# Comparison of Water Injection, Gas Injection, and Water Alternating Gas Injection Scenarios Performance in Sudanese Oil Field

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**Abstract -** *Enhancing the recovery of an oil reservoir is one of the major roles of any oil company. This is achieved by development of the oilfields by employing different techniques such as Water injection, gas injection, water alternate gas (WAG) injection and even thermal methods. In this work a simulation study was performed in KEYI oil field models to determine the optimal production strategy. Water injection, Gas injection and Water Alternate Gas injection Scenarios were compared for a Sudanese oil field. Results indicated that WAG injection technique better recoveries than water or gas injection.*

***Key Words*: Water injection, Gas injection, WAG injection, Reservoir Simulation, KEYI oil field, Eclipse software.**

## 1. INTRODUCTION

Hydrocarbon is produced from the subsurface through primary, secondary, and tertiary (Enhanced Oil Recovery, EOR) methods. The primary stage is the period in the oil recovery process when oil flows naturally to the wells due to natural energy such as depletion drive, initial pressure gravity, and water drive. Secondary recovery are recovery techniques used to augment the natural recovery of the reservoir by injection fluid (gas or water) in the reservoir the oil to flow in to the wellbore the surface [5]. Water and gas injection are the most common methods of secondary recovery. In this process, water is injected into the reservoir to maintain the pressure and also to sweep the residual oil. In order to select the most economical scenarios of water injection, a tool to forecast performance is essential [3] and gas injection is the act of injection gas in to an oil reservoir for the purpose of effectively sweeping the reservoir for residual oil as well as maintenance of pressure. Substantial quantities of oil normally remain in the reservoir after primary and secondary recovery, which can be economically recovered through water alternating gas injection [4]. Water alternate gas (WAG) injection was originally intended to improve sweep efficiency during gas flooding. Intermittent slugs of water and gas are designed to follow the same route through the reservoir. Either gas is injected as a supplement to water or water is injected as a supplement to gas, primarily to reach other parts of the reservoir [1]. WAG injection is improving oil recovery by taking advantage of the increased microscopic displacement of gas injection with the improved macroscopic sweep efficiency of water injection. Compositional exchanges between the oil and gas during WAG process can also lead to additional recovery [6]. Moreover, distinction should be drawn between miscible and immiscible WAG injection. Immiscible wag injection, water and gas can be injected simultaneously rather than intermittently [1]. Reservoir simulation provides a prediction of reservoir performance. There are several methods of simulation from simple to complex ones. The choice of each of these methods depends on the available data and the level of desirable accuracy [2].

### 1.1 Objective of the Study

The main scope of the present work is to make a simulation study in to KEYI oil field in order to optimize oil recovery. Simulation study used to determine the suitable method for increase and enhanced recovery. In order to a accomplish the aim of this study, the simulation model was developed using three – phase, 3D, and black oil option in Eclipse software.

## 2. MATERIALS & METHODS

### 2.1 Materials

#### *2.1.1. Reservoir Description*

A three – dimensional reservoir model was established as a base model for the simulation study studied in Sudanese oil field.
Reservoir simulation studies for KEYI oil field, Muglad basin, Sudan. The synthetic reservoir description is based on an actual producing field. The geological model is a synthetic oil zone sector of a Sudanese oil field. Reservoir pressure at datum depth is 1754.957 Psia. The datum depth of reservoir is about 4429.134ft. KEYI oil field is a fault nose; the internal structure id simple with no obvious fault. Reservoir is highly heterogeneous, characterized by medium porosity and medium – high permeability according to the stratigraphy and development of sand bodies, in Zaqa, Chazal layers, more than dozen individual sand bodies are classified

delayed, but there are six main oil bearing sand layers. The average horizontal permeability is 966.75 md and average porosity is 0.22. The average vertical to horizontal permeability is 0.1. The base model contains $[49 \times 63 \times 12]$ grid block of which [37044] blocks are active. The X and Y dimension of each grid block are164 ft and the vertical direction: 13 – 210 ft. The model is divided into 12 layers vertically, there are 6 main oil bearing sand layers respectively. GA4, GA5, GB1, ZD2, AND ZD3, different layers have different oil water contacts.

### *2.1.2 Well specification*

22 wells (13 wells as production wells and 9 wells as injection wells) are specified in the area under study. The production is initially 2000 (STB/DAY) when gas oil ratio (GOR) at the production well reaches 15 (MSCF/STB) the production well will be shut. The bottom - hole pressure lower limit is 1700 Psia. Consider some constrains which is classified bellow:

- Water oil ratio should not exceed the value 20:1. In other word the fraction of water must less than 0.99.
- Producing gas oil ratio (GOR) should be less than 15 MSCF/STB.
- 
- Well Bottom Hole Pressure must be greater than 1500 Psia.
- The injection rate is set to value of 2000 STB/DAY.
- Pressure of injection wells should not exceed the 7000 Psia.
- Well bore radius of both injection and production wells is 0.124 ft.

### *2.1.3 PVT Analysis of the Reservoir Fluid*

The reservoir contains oil, water, gas, and dissolved gas. The initial reservoir pressure is 1800 Psia. The relative permeability and capillary pressure data and the other PVT are shown in Table 1.

## 2.2 Methods

### *2.2.1 Reservoir Simulation*

KEYI oil field KEYI was proven productive in September 2010, production started from 6 intervals namely, GA4, GA5, GB, ZD1, ZD2, and ZD3. All of these layers distributed in the formations named, the Ghazal Formation, and e Zarqa formation. Core analysis and well logging showed that the reservoir rock is characterized by both medium to high porosity and medium to high permeability. The average matrix permeability is on the order of 20 to 2300 md approximately, with average porosities ranging from 1 to 30 %.Based on geological model, up-scaling was done based on six zones (GA4, GA5, GB, ZD1, ZD2, and ZD3) divided to 12 single layers. Based on that information the reservoir

**Table – 1:** PVT Properties

| PVT for Water | | | |
|---|---|---|---|
| W- Phase Pressure | W- FVF | W- compressibility | W-viscosity |
| 1885.49 | 1.03 | $4.63\times10^{-6}$ | 0.0.65 |
| Equilibrium Condition | | | |
| Datum Depth(ft) | Pressure at Datum Depth(Psia) | WOC(ft) | GOC(ft) |
| 4450 | 1800 | 4420 | 3280.84 |
| | | | |
| PVT for the Dead oil | | | |
| Oil Phase Pressure(Psia) | Oil FVF(bbl/stb) | Oil Viscosity(cp) | |
| 127.5 | 1.1045 | 17/8 | |
| 201.0 | 1.1002 | 18 | |
| 423.0 | 1.0945 | 19 | |
| 715.5 | 1.0919 | 20.1 | |
| 1000.5 | 1.0897 | 21.15 | |
| 1515.0 | 1.0866 | 23.05 | |
| 2162.0 | 1.9831 | 25.60 | |
| 3015.0 | 1.0792 | 28.57 | |
| 4015.0 | 1.0749 | 32.1 | |
| 5015.0 | 1.0708 | 35.6 | |
| Water – Oil Saturation Table | | | |
| Sw | Kro | Krw | |
| 0.30 | 1.0000 | - | |
| 0.39 | 0.4508 | 0.0025 | |
| 0.46 | 0.2275 | 0.0160 | |
| 0.51 | 0.1312 | 0.0361 | |
| 0.56 | 0.0724 | 0.0618 | |
| 0/58 | 0.0475 | 0.0778 | |
| 0.60 | 0.0383 | 0.0861 | |
| 0.62 | 0.0278 | 0.0968 | |
| 0.63 | 0.0214 | 0.1057 | |
| 0.65 | 0.0141 | 0.1151 | |
| 0.67 | 0.0094 | 0.1256 | |

Model for the KEYI area is developed using two-phase, 3D and black oil options in Eclipse. The grid dimension is (49x63) with (3087) grid blocks in the horizontal direction and (12) grid blocks in the vertical direction. A total number of (37044) grid blocks were used to simulate the area. The twelve main zones were modeled with six intervening shale layers. It was assumed that there was no vertical communicating in the matrix between the twelve different sand zones, by setting the transmissibility of matrix in the intervening shale to be zero. This assumption agrees with recent horizontal core analysis. Figure (1) shows 3D of KEYI oil field.

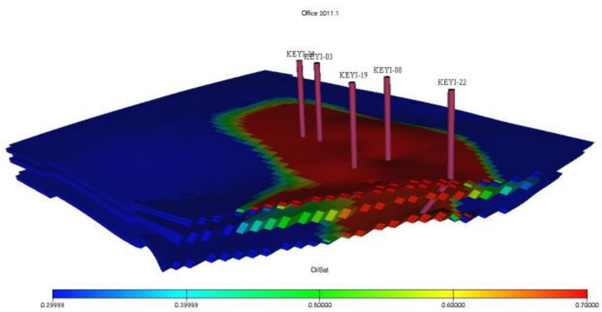


**Fig -1**: 3D of KEYI Oil Field

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 08 | Aug 2022 www.irjet.net p-ISSN: 2395-0072

### *2.2.1 Injection Scenarios:*

Our base run has $[49 \times 63 \times 12]$ Grids. This base run has been used for each three EOR process. First, Water injection and then Gas injection and finally Water Alternating Gas (WAG) process has been investigated. After that the effect of different parameters (WAG cycle time and WAG injection rate) for the Water Alternating Gas injection have been analyzed.

**Water injection Method:** First we start with water injection. We use BASE RUN or $[49 \times 63 \times 12]$ grids. We use many time steps allow water to reach producing wells and fractional flow of water reach the value of 0.99. We test two cases of water injection and run the Data file for the water injection with ECLIPSE software and obtained the results which shown as graphs. Figure (2) shows 3-D graphs of final state of the KEYI oil field during water injection in cross sectional view around injection well.

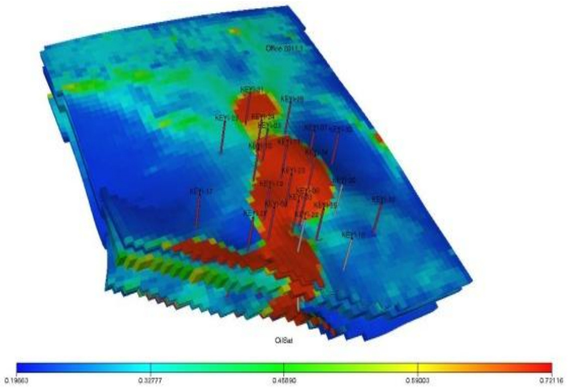

**Fig 2:** Final state of the model after Water Injection

The results of the water injection project were shown by Figure (3). By looking at the oil recovery curve (FOE). We see that the maximum oil recovery with water injection is 26.37 %, which is equivalent to the 8.8 $\times 10^6$STB of the cumulative oil production (FOPT).

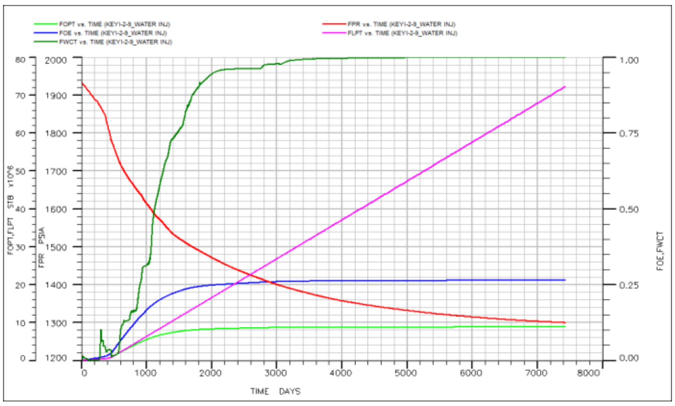

**Fig 3:** Field result of base case for Water Injection

**Gas Injection Method:** After running the model for water injection and seeing the result. We run the Base Run $[49 \times 63 \times 12]$ for the Gas Injection Project and seeing the result. We injected the Gas with Rate 2000 MSCF/DAY and the pressure of injection well should not exceed the 7000 psia. Also the producing GOR should not exceed the 15 MSCF/STB. Figure (4) shows 3-D cross section around the injection well after gas injection.

By looking at the result graphs for the field Figure (5) we can see that the ultimate oil recovery for the gas injection is 23.78 % which results in the production of 7.9 $\times 10^6$STB of crude oil. As we know the Gas Injection is mostly used as pressure maintenance method in gas cap rather than EOR methods. If we compare the Water Injection with Gas Injection, we can conclude that Ultimate Recovery of Water Injection is higher than Gas Injection. Also the reservoir pressure of Water Injection at the end of the project is much higher than the final reservoir pressure of Gas Injection method.

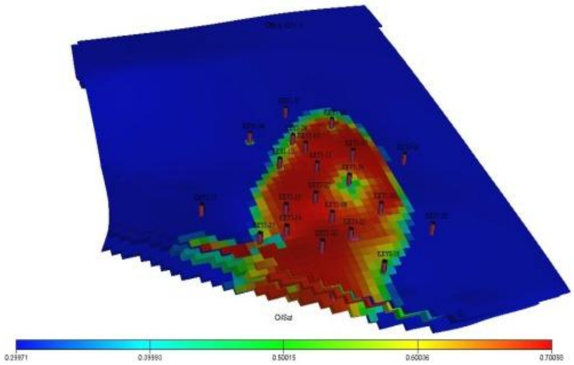

**Fig 4:** Final state of the model after Gas Injection

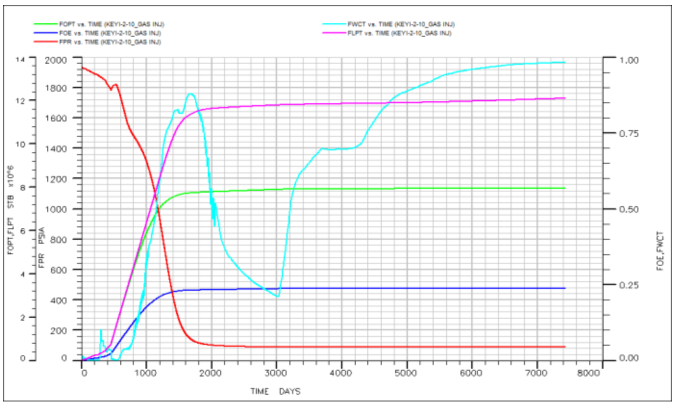

**Fig 5:** Field result of base case for Water Injection

**Water Alternating Gas (WAG) Injection method**: We use the Base Run for Water Alternating Gas (WAG) injection in KEYI oil field. The period for injection wells (Water and Gas injection) is 7426 days. It means that water injected for one year and in this period the gas injector wells are shut, and during the injection of gas for one year, the water injector wells are shut. Figure (6) shows 3-D cross section around the injection wells after WAG injection.

By analyzing the result of WAG technique, Figure (7) we can find the ultimate recovery of this EOR method for typical 26.46 %. The total oil production of WAG method is 8.83 $\times 10^6$STB of crude oil.

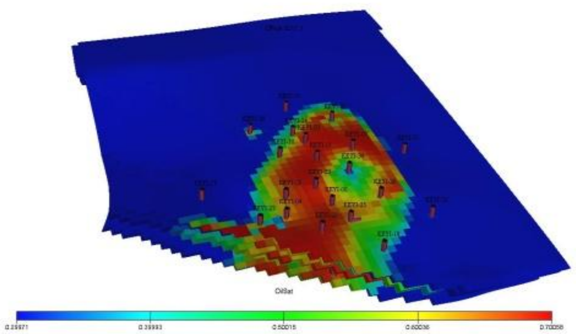

**Fig 6:** Final state of the model after WAG Injection

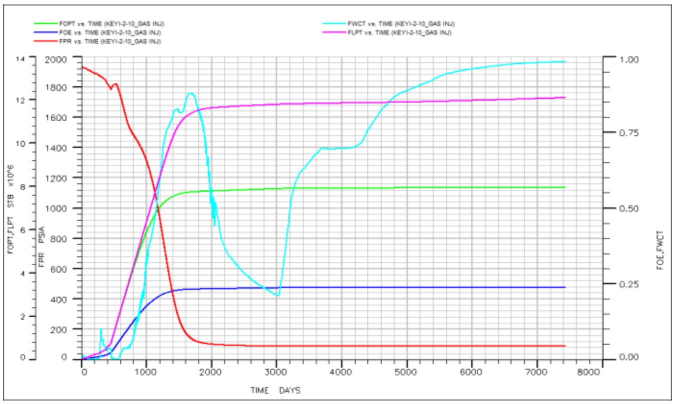


**Fig 7:** Field result of base case for WAG Injection

## 3. RESULTS & DISCUSSION

The overall result for water injection, Gas Injection and Water Alternate Gas (WAG) in term of oil recovery efficiency (FOE), Oil Production Total (FOPT). Have been compared in tables (2 and 3) in the following:

**Table 2:** Field Oil Efficiency (Recovery Factor)

| EOR method | Ultimate Recovery Factor (%) |
|---|---|
| Water Injection(days) | 26.37 |
| Gas Injection(days) | 23.78 |
| Water Alternate Gas(WAG)(days) | 26.46 |

**Table 3:** Field Oil Production Total ($\times 10^6$STB)

| EOR method | Field Oil Production Total($\times 10^6$STB) |
|---|---|
| Water Injection(days) | 8.8 |
| Gas Injection(days) | 7.9 |
| Water Alternate Gas(WAG)(days) | 8.83 |

From Figures (8 to 11) it has been concluded that the water injection is the best choice for our model, because water injection has the greatest recovery factor. If one want to have the overall view to these three EOR methods, it can be said that the water alternate gas injection is the best.

Following results analyze different parameters (FOPT, FOE, FPR, and FWCT) of the 3 methods (Water Injection, Gas Injection, and Water Alternating Gas Injection). By looking at the water cut curve for these three methods, Water flooding has the earlier breakthrough of water due to water injection. And gas injection has the lowest fractional flow of water.

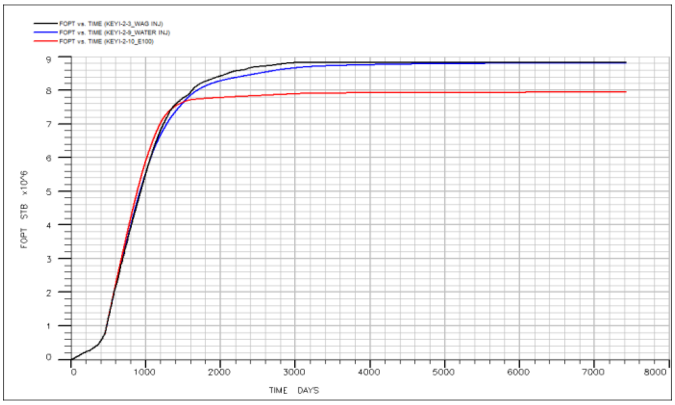


**Fig 8:** Compare the field result of **FOPT** for WI, GI, and WAG injection methods

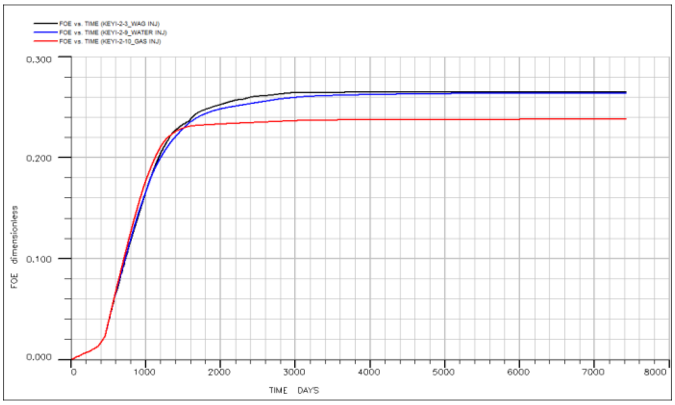


**Fig 9:** Compare the field result of **FOE** for WI, GI, and WAG injection methods

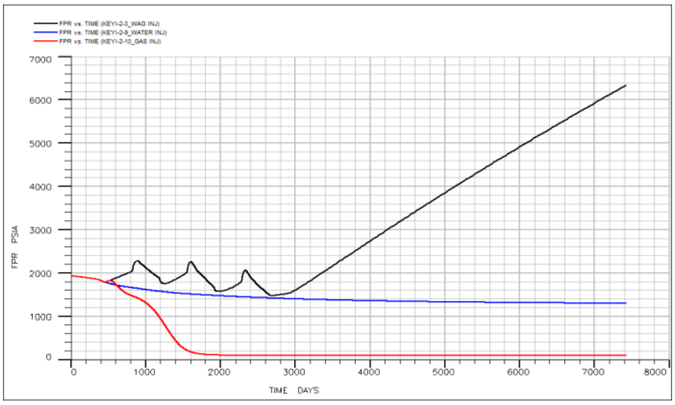


**Fig 10:** Compare the field result of **FPR** for WI, GI, and WAG injection methods

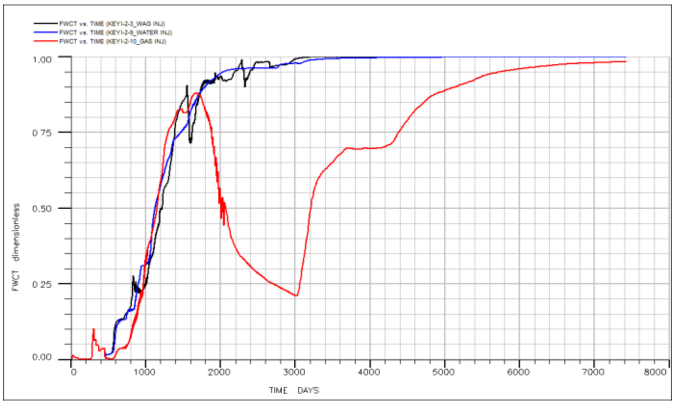


**Fig 11:** Compare the field result of **FWCT** for WI, GI, and WAG injection methods

## 4. CONCLUSION

By analyzing the obtained results in the previous section the following remarks are concluded:

1. The best method to choose as EOR for KEYI oil field is WAG Injection.
2. WAG Injection has the largest Total Field Recovery.
3. WAG Injection has the highest Reservoir Pressure at the end of the project.
4. The main disadvantage of the Water Flooding is its high fractional flow of water.
5. Also the Water Flooding method has the lowest value of Producing GOR.
6. After Water Flooding, the method of Water Alternate Gas (WAG) has the largest Oil Recovery.
7. Gas Injection has the lowest Field Oil Recovery. As we mentioned before, Gas Injection is almost use as Pressure Maintenance Method rather than EOR method.

## ACKNOWLGEMENTS

First of all, I would like to express my special appreciation and great gratitude to my advisor ***Professor Liu Yue Tian*** for accepting me into his group, providing a wonderful combination of advice support and friendship. ***Professor Liu Yue Tian*** is always available to answer my questions, or to help me in finding the right path to answers. When I felt depressed because of some unsuccessful struggling, Professor ***Liu Yue Tian*** kept her belief in my ability of solving problems and encouraged me to overcome the difficulties eventually. He has provided positive encouragement and a warm spirit to finish this thesis. It has been great pleasure and honor to have him as my supervisor. I will forever be thankful and recognition are due to ***Professor Zhang Laibin, the president of China University of petroleum***, who encouraged me to come to China by give me this chance to study PhD, and believed I had the conditions to undertake and to succeed in the adventure of PhD.

I would also like to thank ***China University of Petroleum***, ***the foreign student office, Sudan University of science and technology, The College of Petroleum Engineering & Technology, and Sudanese Ministry of Higher Education*** for their financial support.

My deepest gratitude goes to my entire family member. It would not be possible to write this paper without the support from them.

I would like to thank my husband ***Montasir Yosif Mohammed Salih*** for his love, patience and unwavering support.

Also I will forever be thankful to my lover ***Nahid and Noun*** for them love and help.

Lastly I wish to express my heartiest gratitude to my colleagues for helps.

## N0MENCLATURES

**EOR**: Enhanced Oil Recovery
**WAG**: Water Alternating Gas
**FOPT**: Field Oil Production Total
**FOE**: Field Oil recovery Efficiency
**FPR**: Field average pressure
**FWCT**: Field Water Cut
**WI**: Water Injection
**GI**: Gas Injection

**REFFRENCES**

[1] Caudle, B.H. and A.B. Dayes, 1958. Improving miscible Displacement by Gas-water Injection, Trans, AIME, 213: 281-84

[2] Ertekin, T., J.H. Abou-Kassem, and G.R. King, 2001. Basic applied reservoir simulation. Society of Petroleum Engineers, Richardson, Tex.

[3] Fanchi, J.R., 2001. Principles of Applied Reservoir Simulation, Second Edition. Gulf Professional Publishing, Burlington.

[4] Fatemi, M. S., Sohrabi, M., Jamiolahmady, M., Ireland, S., & Robertson, G. (2011). Experimental Investigation of Near-Miscible Water-Alternating-Gas (WAG) Injection Performance in Water-wet and mixed-wet Systems. SPE Offshore Europe Oil and Gas Conference and Exhibition (pp. 1-16). Aberdeen

[5] Speight, J. G. (2009). Enhanced recovery methods for heavy oil and tar sands. Houston: Gulf Pub. Co.

[6] Stenby, E., Skauge, A., & Christensen, J. (2001). Review of WAG Field Experience. SPE Reservoir Evaluation & Engineering, 1-10