CORE HETEROGENEITY IDENTIFICATION AND QUANTIFICATION THROUGH NOVEL MAGNETIC TRACER TESTS

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ABSTRACT

Most of the widely used techniques for identifying and quantifying heterogeneity are performed at the core scale in the laboratory. Tracer tests are often used to identify and quantify the degree of heterogeneity of core samples through the analysis of breakthrough curves. The information obtained from the tracer displacement tests can be crucial for hydrocarbon recovery.

In this work, we have used a magnetic tracer which is completely dissolved in water. A total of four core flood experiments are conducted on cores with different properties which included: a high permeability core, a core with an induced longitudinal fracture, a low permeability core, and a composite core made of low and high permeability halves. Volume magnetic susceptibility (VMS) of the dry cores is measured on a Bartington MS2C coil sensor whereas VMS of the effluent samples is measured on a Bartington MS2B kit. By analysis of the adsorption and the desorption curves obtained from the measurement of the effluent samples, the information necessary for characterising heterogeneity of the cores is obtained. In order to verify the accuracy and reliability of the core heterogeneity results, the results are compared with the conventional chemical tracer method. For this purpose, a Lithium tracer test was carried out. Comparison of the result of the magnetic tracer test with that of lithium tracer test shows a very good agreement. The portable nature of the magnetic susceptibility tools used in our experimentation allows the tests to be performed in the field as well as the laboratory. The short execution time of the magnetic susceptibility measurements on the core and effluent samples allows the results to be obtained quickly compared to other conventional techniques. A fully dissolved and homogeneous magnetic tracer solution helps to preserve the petrophysical properties of the core in their native state. Apart from the heterogeneity characterisation of porous media, this tracer technique may also have applications in fines migration identification and quantification during core flood experiments.

INTRODUCTION

Identifying permeability heterogeneity or the preferential fluid flow path in the porous media is of the utmost importance for reservoir engineering and will ultimately lead to successful implementation of recovery mechanisms. The tracer test is a well-known technique for reservoir heterogeneity characterization performed at either the core scale [1] or at the field (interwell) scale [2].

Various magnetic susceptibility techniques have been used recently in the characterization of core samples by capturing the mineralogical variation between core samples and by predicting crucial petrophysical parameters in a rapid, cheap and non-destructive way [3-5]. In this paper we investigate an alternative method of characterizing core heterogeneity in which a magnetic tracer is used instead of a chemical or radioactive tracer and which is completely soluble in water. We determine the degree of core heterogeneity through measuring the volume magnetic susceptibility of the effluent samples collected during core flood experiments (both adsorption and desorption) in the laboratory. The Bartington pieces of equipment used in the measurements were calibrated with respect to their calibration samples. Our experiments demonstrate the non-destructive behaviour of the magnetic tracer on the core samples.

CORE SAMPLE SELECTION AND FLUID TYPES

Six different Clashach sandstone plugs are used in this work. Three of these plugs (sample number 2, 3 and 4) are obtained from Clashach block 2, relatively higher permeability sandstone. The remaining three plugs (sample number 1, 5 and 6) are obtained from Clashach block 3, relatively lower permeability sandstone. Table 1 shows the dimensions and permeabilities of the core plugs. Three fluid types are used in the experiments. These are: a brine solution made of 8g NaCl and 2g $CaCl_2$ in 1L of distilled water, a magnetic tracer, and methanol used for cleaning the cores.

Table 1. Plug samples dimensions and properties.

Plug sample	1	2	3	4&5
Length (mm)	90	90	90	90
Diameter (mm)	25.4	25.4	25.4	25.4
Porosity (%)	20	31	N/A	N/A
Tinyperm Permeability (mD)	366	8132	6000	8246 & 355
Normal brine Permeability (mD)	130	3000	N/A	N/A

EXPERIMENTAL PROCEDURE

For a robust comparison an identical flooding scenario is used with the following procedure in all the experiments:

1. Obtain the volume magnetic susceptibility profile along the length of the dry core using Bartington MS2C coil sensor.
2. Wrap the core and load it into the core holder and apply an overburden pressure of 500psi. Fully saturate the core sample with brine.
3. Inject magnetic tracer through the core and collect effluent samples every 2cc. Continue until the core is fully saturated with the magnetic tracer solution.
4. Remove the core and measure its volume magnetic susceptibility profile along the length of the core, at similar points and direction as of the dry core, using Bartington MS2C coil sensor.

5. Measure the volume magnetic susceptibility of the effluent samples collected during the core flood with magnetic tracer using Bartington MS2B kit.
6. Place the core plug back into the core holder. Inject methanol to thoroughly clean the core while collecting effluent samples.
7. Remove the core from the core holder and measure the volume magnetic susceptibility profile of the cleaned core using Bartington MS2B coil sensor.
8. Measure the volume magnetic susceptibility of the effluent samples using Bartington MS2B kit.

RESULTS AND DISCUSSION

1- Low Permeability Plug

Figure 1 shows the changes in the volume magnetic susceptibility (VMS) profile of core plug 1, which has brine permeability of around 130 mD, due to the magnetic tracer and the methanol injection processes. The solid circles show the VMS profile after injecting Methanol during core cleaning. Core effluent samples were also collected during the injection of the magnetic tracer and methanol. Figure 2 shows the VMS profiles (adsorption and the desorption curves) of these effluent samples.

2- High Permeability Plug

Core plug 2 has a permeability value of about 3 Darcy, which is the highest permeability used in this experiment. Figure 3 shows the VMS profiles for this experiment. The breakthrough occurred at around 0.5 pore volume of tracer injection. Just after the breakthrough there is a slight increase in the magnetic susceptibility followed by a sharp rise as the displacing phase (tracer) which is advancing through the core plug pushes out the resident phase. After injecting around 18cc of the magnetic tracer, the magnetic susceptibility increases gradually but yet does not reach to that of the pure magnetic tracer indicating the presence of brine. After 32cc of the magnetic tracer injection, the magnetic susceptibility of the effluent samples stabilized at 3.6 (10^{-6} cgs) indicating the complete displacement of the saturating phase as the VMS of 2cc pure tracer has the same value. From Figure 3, the methanol effluent profile (desorption) is different from that of the magnetic tracer profile in particular at the beginning of the injection process and the breakthrough occurs at an early stage.

3- High Permeability Fractured Plug

Core sample 3 is a companion plug of the previous high permeability core plug 2 with an artificial fracture, a longitudinal fracture, spanning between injection and production ends. Figure 4 summarizes the results of this test. The breakthrough occurred almost immediately upon the start of injecting the tracer which is attributed to the presence of the fracture. The gradual increase in the magnetic susceptibility profile is best described by the capacitance effect that refers to a long period of low level production of the displaced phase after an early breakthrough of the injected phase.

4- High and Low Permeability Core Plug Halves Separated by a Sealing Fracture

The essence of this experiment is to quantify the effect of different formations on the breakthrough curves. The composite core plug consists of three different layers; two different halves of high and low permeability core samples (samples 4 and 5) separated by a sealing fracture. The sealing fracture is made up of silicone, to bring the different core sides together. An aluminium tape is applied on either side of the seal in order to eliminate the cross flow between high and low permeability halves. The results of this test are shown in Figure 5. The magnetic tracer breakthrough happened just after 4cc injection. Just after the breakthrough there is a sharp increase in the magnetic susceptibility value which is mainly attributed to the contribution of the high permeability part of the composite sample. However, shortly afterward, the brine that saturates the low permeability part of the composite core starts being produced at a very low and steady rate resulting in a long fluctuating tail in the VMS profile. During the subsequent desorption, methanol breakthrough took place immediately. There is no cross flow between the very high permeable side of the core (sample 4 half) and the relatively low permeable side (sample 5 half) due to the presence of the non-permeable zone along the length of the core plug. The two separate flow paths, the high permeability path and the low permeability path, contribute to the effluent outcome. Most of the methanol injected prefers to flow through the high permeability side of the core, leaving the other side of the core not completely clean regardless of the amount of methanol injected. The methanol effluent photos shown in Figure 6 further indicate the presence of the magnetic tracer.

Figure 6: Right to Left: shows the effluent samples obtained by injecting the core sample with methanol after it was flooded with the magnetic tracer. The light muddy color of the effluent samples (far left) indicates that the magnetic tracer has not been flushed out of the core sample fully and is continuously being produced at smaller concentrations. Dark colored samples (far right) indicate higher concentration of the magnetic tracer in the solution at the start of methanol injection.

COMPARING THE BREAKTHROUGH CURVES

Figure 7 compares the results of the core flood experiments highlighting the effect of the conditions of each test in particular the heterogeneity of the core on the shape of the adsorption and desorption curves as well as the breakthrough of the displacing fluid. The figure is divided into two categories; the first category is represented by the adsorption curves, and the second category is illustrated by the desorption curve. There are four curves in each category that correspond to the four different core samples.

VALIDATION OF THE METHOD

The magnetic tracer test results were validated against the Lithium tracer test. For this, a low permeability sample number 6 was taken from Clashach block 3. Figure 8 shows the change in the Lithium and magnetic tracer concentrations during both adsorption and desorption processes. It is clear that there is a very good agreement between the results of the adsorption and desorption profiles obtained on the same core plug which indicates the reliability of the new tracer technique as an alternative to the existing chemical and radioactive tracer techniques.

CONCLUSIONS

The experimental data mentioned in the paper demonstrate that the new magnetic tracer can be used in the characterization of core samples in the laboratory. The experimental results demonstrate the non-destructive behaviour of the magnetic tracer on the core samples. The new magnetic tracer is completely dissolved in water and hence does not alter the petrophysical properties of the core compared to some of the conventional tracers. The new tracer can potentially be used in determining heterogeneity on a reservoir scale.

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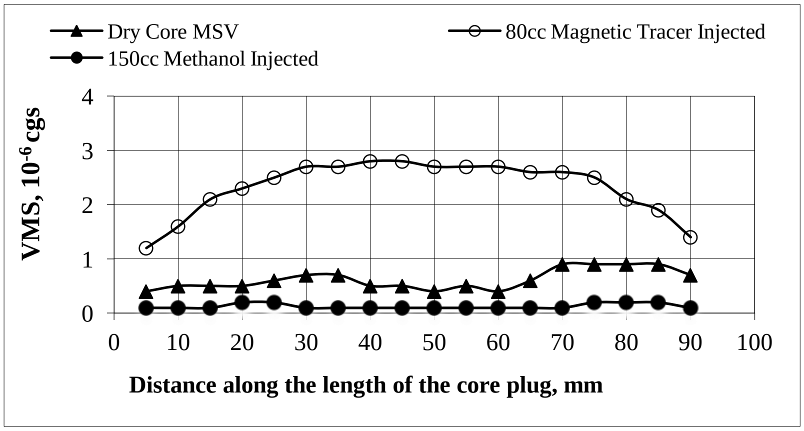

Figure 1: shows the changes in the volume magnetic susceptibility (VMS) profile along the length of the dry core as well as after injecting 80cc & 150cc of the magnetic tracer and methanol respectively.

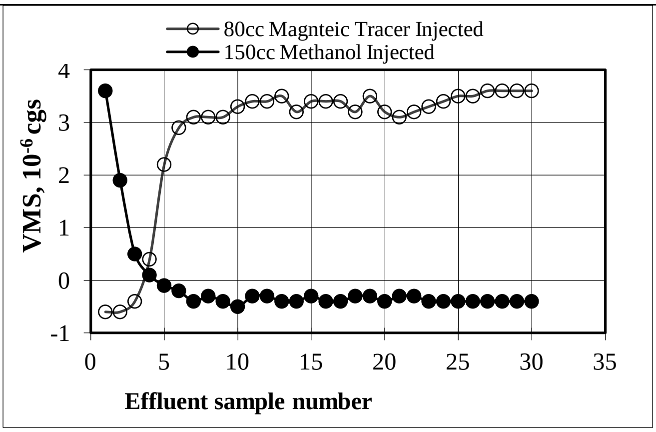

Figure 2: Shows the VMS profile of the effluent samples during adsorption and desorption stages of Experiment 1.

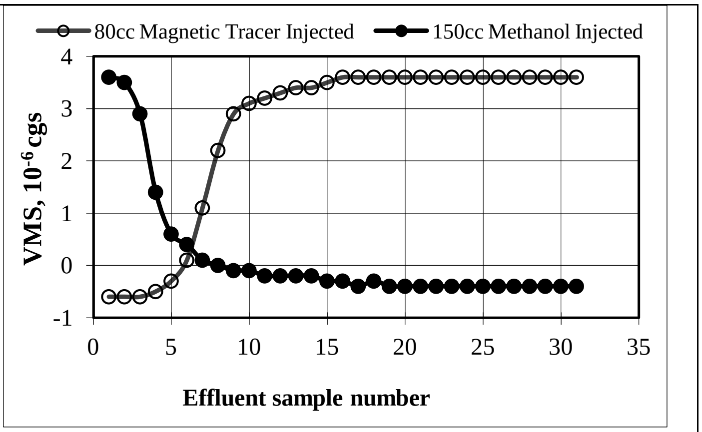

Figure 3: Shows the VMS profile of the effluent samples during adsorption and desorption stages of Experiment 2.

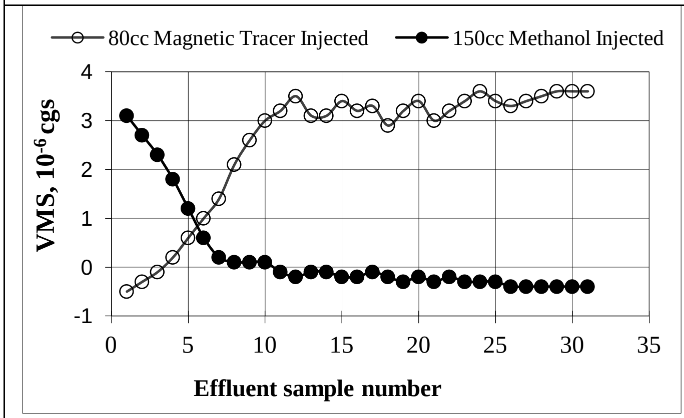

Figure 2: Shows the VMS profile of the effluent samples during adsorption and desorption stages of Experiment 3

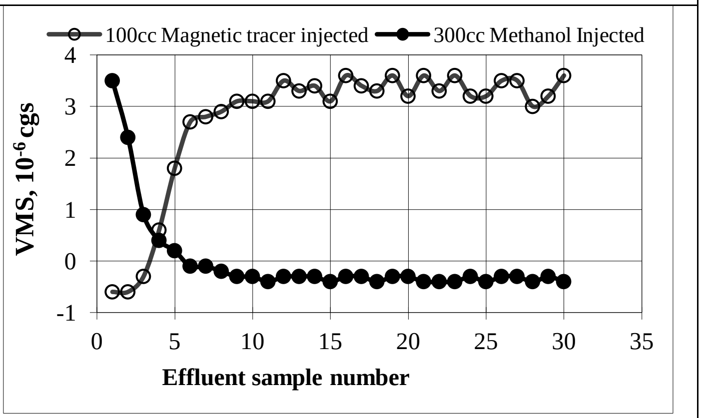

Figure 3: Shows the VMS profile of the effluent samples during adsorption and desorption stages of Experiment 4

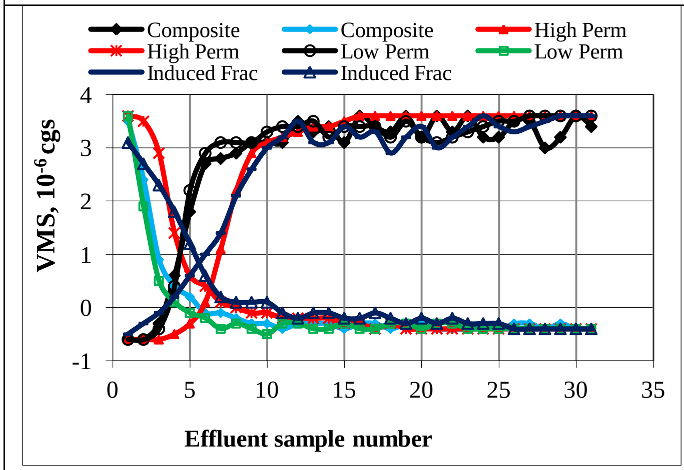

Figure 7: Shows the VMS profile of the effluent samples of the previous flooding experiments 1, 2, 3, and 4.

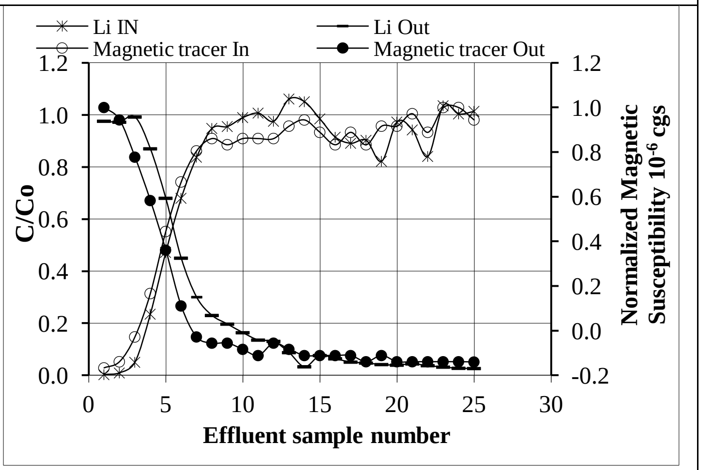

Figure 8: Shows a comparison of the magnetic tracer test with that of Lithium tracer test.