. The trend then became steady for the next 10 minutes and at the end of the first cycle water flood, the residual crude present in the porous media reduced to 52%. The initial amount of residual crude oil present in the porous media before the third cycle gas flood was 40% which then gradually reduced to an all-time low of 34%. The graph showed that there is a significant impact on the oil recovery where, almost 58% of the residual crude was successfully recovered with the onset of all three cycles of alternate flooding.

![Figure 4](image2.png)

**Figure 4.** Comparison of the residual crude oil present in the porous media after first cycle water flood and third cycle gas flood.
6. Conclusions
In this study, experimental tests were conducted in a transparent water wet microporous model
composed of glass beads and initially filled with crude oil. Alternate cycles of gas and water were
injected to characterize the dynamics of three-phase flows and its associated oil recovery. It was
observed that, the continuous cycles of WAG injection have helped the saturated residual oil to spread
across the porous region and effectively displaced the residual oil that remained inside the water wet
porous media after the initial water flooding. The effect of brine viscosity, density and salinity on
WAG process are still under analysis. Future work will be focused on effects of polymers and
nanofluids on water alternating gas (WAG) process.

7. References
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