PERFORMANCE OF SWAG INJECTION VERSUS ALTERNATING AND CONTINUOUS INJECTION OF WATER AND GAS IN LOW GAS-OIL IFT AND MIXED-WET SYSTEMS

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ABSTRACT

In some reservoirs, gas and water are both available for injection as a means of improving recovery. In such cases it may be advantageous to inject a combination of gas and water either alternately (WAG) or simultaneously (SWAG). Obviously, gas or water can also be injected separately and continuously. Unfortunately, little experimental evidence, under reservoir conditions, is available to allow a direct comparison of the performance of these various injection strategies. Operationally, SWAG injection may be less problematic compared to WAG as it avoids significant pressure and temperature swings associated with WAG injection. However, there are many other parameters that may affect economic evaluation of these processes.

We report the results of a comprehensive series of well-controlled core-flood experiments which includes continues gas injection (CGI), two series of WAG, and two series of SWAG injection tests. The difference between the two WAG experiments is the order in which gas and water injection is carried out. The first WAG test started with water injection whereas the second WAG experiment started with gas injection. The difference between the two SWAG experiments is the gas/water ratio, which was 0.25 for the first one and 1.0 for the second SWAG test.

The coreflood results show that WAG injection has a superior performance over CGI and SWAG injection. Oil recovery by the WAG test started with water injection was higher than the WAG started with gas injection. SWAG performed better compare to CGI. However, surprisingly, SWAG resulted in lower oil recovery compared to primary waterflood in this mixed-wet system. It was observed that increasing the gas/water ratio in SWAG leads to faster gas breakthrough, higher produced gas/oil ratio and further reduction in the performance of SWAG. Compared to the other injection strategies, a very high pressure drop across the core was observed during SWAG injection indicating injectivity problems with the application of the process in mixed-wet rocks. The results

show that for mixed-wet rocks, amongst the injection strategies tested, SWAG is the worst and alternating injection of water and gas (WAG), starting with a water flood period, are the best injection strategies.

INTRODUCTION

For many oil reservoirs poor sweep efficiency has been a problem in gas injection processes. This happens due to high gas mobility compare to the oil and water. Therefore, continuous gas injection may not result in economically significant additional oil recovery. In order to elevate this problem, gas can be injected alternately with water (WAG). In some oil reservoirs a relatively small amount of produced gas and/or a rapidly falling gas rate makes it uneconomical to develop a gas export solution. In offshore oil fields, it usually is not economically viable to supply gas to these reservoirs for a continuous gas injection scenario (due to remoteness). In such reservoirs, re-injection of the produced associated gas together with water in a SWAG (simultaneous water and gas) injection scheme would provide reservoir pressure support, better sweep and hence increased recovery. Both WAG and SWAG are believed to reduce the gas mobility and hence increase the sweep efficiency [1]. WAG process has been extensively studied before [2-8]. However, less experience has been gained in SWAG compared to WAG and hence the process is less known.

The first simultaneous water and solvent injection (SWAG) study was carried out by Caudle and Dyes, 1958 [9]. Their laboratory studies have shown that the increase in the sweep efficiency for a five-spot pattern can reach 90% with SWAG, whereas, if continuous gas injection is implemented, only 60% of oil is recovered. It should be mentioned that in their original work, the wettability of the porous medium and type of gas had not been identified. Blackwell et al., 1960 [10] showed that higher recoveries were obtained with water-solvent mixtures as compared to water or solvent injection alone. In their experiments hexane was used as the solvent and Lucite sand pack (with an absolute permeability of 190 D) was used as the porous medium. Although not mentioned in their original work but the wettability of the porous medium is believed to have been water-wet.

Field studies on miscible CO_2 flooding [11] shows that SWAG appears to provide better control of the gas mobility than WAG, resulting in improved sweep efficiency as well as more steady gas production and GOR response. Quale et al., 2000 [12] and Berg et al., 2002 [1] reported improved oil recovery for SWAG injection of the produced associated gas in Siri field. The main contributions to increased recovery come from improved sweep, oil swelling and reduced residual oil saturation. It was also noticed that combined water and gas injection may result in lower injectivity than single-phase injection. Injectivity considerations should therefore be taken into account for field application of SWAG. Sohrabi et al. (2008) [13] performed micromodels visualization of SWAG injection after waterflooding. The original work was performed on water-wet micromodels using hydrocarbon gas. They concluded that a significant oil recovery by

SWAG can be achieved and that the ultimate oil recovery by SWAG is independent of the SWAG ratio.

Experimental data on the performance of near-miscible SWAG injection is very scarce and this lack of data becomes even more severe for mixed-wet systems. In this paper, we present the results of new coreflood experiments, at near miscible conditions, performed on a 65 mD and a 1000 mD core sample, including WAG injection, SWAG injection and SWAG-tail gas injection scenarios. More experimental results on the comparison of the performance of WAG injection with water flooding and gas injection can be found in a previous publication of the authors, Fatemi et al., 2012 [8].

METHODOLOGY

Experiment Materials

<u>Rock Properties</u>

Two different sandstone cores with one order of magnitude difference in their absolute permeabilities were used in this study. Table 1 and Table 2 show the physical properties of these cores. The wettability of the cores was changed from water-wet to mixed-wet by aging in a suitable crude oil. In all the reported experiments (except SWAG-tail gas injections), the immobile water saturation was established at the beginning of each test and its quantity and variation along the core was obtained by material balance and by x-ray scanning to make sure that it remains the same in all the tests. More details on the wettability alteration procedure and immobile water establishment and its evaluation using x-ray can be found elsewhere [8].

<u>Fluids</u>

Fluids used in the experiments were water, gas and oil. The brine (water phase) used in the tests was synthesized using NaCl and $CaCl_2$ in distilled and degassed water. The hydrocarbon fluid system (oil and gas phases) used in the coreflood experiments was prepared from a binary mixture of methane and *n*-butane. To eliminate mass transfer during the displacement experiments, all the fluids (oil, gas, and brine) were pre-equilibrated at test pressure and temperature of 12.69 MPa (1840 psia) and 38°C (100°F) and were kept under equilibrium at these conditions in high pressure transfer vessels kept in a temperature controlled oven (Figure 1). Fluid mixing was repeated several times prior to each experiment to ensure that phase equilibrium conditions were satisfied. Considering that the critical pressure of this hydrocarbon mixture at 38ºC (100ºF) is about 12.86 MPa (1865 psia), the pressure at which the experiments have been conducted 12.69 MPa (1840 psia) is very close to its critical point and hence the gas and oil are nearly miscible (very low gas-oil IFT, ~ 0.04 $mN.m^{-1}$).

Experimental Methodology

WAG Injection (65mD, Mixed-Wet Core, Near-Miscible Fluid, DIDIDIDI)

This WAG experiment started with gas injection (Drainage, represented by D) in order to compare its performance with a previous WAG test that had been started with water injection (Imbibition, represented by I) [8]. Comparing the performance of these WAG tests would show the dependency of the oil recovery by WAG injection on the order of gas and water injection in mixed-wet rocks. The results of this WAG experiment would also be applicable to those reservoirs which are already under gas injection and are being considered for WAG injection. Before the start of the test, the immobile water saturation was established (S_{wim}=18%). The core was then saturated with live oil with an initial saturation of 82% and WAG injection started with a primary gas injection at the test pressure of 12.69 MPa (1840 psia) and temperature of 38ºC. Four cycles of gas injection followed by water injection (alternating injection of brine and gas) were carried out at the rate of 25 $cm^3.h^{-1}$.

SWAG Injection (65mD, Mixed-Wet Core, Near-Miscible Fluid, Q_g/Q_w=0.25)

This experiment was carried out using the same mixed-wet 65mD core and near-miscible gas-oil system used in the previous test. Having established an initial oil saturation of 82% and immobile water saturation of 18% at 1840 psia, water and gas were simultaneously injected through the core. Water was injected at the rate of 40 $cm^3.h^{-1}$ while gas was injected at 10 $cm^3.h^{-1}$ making a total fluid injection rate of 50 $cm^3.h^{-1}$ and a SWAG ratio of 0.25 (vol/vol both at 1840psia and 38^{o}C). SWAG injection continued until almost 1.2 PV of fluids had been injected. SWAG injection resulted in some additional oil recovery up until the water breakthrough (BT). However, after the BT, no significant additional oil recovery was observed.

SWAG-Tail Gas Injection (65mD, Mixed-Wet, Near-Miscible)

We also investigated the effect of injecting gas at the end of the period of SWAG injection. SWAG injection stopped after around 1.2 PV, and then continuous gas injection started at the rate of 50$cm^3.h^{-1}$. This gas injection continued until a total of 2.8 PV of gas was injected.

SWAG-Tail WAG Injection (65mD, Mixed-Wet, Near-Miscible)

This test was performed to investigate the effect of alternating injection of gas and water on recovery of the remaining oil after SWAG injection. At the end of the gas injection period carried out after SWAG injection, injection fluid was switched to brine which was injected into the core at the rate of 50 $cm^3.h^{-1}$. After 0.6 PV of water injections there was no change in the fluids' average saturation values in the core. At this stage, water injection stopped and injection of equilibrated gas at the rate of 50 $cm^3.h^{-1}$ started to complete the WAG cycle.

SWAG Injection (65mD, Near-Miscible, Mixed-Wet, Q_g/Q_w=1.0)
To examine the effect of water/gas ratio on the performance of SWAG injection in our mixed-wet system, another SWAG injection test was carried out but with the gas/water ratio of 1.0. As in the previous SWAG test (with gas/water ratio of 0.25), the experiment was carried out with the same core and near-miscible gas-oil system. Having established an initial oil saturation of 82% and an immobile water saturation of 18% at 1840psia, water and gas were simultaneously injected through the core. Each fluid (water and gas) was injected at the rate of $25cm^3.h^{-1}$ (i.e., a total fluid injection rate was $50cm^3.h^{-1}$ and the SWAG ratio was 1.0). SWAG injection continued until almost 1.65 core PV had been injected. Similarly to the previous SWAG test, there was no significant additional oil recovery after the water breakthrough.

SWAG Injection (1000mD, Near-Miscible, Mixed-Wet, Q_g/Q_w=0.25)
This SWAG test was performed on the 1000 mD mixed-wet core but the same fluids (oil, gas and brine) that were used in the tests on the 65 mD core were used here as well. Other experimental conditions were also the same as those used in the tests on the 65 mD core sample (P = 1840 psia, T = 100ºF and IFT_{o-g}=0.04 $mN.m^{-1}$). First, an immobile water saturation was established (S_{wim}=8%) and then the core was saturated with equilibrated oil at the test pressure of 1840 psia. Having established the initial saturation condition of S_{wi}=8% and S_o=92%, water and gas were simultaneously injected through the core. To achieve SWAG ratio of 0.25, gas and water were injected at 40 and 160 $cm^3.h^{-1}$ respectively (total fluid injection rate of 200 $cm^3.h^{-1}$). SWAG injection continued until almost 2 PV (gas and water) had been injected.

RESULTS AND DISCUSSION

Effect of Injection Sequence on WAG Process (65mD, Near-Miscible, Mixed-Wet)
Figure 2 compares oil recovery of the two WAG tests performed on the 65mD mixed-wet core sample. As mentioned earlier, the only difference between these two experiments was the order in which water and gas were injected into the core. This figure shows that the rate of oil production and also the ultimate oil recovery achieved is higher in the case of WAG test starting with water. This is due to the very high efficiency of the primary water injection compare to the primary gas injection in mixed-wet systems (Fatemi et al., 2012). Figure 2 shows that, although for the 1st WAG cycle (1st water injection and 1st gas injection), larger volumes of gas have been injected in the WAG test started with gas, the ultimate oil recovery for this period is less for this WAG test compared to the WAG started with water injection. Figure 2 shows that although in our experiments the order of injection of gas and water periods does not significantly influence the ultimate oil recovery achieved (only around 5% difference), but the rate of oil production and the amount of oil recovery for the same volume of WAG injected is lower for the WAG started with gas. This is especially true for the first cycles of WAG which are more relevant to field applications. It is therefore recommended that in mixed-wet systems WAG injection begins with a primary water injection.

Effect of Gas/Water Ratio on SWAG Process (65mD, Near-Miscible, Mixed-Wet)
Figure 3 shows the results of the two SWAG injection experiments, at the gas/water ratio of 0.25 and 1.0. As expected, at the higher gas/water ratio, the gas breakthrough happens earlier and the water breakthrough is delayed. It is also interesting to note that the ultimate oil recovery has stayed almost the same for both SWAG ratios. In other words, increasing the ratio of the injected gas (from 0.25 to 1.0) has not affected the ultimate amount of oil recovery, but it has delayed its production by about 0.3 core PV of fluid injection. The observed independency of the ultimate oil recovery from gas/water ratio in these tests is in line with previous findings on SWAG injection in micromodel experiments [13]. However, those experiments had been carried out in a water-wet porous medium. Based on their micromodel studies, Sohrabi et al. (2008) concluded that in near-miscible SWAG injection, ultimate oil recovery was independent of SWAG ratio, in the range of 0.2 to 0.5.

Figure 4 presents the cumulative amount of produced gas versus cumulative amount of produced oil for the two SWAG scenarios. The Figure shows that much more gas was produced for SWAG ratio (Q_g/Q_w) of 1.0 compared to that produced with SWAG ratio of 0.25, for the same amount of produced oil after 0.3 PV of oil production. This means that hydrocarbon gas requirement is much higher with gas/water ratio of 1.0 than gas/water ratio of 0.25.

Different Injection Scenarios (65mD, Near-Miscible, Mixed-Wet)
In this section we compare the performance of SWAG injection with other injection scenarios, i.e., water flood, gas injection, WAG1 (started with water flood), and WAG2 (started with gas injection). Figure 5 compares the performance of the two SWAG injection tests with those of primary water flooding and primary gas injection. It should be borne in mind that in these experiments the SWAG tests began from the start of oil production (not in tertiary mode after conventional water flooding).

Figure 5 which is for the tests performed on the 65mD mixed-wet sample, shows that the recovery by the primary waterflooding is the highest, followed by SWAG with Q_g/Q_w = 0.25 and then by SWAG with Q_g/Q_w = 1.0. The lowest oil recovery in this series was obtained by the primary gas injection. Figure 6 shows the amount of cumulative produced gas versus cumulative produced oil, which shows lower GOR for SWAG tests compared to primary gas injection. It can be seen that with simultaneous injection of gas and water, the amount of gas required for injection (and the produced GOR) is much less than that required in primary gas injection. But for a mixed-wet system, primary waterflooding gives the highest oil recovery. Moreover, our experiments show that co-injection of gas and water would produce oil at lower rate and results in less cumulative oil production than that obtained by water flooding, as in Figure 5.

Figure 7 shows pressure drop across the core for the three experiments; SWAG Q_g/Q_w = 1.0, primary water injection and primary gas injection. It should be mentioned that in the case of gas and water flooding, the rate of water injection was $25cm^3.h^{-1}$. For the SWAG test, water injection rate was also kept at $25cm^3.h^{-1}$ (a total gas and water rate of $50cm^3.h^{-1}$). For comparison between SWAG and water flooding results, two options were possible. First, to keep the total injection rate the same in both SWAG and waterflooding (i.e., Q_w+Q_g for SWAG test = Q_w in waterflood test), or keep the water injection rate the same in both experiments. Since previously for the SWAG Q_g/Q_w = 0.25 test in 1000mD sample, the first option had been applied (see the following section), in the 65mD core, we applied the second option. Figure 7 shows that gas injection has a negligible pressure drop compared to water injection, but its simultaneous injection with water, raised the pressure drop from 20 psi (in the case of waterflooding) to around 70-80 psi for SWAG injection.

Figure 8 compares the performance of the two SWAG tests with those of WAG_{IDIDID} and $WAG_{DIDIDIDI}$. At the end of the 1st WAG cycle (W+G or G+W), both WAG scenarios performed better than both SWAG tests. Figure 9 shows pressure drop across the core for the two WAG tests and the SWAG test with Q_g/Q_w = 1. The water injection rate for these experiments was $25cm^3.h^{-1}$. The Figure shows that, in the $WAG_{DIDIDIDI}$ test, after each gas injection stage (drainage), the resistance to the flow of water in the next stage of injection (imbibition), is increased. Each stage of water injection exhibits even higher resistance (pressure drop across the core) to the flow than the previous stage. But this is not the case for the WAG_{IDIDID} since the pressure drop across the core for the 2nd and 3rd periods of imbibition remains almost the same (~ 27-30 psi). Comparing the two WAG tests, we can see that the one starting with drainage ($WAG_{DIDIDIDI}$) shows much higher pressure drop than the WAG that starts with imbibition (WAG_{IDIDID}).

Figure 10 shows the performance of the extension of the SWAG $_{Qg/Qw}$ = 0.25 test (SWAG + Gas Injection +WAG) with those of water flood and gas injection. Figure 11 compares the performance of the same series of tests (SWAG + Gas Injection +WAG) with WAG1 and WAG2 injection scenarios. From these Figures it can be concluded that in addition to the observed poor performance of the SWAG injection test in the mixed-wet system, even the subsequent gas injection and/or WAG injection is not much beneficial for further oil recovery.

Effect of Permeability on SWAG Performance (Q_g/Q_w = 0.25)

Figure 12 compares the performance of the SWAG injection in the 1000 mD and the 65 mD core samples. SWAG performed better in the 1000mD core compared to the 65mD sample. Figure 13 shows the performance of different injection scenarios carried out in the 1000 mD mixed-wet core. For the conditions of our experiments, WAG performance was best followed by waterflooding. SWAG injection recovered less oil compared to water flood and gas injection. This is in agreement with the results obtained for the 65mD mixed-wet core. From these two series of tests performed on mixed-wet core samples (1000mD and 65mD), it is concluded that simultaneous injection of gas and water (SWAG) has lower recovery compared to conventional water flood or WAG injection. Figure 14 shows the pressure drop across the core for different injection scenarios performed on the 1000 mD mixed-wet sample. The total injection rate for each of these experiments was the same and equal to 200 $cm^3.h^{-1}$. This means that for waterflooding, the injection rate of water is 200 $cm^3.h^{-1}$ while for SWAG injection, the rate of injection of water is 100 $cm^3.h^{-1}$. Although water injection rate in SWAG is half of that in the water flood test, the pressure drop across the core is the highest during SWAG injection. This result is consistent with what we have observed and presented for the 65 mD core. SWAG injection, therefore, resulted in lowest amount of ultimate oil recovery and highest differential pressure (lowest injectivity).

CONCLUSIONS

We have reported the results of a comprehensive series of coreflood experiments using two different cores under mixed-wet and low gas-oil IFT conditions. The following conclusions can be drawn from these coreflood results.

1) Comparison of the amount of oil recovered by WAG, SWAG, gas injection and waterflood reveals that, for the conditions of our experiments, WAG has a superior performance over other injection strategies tested in mixed-wet systems. In terms of oil recovery, the order of injection strategies from highest to lowest is; WAG, water flooding, SWAG and gas injection.
2) The results also reveal that the performance of WAG injection would be adversely affected (lower oil recovery and injectivity) if WAG injection begins with a gas injection period (instead of water), in mixed-wet rocks.
3) Our results on the effects of SWAG (gas/water) ratio of 0.25 and 1.0 show that the rate of oil recovery in mixed-wet systems decreases by increasing the gas fraction. However, the ultimate oil recovery achieved remained almost the same for the two SWAG ratios tested.
4) In addition to the lower oil recovery obtained by SWAG in the mixed-wet systems, it was also noticed that SWAG injection results in considerably lower injectivity than what was observed for single-phase fluid injection. Although some degree of injectivity reduction is expected when water and gas injection is combined, the observed reduction in injectivity for SWAG was unexpected and disproportionate to the amount of additional oil recovery obtained from it.

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REFERENCES

1. Berg L.I., Stensen J.A., Crapez, B., Quale, A., (2002): "SWAG behavior based on Siri field data", SPE-75126, presented at SPE/DOE IOR symposium, April 13–17, Tulsa, Oklahoma, USA.
2. Skauge A. and Aarra M., (1993):" Effect of wettability on oil recovery by WAG", presented at 7th EAPG IOR Europe, 27–29 October, Moscow, Russia.
3. Larsen J.K. and Skauge A., (1999):"Simulation of the immiscible WAG process using cycle-dependent three-phase relative permeabilities", SPE-56745, presented at SPE Annual Technical Conference and Exhibition, 3–6 October, Houston, Texas, USA.

4. Christensen J.R., Stenby E.H., Skauge A., (1998):"Compositional and relative permeability hysteresis effects on near miscible WAG", presented at SPE/DOE Improved oil recovery symposium, 19–22 April, Tulsa, Oklahoma, USA.
5. Larsen J.K., Bech N., Winter A., (2000):"Three-phase immiscible WAG injection: Micromodel experiments and network models", presented at SPE/DOE Improved oil recovery symposium, 3–5 April, Tulsa, Oklahoma, USA.
6. J.R. Christensen, E.H. Stenby, A. Skauge, 2001:"Review of WAG Field Experience", *SPE Reservoir Evaluation & Engineering*, **4**, Number 2, pp. 97-106.
7. Sohrabi M., Tehrani D.H., Danesh A., Henderson G.D., (2004):"Visualisation of oil recovery by Water Alternating Gas (WAG) injection using high pressure micromodels". SPE-89000, *SPE Journal*, **9**, Number 3, pp. 290–301.
8. Fatemi S.M.; Sohrabi M.; Jamiolahmady M.;"Ireland S., (2012):"Experimental Investigation of Near-Miscible Water-Alternating-Gas (WAG) Injection Performance in Water-wet and Mixed-wet Systems", Manuscript SJ-0711-0004, SPE-145191, accepted for publication in SPE Journal.
9. Caudle B.H. and Dyes A.B., (1958):"Improving Miscible Displacement by Gas-Water Injection", *Petroleum Transactions*, AIME, **213**, pp. 281-283.
10. Blackwell R.J., Terry W.M., Rayne J.R.; Lindley D.C.;"Henderson J.R.; (1960): Recovery of Oil by Displacements with Water-Solvent Mixtures". *Petroleum Transactions*, **219**, pp. 293-300.
11. Stephenson D.J., Graham A.G., Luhning R.W., (1993):"Mobility control experience in the Joffre Viking miscible carbon dioxide flood", *SPE Reservoir Engineering*, **11**, Number 3, pp.183–188.
12. Quale E.A., Crapez B., Stensen J.A., and Berge L.I., (2000):"SWAG Injection on the Siri Field - An Optimized Injection System for Less Cost", SPE-65165, presented at the SPE European Petroleum Conference, 24–25 October, Paris, France.
13. Sohrabi M., Danesh A., and Jamiolahmady M., (2008):"Visualization of Residual Oil Recovery by Near-miscible Gas and SWAG Injection Using High-pressure Micromodels". *Transport in Porous Media*, **74**, Number 2, pp. 239-257.

Table 1: Physical properties of the 65mD core sample.

Property	*Value*	*Property*	*Value*
Length	60.5 cm	K_{abs}	65 mD
Diameter	5.082 cm	Φ	18.2 %

Table 2: Physical properties of the 1000mD core sample.

Property	*Value*	*Property*	*Value*
Length	67.1 cm	K_{abs}	1000 mD
Diameter	4.98 cm	Φ	17 %

Table 3: Summery of the 3-phase experiments on mixed-wet cores at 1840 psia, presented in this paper.

Core	*Experiment*	*Direction*
65 mD	WAG	DIDIDIDI
65 mD	SWAG (Q_g/Q_w=0.25)	(So↓, Sw↑, Sg↑)
65 mD	Gasflooding**	(So↓, Sw↓, Sg↑)
65 mD	WAG ***	ID
65 mD	SWAG (Q_g/Q_w=1)	(So↓, Sw↑, Sg↑)
1 D	SWAG (Q_g/Q_w=0.25)	(So↓, Sw↑, Sg↑)

*1840 psia = 12.69 MPa

** performed at the end of the SWAG experiment (No. 2)

*** performed after SWAG-Tail Gasflooding (No.3)

Table 4: Coreflood experiments presented in Fatemi et al. (2012).

Core	*Experiment*	*Direction*
65 mD	Gas Injection	Drainage
65 mD	Water Injection	Imbibition
65 mD	WAG	IDIDID
1000 mD	Gas Injection	Drainage
1000 mD	Water Injection	Imbibition
1000 mD	WAG	IDID

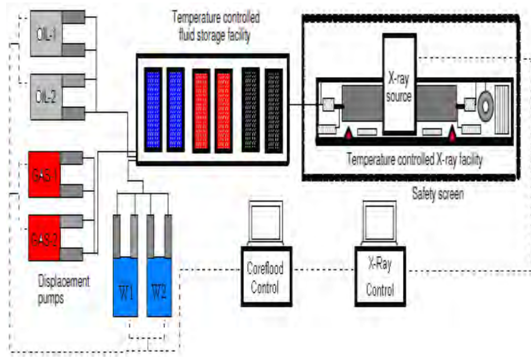

Figure 1: Schematic representation of coreflood facility including x-ray saturation monitoring system.

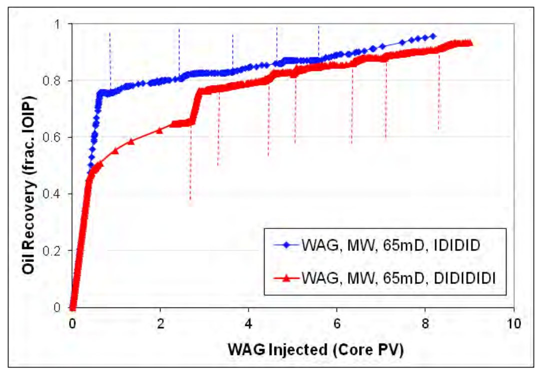

Figure 2: Comparison of oil recovery by two different WAG scenarios (DIDIDIDI and IDIDID); (65mD, mixed-wet).

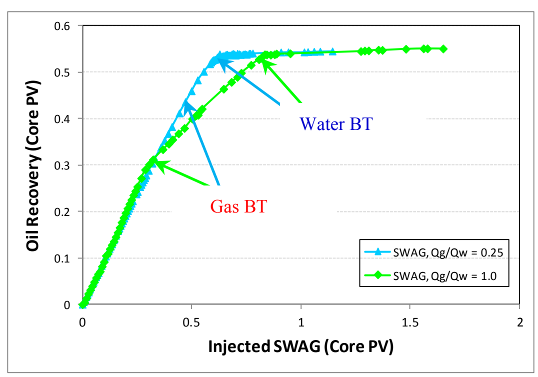

Figure 3: Effect of water/gas ratio on the recovery performance of the SWAG injection (65mD, Mixed-Wet, Near-Miscible).

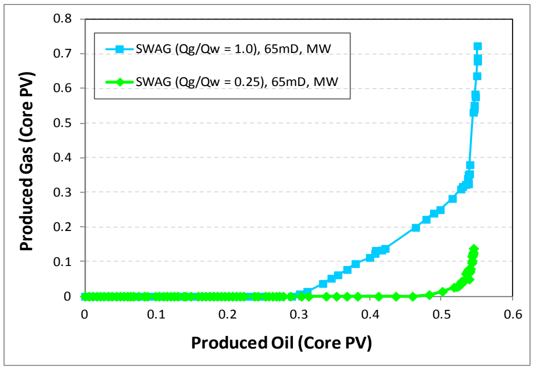

Figure 4: Produced gas vs. recovered oil for two SWAG injections shows lower GOR for the case of Q_g/Q_w=0.25 (65mD, Mixed-Wet, Near-Miscible)

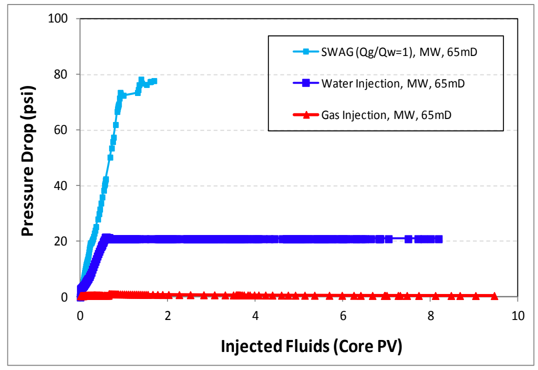

Figure 7: Pressure drop across the core for primary water injection, primary gas injection and SWAG (Q_g/Q_w=1); (65mD, Mixed-Wet, Near-Miscible)

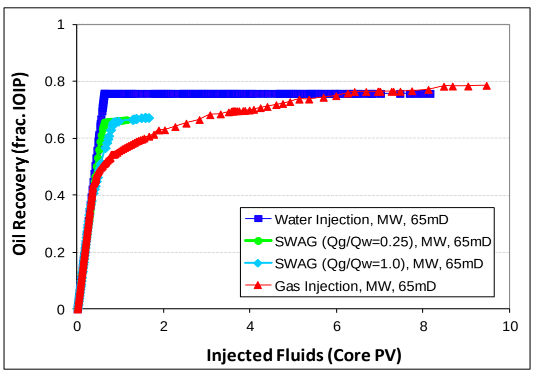

Figure 5: Comparison of the recovered oil for SWAG injections with primary gas injection and primary water injection (65mD, Mixed-Wet, Near-Miscible)

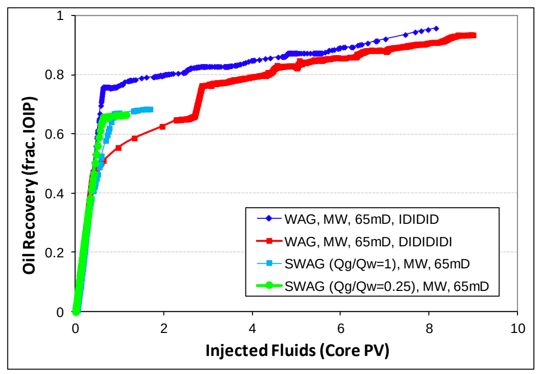

Figure 8: Comparison of the recovered oil for SWAG injection with two WAG injection scenarios (65mD, Mixed-Wet, Near-Miscible)

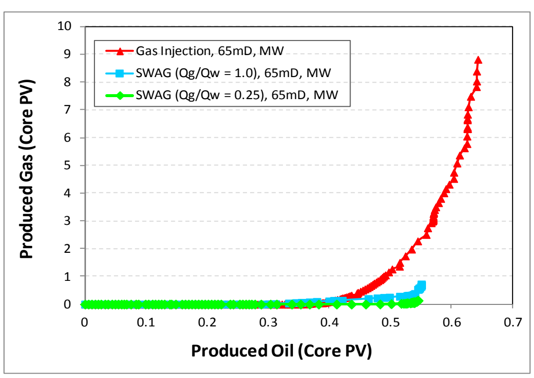

Figure 6: Produced gas vs. produced oil for gas injection and two SWAG injections (65mD, Mixed-Wet, Near-Miscible)

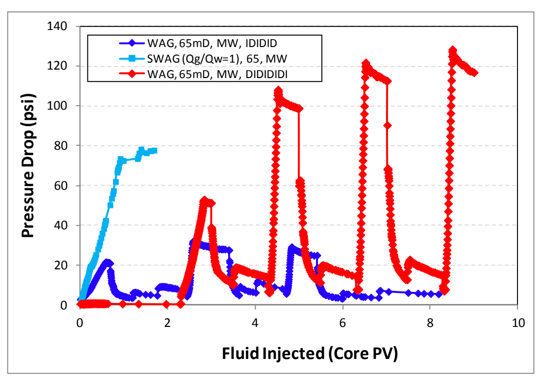

Figure 9: Pressure drop across the core for SWAG (Q_g/Q_w=1) and two different WAG injection scenarios (65mD, Mixed-Wet, Near-Miscible)

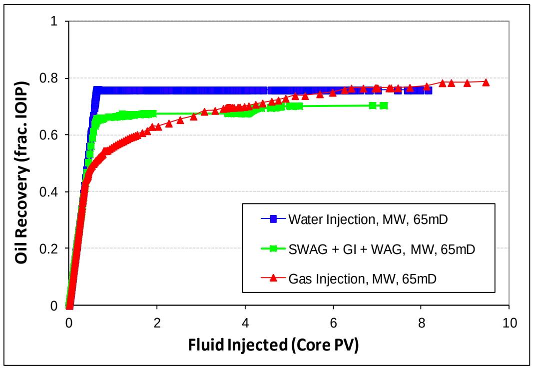

Figure 10: recovered oil for the case of gas injection, water injection and the extension of the SWAG test (SWAG+GI+WAG); (65mD, Mixed-Wet, Near-Miscible)

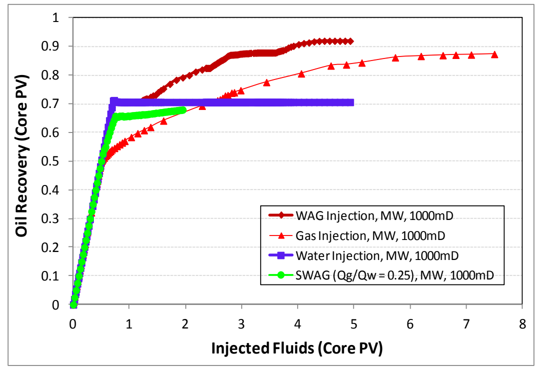

Figure 13: Recovered oil for different injection scenarios (1000mD, Mixed-Wet, Near-Miscible).

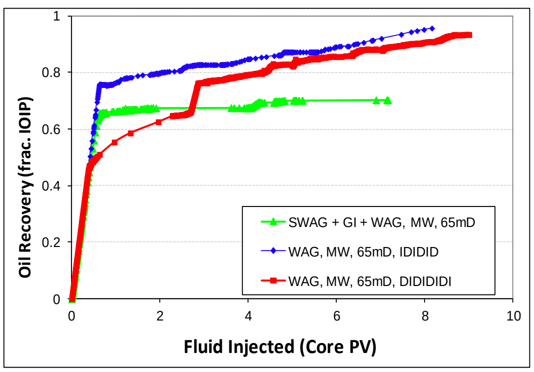

Figure 11: Recovered oil for the two WAG injection scenarios and the extension of the SWAG test (SWAG+GI+WAG); (65mD, Mixed-Wet, Near-Miscible)

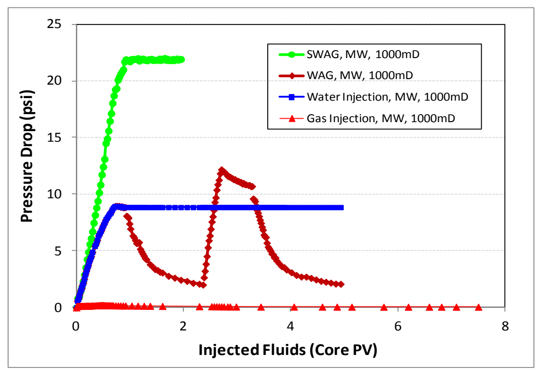

Figure 14: Pressure drop across the core for different injection scenarios (1000mD, Mixed-Wet, Near-Miscible).

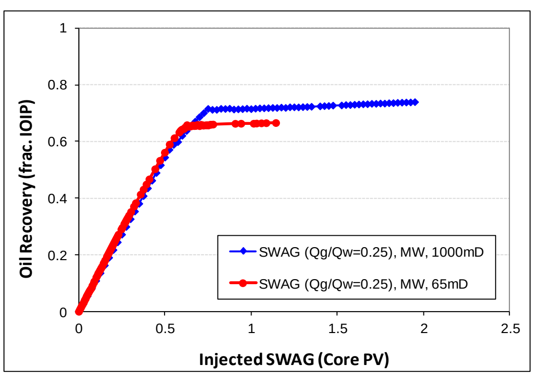

Figure 12: Effect of permeability on performance of SWAG injection (Q_g/Q_w=0.25, Mixed-Wet, Near-Miscible).