# A SIMULATION STUDY OF LOW CONCENTRATION SURFACTANT ENHANCED WATER ALTERNATING GAS FLOODING

Perekaboere Ivy Sagbana, Sarkodie Kwame, Farzin Vajihi, Diaz Pedro, Ali Soleiman

Department of Petroleum Engineering, London South Bank University

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## ABSTRACT

A large amount of oil still remains trapped in the reservoir after primary and secondary means of oil recovery. Gases which have been injected either in a miscible or immiscible state with the oil have problems of gravity segregation, viscous fingering, and channelling.

In this paper, a new method has been proposed known as surfactant enhanced water alternating gas flooding (SWAG) were a slug of low concentration surfactant is injected into the reservoir and then followed by a gas and then water slug. The results from this method will be compared to conventional water alternating gas flooding (WAG), water flooding and gas flooding.

Eclipse reservoir simulator was used to evaluate the performance of this method. The data used to build the model used for simulation was obtained from laboratory experiments. The results obtained shows that oil recovery improved significantly when low concentration surfactant was injected before water alternating gas flooding and increasing surfactant concentration will improve oil recovery until a peak concentration is reached and any further increase does not affect oil production. Water cut was delayed for surfactant enhanced WAG when compared to water flooding, water alternating gas flooding and gas flooding.

## INTRODUCTION

The petroleum industry today is focusing on improving oil recovery factor (RF) from oilfields as well as keeping an economic oil rate during production. This is because it is becoming increasingly difficult to discover new fields (Muggeridge et al, 2013).

Due to the decline in oil production and large amounts of oil remaining trapped in the reservoir after applying the common enhanced oil recovery techniques, it is reasonable to use methods that are profitable to improve oil recovery (Salehi et al, 2013). Gas injection is known to be the second largest enhanced oil recovery technique. However, the high gas mobility and low density decreases the sweep efficiency of gas injection thus affecting oil recovery. The low sweep efficiency in gas injection occurs as a result of the injected gas rising to the top of reservoir. This leads to oil overriding due to early gas breakthrough and viscous instability (Renkema and Rossen, 2007).

The WAG injection has been proposed as a method to improve sweep efficiency of gas injection. This is done mainly by using the water to control the mobility of the displacement and to stabilise the front. The WAG injection process combines the improved displacement efficiency of the gas flooding with an improved macroscopic sweep by water injection. Despite the satisfying results of injecting water and gas alternatively, the reduction of oil-gas contact in the presence of water decreases the effectiveness of WAG (Syahputra et al, 2000). Several studies have also reviewed the problems associated with a WAG injection process and discussed that the main issue is the water-blocking phenomena (Rao et al, 2004). The water isolates the residual oil from coming in contact with gas.

Salehi et al (2013) conducted surfactant alternating gas flooding (SAG) experiment in their study in other to create foam to overcome the water blocking effect experienced during WAG. They studied the effect of SAG ratio on oil recovery and compared their results to conventional waterflooding, gas flooding and WAG. Their results showed that oil recovery in SAG is related to the SAG ratio and recovery factor for SAG was higher compared to WAG, waterflooding and gas flooding.

Adbi et al (2014) examined the improvement of oil recovery during waterflooding and WAG in the presence of alsphatene depositions on a rock using non-ionic surfactant. This study was conducted because the presence of asphaltene in oil reduces recovery factor during production. Their results showed an incremental oil recovery when non-ionic surfactant was introduced into the injection water for WAG compared to the absence of surfactant.

Majidae et al (2014) conducted an experimental and numerical study of chemically enhanced WAG (CWAG). A new technique was developed which involves the injection of alkaline, surfactant and polymer additive as a chemical slug during WAG process to minimise water-blocking effect by interfacial tension reduction and improving mobility ratio with the polymer. Their results showed that CWAG achieved 26.6% more than twice the oil recovery from conventional WAG.

Harsen et al (1995) performed numerical simulations to study surfactant effect on WAG process in a heterogeneous reservoir. They concluded the foam created during surfactant interaction with gas blocks the highly permeable region in the reservoir. The advantages of this method over WAG are the reduction of gas-oil ratio and diversion of water which ultimately leads to increase oil recovery rate.

Memon et al (2016) investigated the impact of foaming surfactant in WAG flooding using $CO_2$ gas and different surfactant blends in displacement experiments. They discussed that increase in oil recovery when surfactant is present in WAG is as a result of the control of $CO_2$ mobility by the surfactant which was able to create a stable foam.

The different works published in the literature have shown that surfactant can improve the efficacy of WAG. In this study, the objective is to demonstrate the oil recovery potential of low concentration surfactant enhanced water alternating gas flooding and compare the recovery to other conventional recovery methods numerically.

## METHODOLOGY

The approach employed for this black oil simulation study, was to validate the effectiveness of a low concentration Surfactant enhanced water alternating gas (SWAG) recovery method. The data used to run the simulation for water flooding, gas flooding, water alternating gas flooding and surfactant enhanced water alternating gas flooding were obtained from laboratory experiments. The surfactant used was alcohol alkoxy sulfate. The performance comparisons of different EOR methods which are SWAG, WAG, water, gas flooding was conducted using Eclipse simulation software. The comparative analysis of each recovery method was based on:

1) Oil Recovery,
2) Water Cut, and
3) Pressure decline

### Grid description

A simple box model of 10 x 1 x 1 was used for the simulation. The reservoir rock is assumed to be sandstone and homogeneous. The rock property is a representative of the core sample used for core flooding experiments to obtain relative permeability curves. The laboratory units' option in Eclipse software was used to run the simulation. Rock and fluid properties are detailed in the Tables 1 and 2 and were specified in the 'PROPS' section. Time step used was 60 x 0.01 which gave a total simulation time of 1.8 hours. The model consists of one injection well and one producer well which were completed in the first and tenth blocks of the model.

Table 1: Rock Properties

| | |
|---|---|
| Porosity | 0.18 |
| Perm X, Y, Z | 100 x 100 x 75 (mD) |
| Reservoir size | 10 x 2 x 3 (cm) |

Table 2: Fluid properties

| | |
|---|---|
| Oil viscosity | 20 cp |
| Water viscosity | 1.01cp |
| Oil density | 0.926 g/cc |
| Water density | 1.00 g/cc |
| Initial pressure | 350 Atm |

**Relative permeability (Rel perm) curves**

Relative permeability (rel perms) of gas, oil, surfactant and water derived from core flooding experiments were inputted in the PROPS section of the eclipse data file for SWAG, WAG, water flooding and gas flooding simulations. Figures 1, 2 gives the rel perm curves with associated capillary pressure for water and surfactant flooding while Figure 3 shows the rel perm curves for gas flooding. The rel perm used for water alternating gas flooding was the combination of the gas/oil and water/oil rel perm curves used for water flooding and gas flooding. While for SWAG, a combination of surfactant/oil and gas/oil rel perms were used for the simulation.

**The surfactant model**

Surfactant phase is introduced using the SURFACT keyword in the RUNSPEC section for the simulation of SWAG. The combination of two phase surfactant/ oil and gas/oil relative permeability curves were inputted into the PROPS section. This curve showed a reduction in the residual oil saturation due to a reduction in water oil capillary pressure trend when compared to that from other recovery methods. The Trend between surfactant concentrations and surface tension between oil and water was derived from lab experiments and inputted using The SURFST keyword. The concentration range used was between 0.001 – 0.5 g/scc with a corresponding surface tension range of 7 – 7.93469E-06 cp (as defined in Eclipse).
The capillary de-saturation function describes the transition between immiscible and miscible conditions as a function of capillary number (Eclipse, 2015). SURFCAPD keyword is used to account for this effect.

Some of the key assumptions made for this model are as follows:

1) Black oil model
2) No surfactant absorption into rock was considered
3) Isothermal conditions

**Recovery methods control strategies**

The control strategy is defined in the SCHEDULE, WCONINJE, where the pressure or flow rate conditions are set. The injection well is mandated to open or shut when certain conditions have been reached. For each recovery method, the flowing schemes were employed:

**Water flooding** – A continuous water injection scheme was initiated in the simulation for the whole simulation time step, with a maximum rate of 10 cc/hr as liquid rate limit.

**Gas flooding** - Based on the economic limit, a gas volume rate was imposed on the injection well for the time of simulation. The gas injection limit was 100 cubic centimetre (cc)/hr.

**WAG** - The scheme involved in this scenario involved the injection of water and then gas and water finally over mid time steps of 0.6 hours each. The injection limit was based on injection rates of water and gas as used in the laboratory core flooding experiment.

**Low concentration surfactant enhanced WAG (L.C SWAG) -**The scheme involved injection of low concentration surfactant slug followed by gas flooding and then water only water injection. Using the black oil model (ECLIPSE 100) calculations are based on a mixture property of water and concentration of surfactant used for the simulation.

## RESULTS AND DISCUSSIONS

Figure 4 presents the diagram of the synthetic reservoir model. Oil recovery factor for low concentration surfactant enhanced WAG was compared with water flooding, gas flooding, water alternating gas flooding in Figure 5. The results showed that surfactant enhanced WAG gave the highest oil recovery (FOE) of 58 % when compared to the other methods. Gas flooding yielded the least recovery of 37%. The poor performance of gas flooding was due to inefficient sweep of oil by gas through the reservoir. The FOE for the water flooding was 48 % and 47% was derived from the WAG. The benefit of surfactant enhanced WAG over the other recovery methods is the mechanism in which this method utilises to improve oil recovery. The mechanisms involved are lowering water/oil interfacial tension by the surfactant and reduction of gas mobility when the gas interacts with the surfactant.

Figure 6 presents water cut for each enhanced oil recovery process. The water flooding compared to the WAG method saw an increase in water cut at the end of the simulation (95%) and thus might be of concern for operators on issues of early water treatment and handling which obviously would come at a cost. Furthermore, the WAG method gives a trade-off between water handling and gas injection; for this reason, the WAG method was combined with low conc. Surfactant flooding. Surfactant enhanced WAG gave a delayed water production at time 0.4 hours this shows an indication of better field management and reduced cost on handling water and even gas injected.

The pressure decline of each recovery method is considered and illustrated in Figure 7. Gas flooding method presented the least decline in pressure and thus a poor FOE realisation over the period of 2 hours. The surfactant enhanced WAG presented significant declining pressure differentials indicating excellent FOE of 58% compared to WAG and water flooding which also showed significant decline as well. Adding to the efficiency of surfactant enhanced WAG over the WAG, water flooding and gas flooding, it can be reiterated with a higher-end simulation reservoir pressure of 179 Atms combined with delayed water cut was achieved.

Figure 8 presents the range of recoveries for SWAG, WAG, water flooding and gas flooding where the range represents the difference between the highest and lowest recoveries. The chart shows the best performance of SWAG as compared to the other recovery mechanisms. SWAG had the highest recovery range at 55% and lowest recovery at 15% followed by water flooding with 46% maximum recovery and 15% minimum recovery and then WAG with 45% maximum and 15% minimum recovery. Gas flooding had the lowest maximum recovery at 30% and minimum recovery at 5%.

Figure 9 shows the effect of surfactant concentration on SWAG. The result shows that oil recovery increased up to an optimum concentration of 0.03g/cc. The maximum oil recovery was achieved at 0.03g/cc and further increase in surfactant concentration does not affect the recovery rate.

## CONCLUSIONS AND RECOMMENDATIONS

The performance comparisons between EOR methods of low concentration SWAG, WAG, water flooding and gas flooding was conducted to evaluate the efficiency of this proposed method. The conclusions made from this study are:

1) The low concentration surfactant enhanced WAG seems most suitable for a medium viscosity reservoir producing better performance compared to conventional WAG, waterflooding and gas flooding.
2) Oil recovery improved in surfactant enhanced WAG and water cut was delayed when compared WAG.
3) Oil recovery in surfactant enhanced WAG can be affected by surfactant concentration. There is a maximum concentration after which increase in surfactant concentration does not affect oil recovery.
4) The efficiency of surfactant enhanced WAG is attributed to the surfactant reduction of water/oil interfacial tension and gas trapping.

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## FIGURES

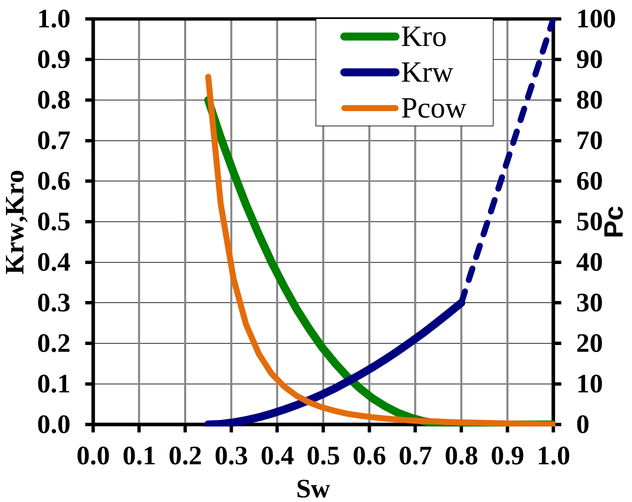


Figure 1: water/oil relative permeability and capillary pressure curves

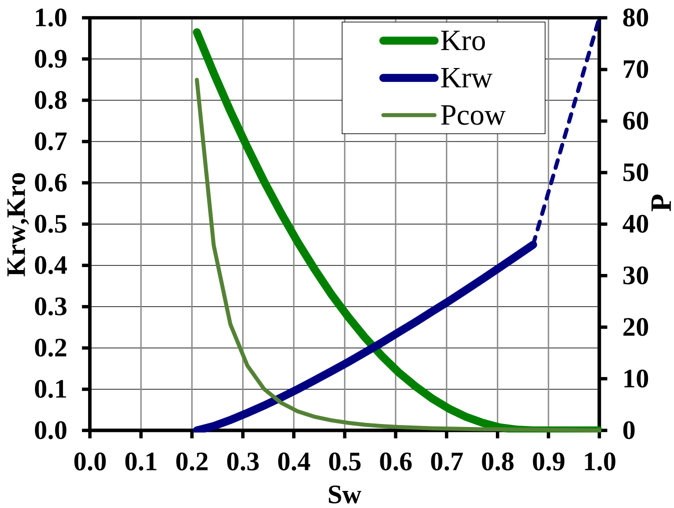


Figure 2: Surfactant/oil relative permeability and capillary pressure curves

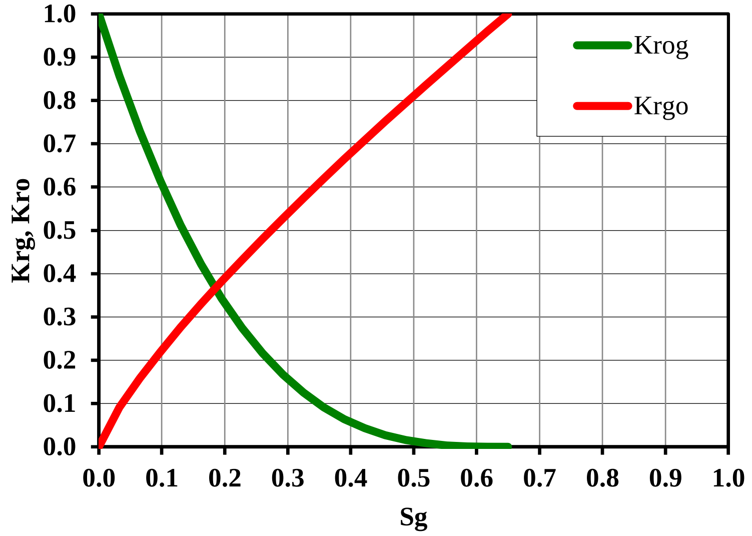


Figure 3: Gas/oil relative permeability curves

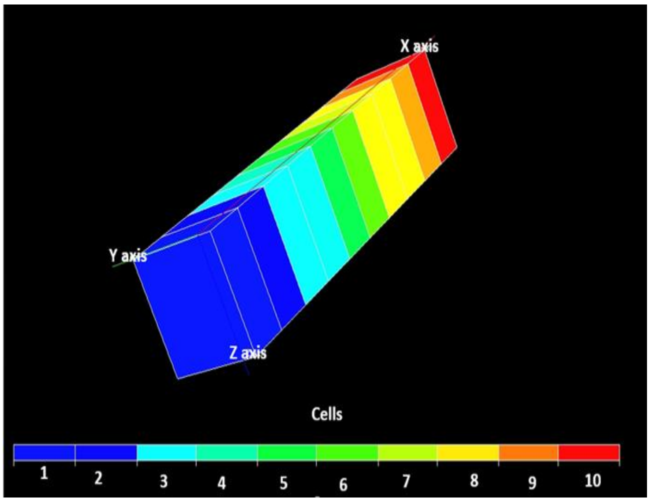


Figure 4: Reservoir model

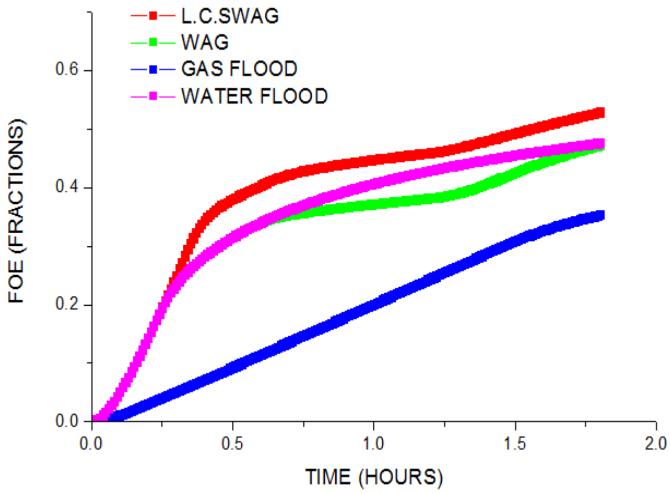


Figure 5: Comparison of oil recoveries for WAG, SWAG, water flooding and gas flooding

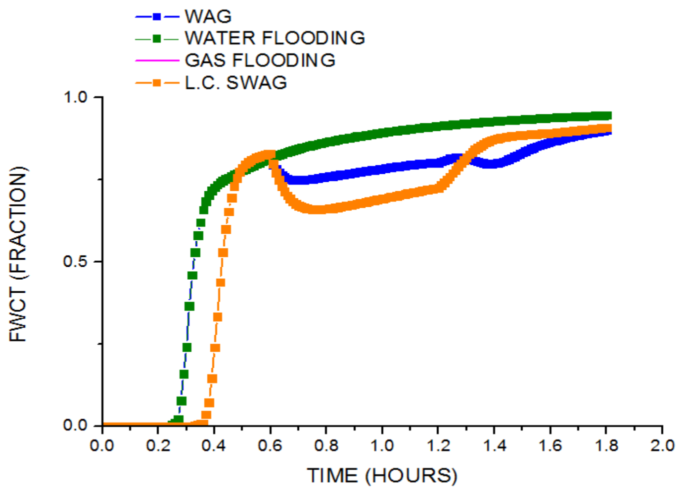


Figure 6: Water cut comparison for WAG, SWAG, water flooding and gas flooding

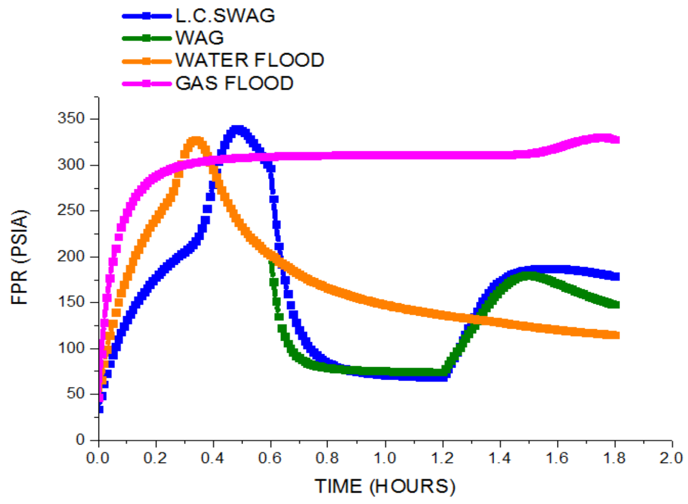


Figure 7: Pressure decline for SWAG, WAG, water flooding and gas flooding

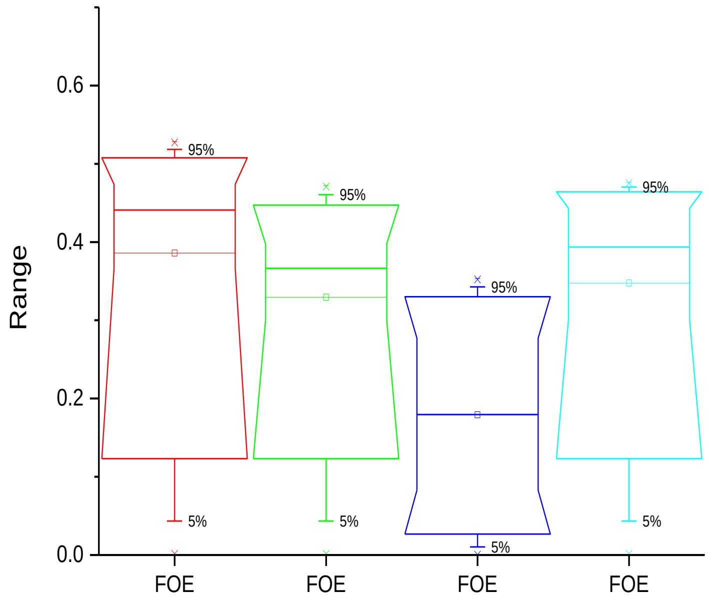


Figure 8: Range of oil recoveries for Swag, WAG, water flooding and gas flooding

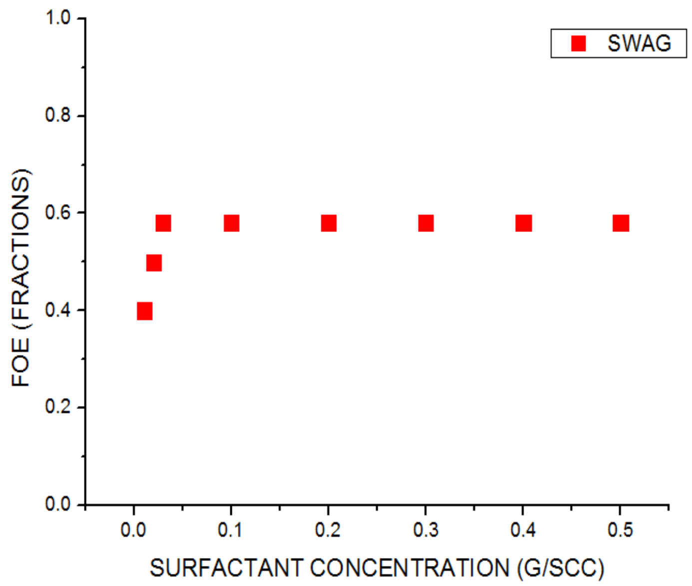


Figure 9: Effect of surfactant concentration on SWAG