

Comparative Study of FAWAG and SWAG as an Effective EOR Technique for a Malaysian Field

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Abstract: At present, petroleum engineering has become economics based field hence all efforts are taken to make sure that we squeeze out the last drop of oil from the reservoir. Field "A", one of Malaysian oil field is a strong candidate for Enhanced Oil Recovery (EOR) which was producing for more than 15 years. Currently Simultaneous Water Alternating Gas (SWAG) along with other techniques tends to improve oil recovery by improving reservoir fluids mobility and providing driving force. Foam can also be added in water alternating gas technique to improve the sweeping mechanism and cut off the gas production which is termed as Foam Assisted Water-Alternating Gas (FAWAG). In this study, a comparison has been made between FAWAG and SWAG in order to come up with the effective method of EOR for a better oil recovery. Core flood experiments have been carried out for evaluating both techniques. Mathematical modeling of FAWAG and SWAG are not included in this comparative study. Experimental results shows that, SWAG tends to address all recovery related problems economically where as foam has been seen to address the problems by assisting other Enhanced Oil Recovery Techniques and proved that foam assistance has given better recovery.

Key words: Comparison, EOR, FAWAG, SWAG and oil recovery

INTRODUCTION

SWAG techniques can improve the sweep efficiency in the depleted oil reservoirs. In gas injection process, the sweep efficiency of injected gas is poor because of low density and viscosity of the gas and reservoir heterogeneity. To improve the sweep efficiency of gas or control the gas mobility, gas is injected together with or alternating with water (Jamshidnezhad, 2008).

According to the Helfferich (1981), a SWAG process is a multi component and multiphase displacement of oil-water by solvent-water. The fundamental mathematical description of the mass conservation equation is similar to different EOR methods (Rouzbeh Ghanbarnezhad *et al.*, 2010). The purpose of SWAG injection is to reduce the residual oil saturation or to allow deeper penetration of the gas in to the lower part of the reservoir (Shehadeh *et al.*, 2010).

Foam Assisted Water Alternating Gas (FAWAG) process uses foam for improving the sweep efficiency during gas injection while reducing gas oil ratio GOR and maximizing production rate in the producer well (Aarra, 2002).

Foam can be injected in to the formation by co-injection of surfactant solution and gas, where alternating solution of surfactant and gas are injected into the formation. Another method for injecting foam in to the formation is, injecting surfactant solution into the upper region and gas is injected into the lower region of the formation (Liu *et al.*, 2011). Foam has been field tested

for hydrocarbon gas and CO₂ and has become an established technology to improve steam performance (Shehadeh *et al.*, 2011). Foam can only be used with other EOR techniques to solve the problems faced by the well in those current injection techniques such as overriding caused by thief zone or gravity override.

Simultaneous Water Alternating Gas (SWAG): SWAG is an enhanced oil recovery process in which gas is mixed with water and the mixture is then injected as two phase mixture in the well to get better oil recovery as in Water Alternating Gas process (WAG, 2011), water and gas injection alternatively are the best solution to cope with the problems such as early breakthrough which occur only when gas is injected individually due to unfavorable oil-gas mobility ratio. Hence simultaneous injection of gas and water would be of greater importance to improve the sweep efficiency by improving the displacement front (Meshal *et al.*, 2007).

Figure 1 shows water/gas drive recovery mechanism showing water/CO₂ injection using RPS machine. SWAG combines the effects (benefits) of microscopic sweep efficiency obtained from miscible gas injection with better economics and frontal stability obtained from water flooding (senergy ltd). Water and gas can be injected alternatively in slugs or simultaneously. The experience of using SWAG is less but the experiments in different fields have suggested that use of SWAG as EOR process can be very crucial as it has been seen less well injectivity and decrease in associated problems have occurred.



Fig. 1: RPS 800-10000 machine

Foam Assisted Water Alternating Gas (FAWAG):

FAWAG process has given tremendous improvement in recovery by improving sweep efficiency during gas injection and gas shut-off even less GOR was seen in most of the process. Foam has increased mobility control of gas flow and has come up with new method for improvement of well flow.

The specific flow properties of foamed gas make foam highly applicable as a gas mobility control for EOR (Chen *et al.*, 2008). Foam properties and foam stability are important in all field applications. Foam properties vary from static tests to dynamic experiments and understanding of foam-oil-interaction is most important to describe foam stability (Aarra *et al.*, 2011). In the heterogeneous formation, foam generation will occur in the high permeability zones first, diverting the fluid flow in low permeability zones (Haugen *et al.*, 2010). Foam does not change water relative permeability or liquid viscosity in the porous medium.

Foam is well known as a selective blocking agent and has shown promise for the diversion of steam under conditions of poor reservoir conformance. The hydrocarbon as in many other tertiary recovery schemes is less viscous and less dense than the fluids in the reservoir. Therefore, it is likely that a significant portion of the reservoir is bypassed due to gravity segregation and viscous fingering. One way to minimize such problems is the injection of foam (Coskuner, 1992). Usually the foam injection has given better results and in most of applications oil rate increased by 1.5-5 times while the water cut seems to be decreased by 20%, (for example from 80 to 60%) (Alex *et al.*, 1998).

FAWAG is usually introduced in reservoirs with WAG already in use. In WAG water displaces the lower part of the oil bearing sands and gas fills the upper part though WAG is considered an oil-recovery enhancement technique but usually injected gas tends to rise to top of the reservoir relatively quickly and its presence can be detected from the oil production from the upper zone. Hence FAWAG can be intended to create a foam barrier that impedes the upward passage of the gas, forcing it

spread laterally and in the process contact previously unswept parts. Hence to achieve that barrier, water and surfactant are injected simultaneously over several days followed by gas injection.

Experimental setup and application: Core flooding runs for SWAG and FAWAG will be carried out on RPS 830-10,000 machine. For SWAG, a mixture of gas (CO₂) and water will be simultaneously injected while for FAWAG application, surfactant, brine solution and CO₂ was used where as surfactant used is sodium dodecyl sulphate (SDS). We are working on a light crude oil 37^o API (from field “A”) with less wax and asphaltene contents while brine to be injected was 30,000 ppm. Both the cores are taken from sandstone reservoirs with almost similar rock properties.

The experiment:

SWAG application: The experiment was conducted at inlet pressure (1000 psi), outlet pressure (800 psi), overburden was set to be 1500 psi and a temperature of 65°C was maintained. The core was saturated for 36 h in brine before the run. Following steps were followed:

- Brine which was prepared earlier (30,000 ppm) is pumped to accumulator B, crude oil into accumulator A and CO₂ in accumulator C.
- In the computer interface software for RPS®, follow the steps below:
- Inject brine solution until the permeability reading stabilizes. This step is done for determining the initial or absolute permeability.
- After core has been saturated with brine crude oil is injected to find saturation of oil S_o in core and with this irreducible water saturation, S_{wir} is also calculated.
- Now, brine solution is injected to determine the volume recovered by primary recovery to calculate irreducible oil saturation, S_{oir} .
- Now SWAG technique as Enhanced Oil Recovery process is applied where by gas (CO₂) from accumulator C and brine solution from accumulator B is injected simultaneously to recover the remaining crude from the core.
- Sample is collected at the outlet manually and the reading is noted.

FAWAG application: The experiment was conducted at same conditions as SWAG experiment. Mixture of surfactant and brine solution was prepared as 2 wt % surfactant in 3000 ppm of brine solution. Following steps were followed:

- All there injectants brine, crude and CO₂ are injected into accumulators B, A and C, respectively.



Fig. 2: Crude oil being recovered at the outlet

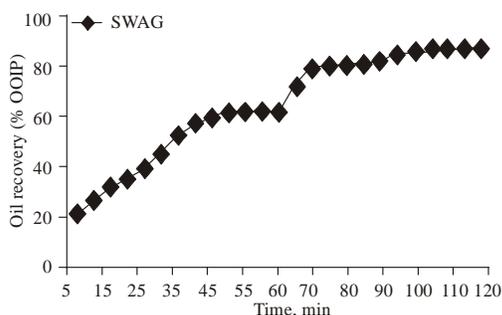


Fig. 3: Recovery after SWAG application

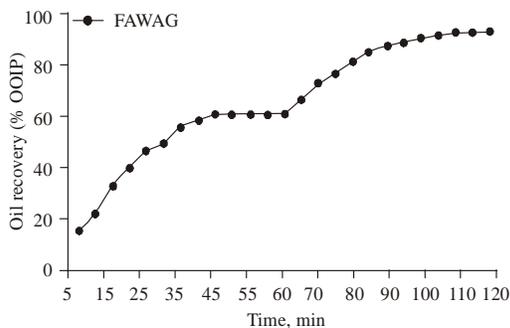


Fig. 4: Recovery after FAWAG application

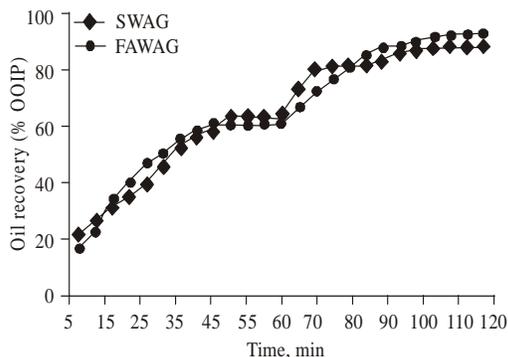


Fig. 5: Comparison between SWAG and FAWAG recoveries

- After achieving S_{wir} and S_{oir} , we apply FAWAG technique with pumping the surfactant brine solution in accumulator B instead of brine and follow the steps for FAWAG application:
- 4 PV of surfactant/ brine is injected followed by 4 PV of CO_2 and again followed by 4 PV of surfactant/ brine followed by 4 PV of CO_2 .
- The crude oil is seen to be recovered at the outlet which is recovered in test tube as shown in Fig. 2.
- After the phases are allowed to settled, recovery details are noted.

RESULTS AND DISCUSSION

The SWAG techniques seem to address the problems in greater details. The recovery seemed to improve tremendously with both the techniques. The ultimate recovery with water flooding was seemed to be 62%, after SWAG application recovery tremendously increased to 88%. SWAG (Fig. 3) gives greater recovery addressing the above mentioned issues.

In FAWAG application the ultimate recovery with water flooding increased to 61% and was seen tremendously increasing to 92% after FAWAG application (Fig. 4). FAWAG address the problems in more detail and tends to improve the recovery.

Hence after comparison as shown in Fig. 5, it can be seen that recovery pattern remains similar but at the end when SWAG seems to stabilize the recovery but at the same time FAWAG seems to improve the recovery as well. Hence, it can be predicted that for better oil recovery, FAWAG can be applied after any WAG technique to manage economically.

CONCLUSION

SWAG and FAWAG with better understanding and proper application tend to provide better recoveries. They tend to address the problems like gas mobility control, gravity segregation and viscous fingering in detail.

FAWAG among the two mentioned techniques used in this research gives better recovery than SWAG.

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