PEOPLE’S DEMOCRATIC REPUBLIC OF ALGERIA
Ministry of Higher Education And Scientific Research

N° Série : ………/2023

Kasdi Merbah University Of Ouargla

Hydrocarbons Faculty of Kasdi Merbah University
Petroleum Production Department

MEMOIRE
In Order to obtain a Master’s Degree
Option : Professional Production Engineering
Presented by :
CHENOUGA CHIRAZ , SOLTANI AYA , ZAOUI BADIAA
-THEME-

EVALUATION OF WATER ALTERNATING GAS INJECTION PILOT IN ZONE 19 IN HASSI MESSAOUD FIELD IN ALGERIA

GRADUATED in : **15/06/2023**

Jury :

Président :	Mr. Kadri Ahmed Yassine	MCA	UKMO
Examiner :	Mr.Boufadesse djamila	MCB	UKMO
Supervisor :	Mr.Ghali Ahmed	MAA	UKMO
Co-Supervisor:	Dr.Adjou Zakaria	Ph.D	UKMO

University year : 2022/2023

ACKNOWLEDGMENT

At the end of this work, we express our gratitude to ALLAH for having given us strength and patience, these fabulous values without which we could not have drawn new strength to carry out our task.

We will not forget to express our gratitude to our supervisor MR.GHALI , co-supervisor DR.ZAKARIA who spared no effort to help us providing this work

We would like to express our thanks to Mr KAFI SALIM, Head of Wireline / Slickline department DP IRARA SONATRACH .

We would also like to express our thanks to Mr MERIOUMA ABD RAOUF and Mr.BOUKHMIS OUALID engineers from DP IRARA SONATRACH .

We thank the members of the jury Mr.KADRI Ahmed Yassine Salim and Ms. Boufadesse Djamila who do us the honor of judging this modest work.

And to all those we have forgotten we also send them a big thank you and God bless you all.

DEDICATION

To my rock , my empror , to the man who worked hard all his Life without whining, to my father : ***Chenouga Kamel .***

To The flower , to the soldier Woman who was patient all the time Encouraging me , giving me and offering me her thoughts, prayers and everything I needed without getting tired of me just one day. To the best mother ever ' ***Souab Naima'***

By and to them both ' ***my parents'*** *Who suffered all their life long to build such a Successful Engineer*

To my Sisters ' ***Ghada and Takwa*** *' who prayed and still praying for me . The sisters who are believing in my goals and ambitions*

To my brother ' ***Kaisser*** *' For encouraging me every single day and pushing me to carry on my path*

To the mentors and teachers ***Mr. Kafi Salim*** *Who is my biggest supporter and* ***Mr.Boublal Belkhir*** *who illuminated my path,fanning the flames of wisdom within.*

My youngest Aunt and my second mother who cares a lot about my success ' ***Mariem Souab '***

To the new Sister and New Family member my sister in law ' ***Chaoui Rawnek '***

To my besties and my second family ' ***Aya , Badiaa , Hadjer , Manel and Hayem '***

Last but not least to the special king who got my back day after day pushing me towards my dreams and helping me achieve a lot , my mentor and friend ' ***Badaoui Mohamed Zohir '***

To all who love , believe and encourage me each one by his name

to my two big families ' ***Chenouga and Souab '***

To ***me*** *! To my patience, my ambition, my determination and persistence to my suffering. Today I would like to thank* ***me*** *for bearing with me . and never giving up and believing in me .*

This memoir is lovingly dedicated to all those who played a part,in shaping the Engineer I have become

Chenouga Chiraz

DEDICATION

I want to dedicate my work to

First, My queen, my Mom, my biggest supporter, the woman who believed and encouraged me in every step I took in my life, who have been the mother, the father, and the shoulder I rely on during all my life, who I wouldn't be the girl I am now without...

Bouidaian Rehifa

My Dad "may Allah have mercy on him", I wish he could be by my side in this special moment but I'm pretty sure he's proud of the baby girl he left in the cradle...

Zaoui Houcine

My brothers and sisters, who gave me all the support and belief, prayers and guidance:

"Kamla, Naima, Ahmed, Wided, Fadhila, Ammar, Wissam, Nouha, Miada"...

My nieces and nephews, all by their names

"Hicham, Ikram, Hadil, Iyad, Zizou, Mimou, Islam, Abdou, Djoud, Sifou, Marame, Sadjed"...

*My colleagues **"Aya and Chiraz"...***

*My friends **"Hadjer, Manel, Halim, Amir, Rahma, Anis, Green and** everyone by his name", thank you for every word and assistance I got from you...*

All the people I met in Ouargla and played a role in my life:

"Aiesec community", "Dr. Guichaoui", "Hakim"

*A special mention to **"Mustapha"***

And last, this work is dedicated to the pure soul inside me, who kept believing and pushing me to be the engineer I am now...

Zaoui Badiaa

Dedication:

For every beginning there is an end, and what is beautiful in any end is the success and the achievement of the goal. I dedicate this modest work, fruit of very long years of work:

To the only woman in my life who suffered a lot to make me who I am and who still gives me hope to live and who never stopped praying for me; My very dear

Mother *GARSSALLAH NADJET.*

To my very dear **Father** , for his encouragement, his support, especially for his sacrifice so that nothing hinders the progress of my studies

SOLTANI YOUCEF.

To my two brothers *WAIL* and *NIDAL EDDINE* .

To my cousin **HASNA .** To my **Grandmother (DJAMILA)** and my **Grandfather (BELGACEM) .** To all my uncles and aunts with their daughters and sons . To all my big family, **SOLTANI** and **GARSSALLAH** .To my best friends each in his name, and to all those I love.

At the end I warmly dedicate this dissertation to my threesomes **CHENOUGA CHIRAZ** and **ZAOUI BADIAA**.

To all the members of my family who have helped me during all my studies.

To the gentlemen **LAIEB NAAMANE**, **KAFI SALIM, BOBLEL BELKHIR**, **MERIOMA ABDERAOUF**, **OUALID BOUKHMIS**, **BENTAHAR MOHAMED SEDIK** for their help and encouragement.

SOLTANI AYA

Abstract:

This thesis is about the application of the Water Alternating Gas (WAG) technique pilot in Hassi Messaoud field in zone 19. It’s an effective technique that has been successfully applied in May 2005 to maintain or increase the production oil rate and decrease the amount of gasflood simultaneously. This study is focused on the efficiency of this technique which did not show any definitive evidence for its success. Moreover, between May 2005 and April 2010 the monthly gasflood injection in zone 19 has decreased by 56%, while the oil production rate had a slight rising by 6 M scm. However, the new technologies of the WAG technique used all around the world are discussed using Prosper software to propose the most applicable one that will enhance the residual oil recovery in the mentioned zone.

Keywords: WAG, displacement efficiency, prosper, oil recovery, sweep mechanism

Résumé:

Ce mémoire est élaboré dans le cadre de l’étude de l’application du pilote d’eau alternatif gaz (WAG) dans le champ Hassi Messouad en zone 19. C’est une technique efficace qui a été appliquée en Mai 2005 avec succès pour maintenir ou augmenter le taux de la production d’huile et diminuer la quantité de gaz injecté en même temps. Cette étude concentre sur l’efficacité de cette technique qui n’a pas montré de preuve définitive de son succès. De plus, entre mai 2005 et avril 2010, l'injection mensuelle du gaz dans la zone 19 a diminué de 56%, tandis que le taux de production pétrolière avait une légère hausse de 6 M scm. Cependant, les nouvelles technologies de la technique WAG utilisées partout dans le monde sont discutées en utilisant le logiciel PROSPER pour proposer la plus applicable qui permettra d’améliorer plus la récupération de pétrole résiduel dans la zone mentionnée.

Mots clés: WAG, efficacité de déplacement , récupération d’huile, mécanisme de balayage et Prosper

ملخص :

تتناول هذه الرسالة تطبيق تقنية حقن الماء و الغاز لمتناوب كتجربة نموذجية في حقل حاسي مسعود في المنطقة 19. إنها تقنية فعالة تم تطبيقها بنجاح في مايو 2005 للحفاظ على معدل إنتاج النفط أو زيادته وتقليل كمية الغاز المحاق في نفس الوقت. تركز هذه الدراسة على كفاءة هذه التقنية التي لم تظهر أي دليل قاطع على نجاحها. علاوة على ذلك، انخفض حقن الغاز المحاق الشهري في المنطقة 19 بنسبة 56% بين مايو 2005 وأبريل 2010، في حين ارتفع معدل إنتاج النفط قليلاً بمقدار 6 مليون متر مكعب. ومع ذلك، يتم مناقشة التقنيات الجديدة لتقنية المستخدمة في جميع أنحاء العالم باستخدام برنامج Prosper لاقتراح التقنية الأكثر تطبيقًا التي ستعزز استرداد الزيت المتبقي في المنطقة المذكورة.

الكلمات المفتاحية بروسبار، استرداد النفط، آلية الدفع الحقن المتناوب للماء و الغاز ، كفاءة الدفع

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Abbreviations List

IOR : improved oil recovery
EOR : Enhanced Oil Recovery
WAG : water alternating Gas Injection
Swag : Simulatneous WAG
HWAG : Hybrid WAG
MWAG : miscible WAG
IWAG : Immiscible
GL : Gas lift
HMD : Hassi Messaoud
LSWAG : Low salinity water alternating Gas Injection
SAWAG : Surfactant Aided Water alternating Gas Injection
NWAG : nanotechnology Water alternating Gas Injection
BHP : Bottom Hole Pressure psi (kg/cm2)
BO : Oil volumetric factor
BG : Gas volumetric factor
GOR : Gas/oil ratio (m3/ m3)
R : Production GOR (m3/ m3)
G :constant gravity
RS : Dissolution GOR (m3/ m3)
Rvs: GOR of free gas (m3/ m3)
OOIP: Original Oil In Place (bbl)
IOIP: Initial Oil In Place (bbl)
M : Mobility ratio
Poh: Pressure in the oil-phase, psi (kg/cm2)
Pc: Capillary Pressure, psi (kg/cm2)
Pw: Pressure of the water phase, psi (kg/cm2)
Qo : Oil flow (m3/j)
Qw: Water flow (m3/j)
Qg: Gas flow (m3/j)
Krw: Water relative permeability(md)
Kro: Oil relative permeability(md)
Krg: Gas relative permeability (md)
Swi: Irreducible water saturation
Sorw: Residual oil saturation at water injection
Sorm: residual saturation on injection of miscible fluids

GENERAL INTRODUCTION

GENERAL INTRODUCTION

Petroleum engineers have long been focused on developing an efficient production method to recover the entirety of oil in hydrocarbon reservoirs. Early on, it was evident that existing production methods were leaving behind approximately 80% of the original oil present in the reservoir.

In recent years, there has been a growing interest in water alternating gas (WAG) processes, which include both miscible and immiscible gas injection. Miscible gas injection helps mobilize residual oil and improve the efficiency of oil recovery processes. However, the significant density gap and unfavorable mobility ratio between the displacing and displaced fluids often result in poor volumetric sweep efficiency during gas flooding. WAG proves to be a superior method in enhancing the volumetric sweep efficiency in heterogeneous reservoirs by reducing density and mobility ratio contrasts.

The iffue that makes us do this study is of WAG injection was first introduced by Caudle and Dyes in 1957. According to Moritis (2004), gas injection accounted for nearly 47.9% of the total enhanced oil recovery (EOR) production in the United States.

In the 1970s, a study conducted on the Hassi-Messaoud Field demonstrated that WAG injection doubled the sweep efficiency upon breakthrough. With straight gas injection, the estimated recovery rate was 40-50%, whereas WAG injection resulted in up to 75% recovery. Consequently, WAG injection can effectively control the gas-oil ratio (GOR) during production **[1]** .

The primary objective of implementing the WAG pilot project in zone 19 of the Hassi-Messaoud Field was to address the issue of increasing gas production and find ways to reduce it. WAG, specifically water alternating gas or water injection, offers a promising solution for controlling gas production volumes. This field exhibits a favorable mobility ratio of approximately 0.3 for waterflooding, leading to excellent volumetric sweep efficiency with water. By employing a WAG injection scheme, the project aims to capitalize on the benefits of both water and gas injection, resulting in enhanced volumetric sweep efficiency and improved oil displacement.

Study Objectives

The main goals of this study are to monitor the progress of the WAG pilot project implementation in zone 19 and evaluate the outcomes. Additionally, a comparison will be made between simulation targets and field applications regarding the timing and volumes of water and gas injection. Furthermore, the data collected from the WAG injection well will be analyzed to assess its impact on the neighboring offset wells and ensure proper monitoring of the project . Additionally it will propose the best suitable new wag technologie should applied in the recent mentionned zone depending on zone 19 challenges

Work Methodology

The research project employs the following methodology:

- Describing the applications and advantages of Water Alternating Gas (WAG) compared to other oil recovery techniques in the petroleum market.
- Examining the current production challenges faced in zone 19 of Hassi-Messaoud Oilfield, focusing on maintaining or enhancing oil production and addressing the high demand for gas injection.
- Utilizing the Zone 19 Geocellular Model to estimate the remaining oil reserves and selecting the WAG pilot area based on layer calculations.
- Providing a comprehensive account of the WAG implementation in zone 19, documenting the progress made from the initial stages until the present.
- Analyzing data collected from surrounding wells of the WAG pilot well, including production tests, pressure tests, recorded logs, and production history.
- Ultimately, evaluating the results of WAG injections and assessing their impact on the observation area
- Providing a full production optimization scenario in zone 19 depending on new wag technologies and prosper software .

Memoir organization

Chapter II : Oil recovery techniques

Chapter II : hassi messaoud wag pilot application in zone 19

Chapter I:

OIL RECOVERY TECHNIQUES

INTRODUCTION

A reservoir is defined as a matrix composed of millions of pores filled with oil, water, and/or gas. When the well is opened for the first time to allow the reservoir to decompress, the recovery of oil will be by the natural drive mechanisms that are called “primary recovery” Or “natural depletion”. When the reservoir pressure begins to decline and the well flow rate decreases, the application of certain techniques that help push the fluids and enrich the pressure is a necessity, hence the term “secondary recovery”. “Tertiary recovery” of oil begins when it is felt that the production from secondary oil recovery is not enough.

The purpose of this chapter is to provide a detailed overview of the various oil recovery techniques. First, primary recovery and its mechanisms, followed by secondary recovery methods and a comparison between them, and finally, a discussion of the different methods of tertiary recovery.

I.1 Primary oil recovery

The extraction of fuels from a reservoir without adding any additional processes (like fluid injection) to boost the reservoir's inherent energy is called PRIMARY RECOVERY Which is the process of recovering oil using one or more natural drive systems. Understanding these drive systems that regulate the behavior of fluids inside the Reservoir is essential for properly comprehending and estimating future performance. The overall efficiency of an oil reservoir is greatly influenced by the oil that can be moved to the wellbore using the energy or driving mechanisms that is available the driving forces that provide the natural energy required for primary oil recovery are as follow **[7]** .

I.1.1 Drive Systems Mechanisms

- Oil Expansion
- Solution Gas drive
- Gas cap drive
- Gravity Drainage
- Water drive
- Combination drive

I.2 Secondary oil recovery

Oil recovery production ranges from 20% to 40% of the OOIP counting on the natural energy of the reservoir, so big amounts of oil can be left behind in the pores. Moreover, throughout the lifetime of the well, the pressure declines until it reaches a certain point when it's crucial to provide external energy in the reservoir for a better recovery. This energy is applied in two processes: water injection and immiscible gas injection; hence the term secondary recovery.

Before proceeding to this phase of oil recovery it must have clearly proven that the natural energy is insufficient, this can take one to two years of production to assert **[3].**

There are two main objectives of secondary recovery:

- Maintain the depleted reservoir pressure.
- Sweep the crude oil from the injection well toward and into the production well **[4].**

I.2.1 Water injection

Water injection is also known as water flooding where water is injected into the reservoir formation of the selected well to displace the residual oil from the injector well to the producer one while maintaining reservoir pressure and keeps it around the bubble point. The first water flooding application was by accident in the 19th century in the Pithole City area of Pennsylvania in 1865 **[5].**

Solution gas-drive mechanisms generally are considered the best candidates for water floods **[2].**

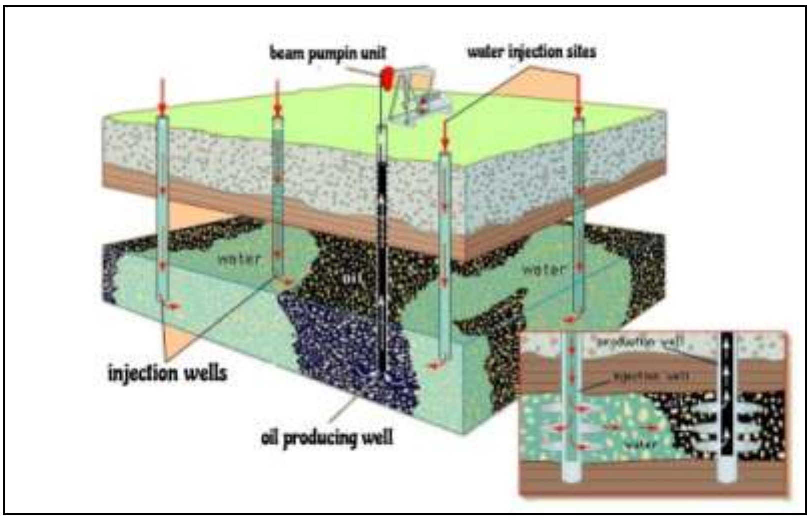


Figure I-1 : Water flooding sweep mechanism [10]

I.2.2 Gas injection

Gas injection is also known as re-injection or gas re-pressurization, where immiscible gas (natural gas) is injected into the reservoir, commonly in the reservoirs with the gas cap. The injected gas molecules dissolve in the oil and reduce its viscosity; thereby increasing its mobility. Carbon dioxide or natural gas is used to re-pressure the well. This process has two main objectives depending on the injection type **[8] :**

- Pressure maintenance
- Oil displacement to the producing wells

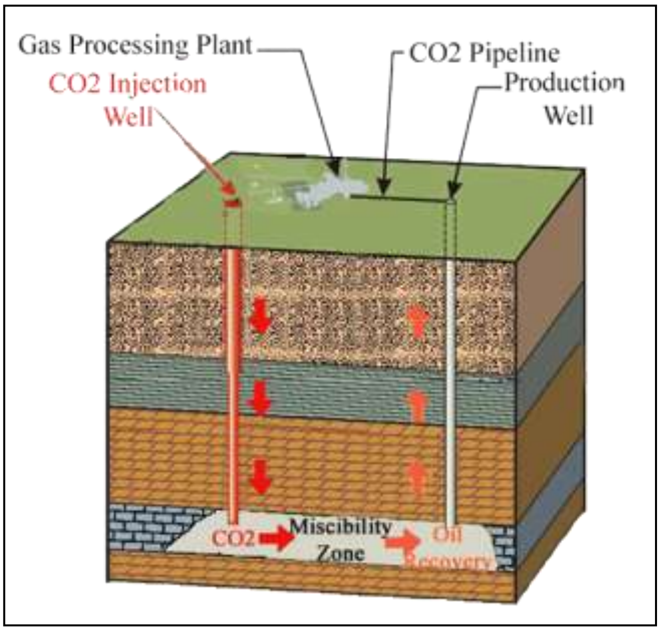


Figure I-2 : Gas injection sweep mechanism [9]

I.3 Tertiary recovery methods

Tertiary recovery processes use new or already known methods, but readapted thanks to the evolution of technologies. They are only involved in 2% of world production.

These are processes that are generally implemented in the last phases of the life of a deposit. But they carry the hope of further increasing recovery rates by a few more points.

Tertiary recovery techniques aim to push the crude more efficiently towards the production wells, to increase the fluidity of the oil to be recovered, or, on the contrary, to reduce the permeability of certain layers of the subsoil whose characteristics interfere with efficient flushing of the tank also called Enhaced Oil Recovery (EOR) **[12].**

I.3.1 EOR methods

a) Non-Thermal methods

We Distinguish three classes of EOR Non-thermal techniques: miscible gas injection, water-alternating-gas injection (WAG), and chemical EOR techniques.

Miscible gas injection

Involves injecting a gas, which is miscible or nearly miscible with oil, into the reservoir to reduce interfacial tension and improve mobility.

WAG

The water alternating gas injection process (WAG) is a tertiary technique commonly employed to improve the efficiency of displacing residual oil that remains unrecovered after primary and secondary recovery methods. In this particular study, transparent water-wet microporous models filled with glass beads and initially containing crude oil were subjected to experimental tests. The objective was to analyze the dynamics of three-phase flows and the subsequent oil recovery associated with alternating cycles of gas and water injection. Advanced image processing techniques were utilized to examine the displacement of residual oil at the conclusion of each WAG injection cycle. The findings revealed that the continuous WAG injection cycles facilitated the spreading of saturated residual oil throughout the porous region, effectively displacing the residual oil that remained within the water-wet porous media following the initial water flooding stage. These experimental results provide detailed insights into the WAG process and serve to validate future numerical models pertaining to this technique

Chemical EOR techniques

Involve altering the interfacial tension between the water and oil using surfactants or alkaline substances to improve wettability and mobilize residual oil trapped in the porous rock structure.

b) Thermal Methods

The most advanced method of enhancing oil production is through the use of thermal techniques, which were first utilized in 1950. These methods have been effectively implemented in numerous countries, including Canada, Indonesia, and Venezuela. They are particularly suitable for heavy oil and bitumen with API gravity ranging from 10 to 20°, as well as tar sands with API gravity of less than 10°. Essentially, thermal techniques involve heating the oil reservoir, resulting in the evaporation of some of the oil and a significant decrease in viscosity. This, in turn, makes it easier to extract the oil and move it toward the producer.

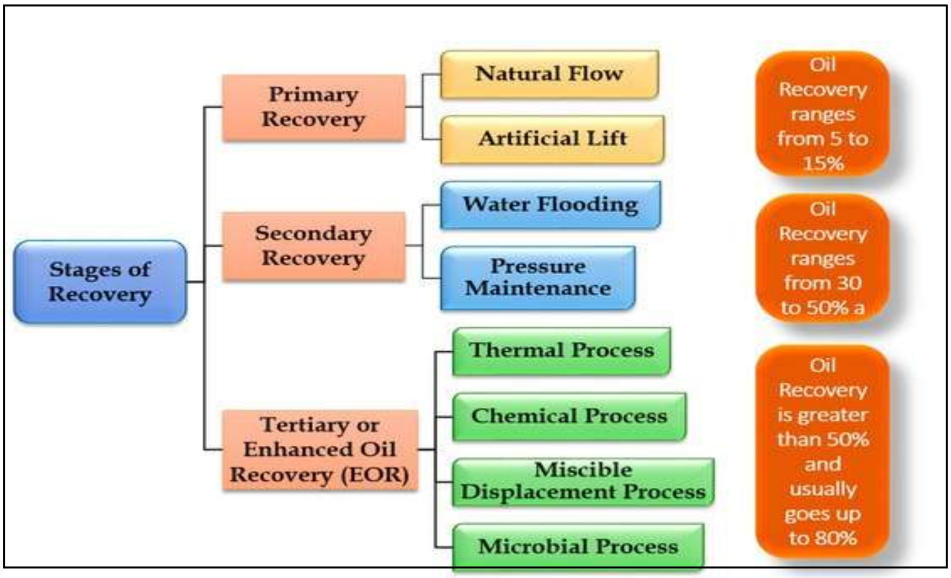


Figure I-3 : Oil Recovery Stages [7]

I.4 WAG Injection literature review

I.4.1 WAG Targets

The main purpose of WAG injection is to increase the microscopic sweep efficiency and contact attic oil in areas that were not reached through water injection. In highly permeable sandstone reservoirs, gravity segregation is common, causing gas to migrate to the top of the reservoir and water to migrate to the bottom. Injected gas can contact attic oil in the upper parts of the reservoir, while the water flood acts as a piston to push the miscible slug forward, reducing the unswept reservoir area and improving the microscopic efficiency. As a result, the residual oil to WAG is less than the residual oil for water or gas alone, leading to improved oil recovery. Combining the improved microscopic displacement efficiency of gas injection with the improved macroscopic displacement efficiency of water injection can enhance oil recovery. The benefits of WAG injection are illustrated in Figures **II.1** , **II.2** , and **II.3**, which demonstrate how it can sweep a larger area in the reservoir.

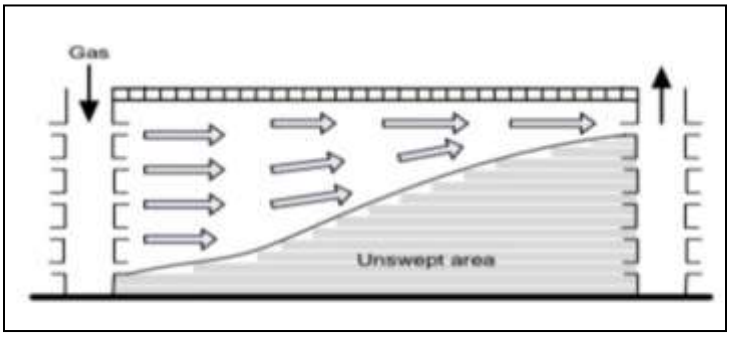


Figure I-4 : Gravity effect in the gas injection

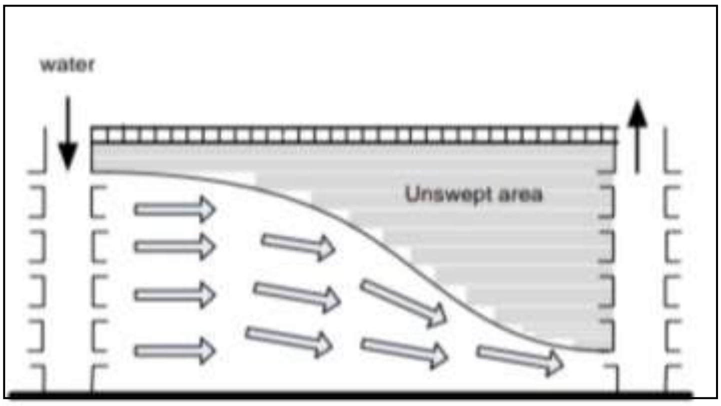


Figure I-5 : Gravity effect in the water injection

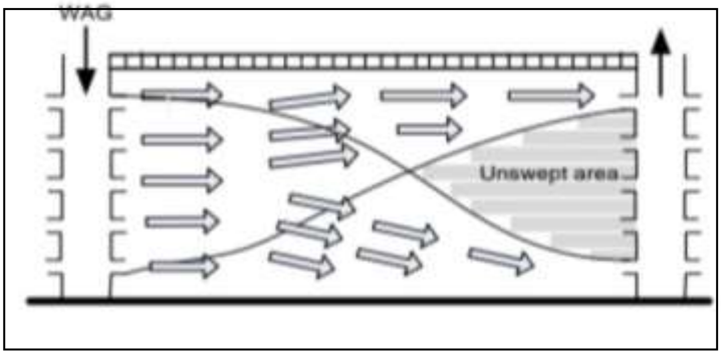


Figure I-6 :The gravity effect during the WAG injection

I.4.2 Parameters Influencing WAG Process

The Water Alternating Gas (WAG) process is a type of enhanced oil recovery (EOR) technique that involves alternating the injection of water and gas into an oil reservoir. This process is used to improve the sweep efficiency of the injected fluids and increase oil recovery rates. The WAG process is influenced by various parameters, including reservoir properties, fluid properties, and operational parameters **[17].**

a. Reservoir Properties:

- **Permeability**: The permeability of the reservoir rock plays a crucial role in determining the success of the WAG process. A high permeability reservoir can lead to poor sweep efficiency and low oil recovery rates.
- **Porosity**: The porosity of the reservoir rock affects the amount of oil that can be trapped in the rock matrix. High porosity can lead to a high residual oil saturation and reduce the effectiveness of the WAG process.
- **Heterogeneity**: The heterogeneity of the reservoir rock can affect the distribution of the injected fluids and influence the effectiveness of the WAG process.

Saturation: The initial oil saturation in the reservoir affects the amount of oil that can be recovered using the WAG process.

b. Fluid Properties:

Water and Gas Properties: The properties of the injected water and gas, such as density, viscosity, and solubility, can affect the effectiveness of the WAG process.

Wettability: The wettability of the reservoir rock influences the distribution of fluids in the reservoir and can affect the effectiveness of the WAG process.

c. Operational Parameters:

Injection Rate: The injection rate of the water and gas can influence the sweep efficiency and oil recovery rates of the WAG process.

Injection Timing: The timing of the water and gas injection can affect the distribution of fluids in the reservoir and the effectiveness of the WAG process.

Injection Volume: The volume of water and gas injected can affect the sweep efficiency and oil recovery rates of the WAG process **[17].**

I.4.3 WAG Advantages

- The WAG (Water Alternating Gas) technique is widely used in various fields to enhance oil recovery and has gained popularity due to its effectiveness.
- The success of the WAG technique depends on the properties of the reservoir and the design of the technique.
- WAG effectively manages reservoir mobility by controlling gas processing and reducing gas cycling, thereby improving overall efficiency.
- WAG helps recover residual oil that traditional techniques may have failed to extract, increasing the total amount of recoverable oil.
- The WAG technique helps maintain the average pressure in the reservoir, preventing collapse and ensuring a more extended and effective recovery process **[15].**

I.4.4 Mechanism of drainage by wag process

The WAG process functions by forcing water out of the tank as hydrocarbons begin to migrate into it. However, due to capillary pressure and the wettability effect of hydrocarbons, the oil cannot displace all the water. This leaves behind a portion of water, known as irreducible water saturation (Swi), which surrounds the sand grains and occupies small capillary spaces. This results in a high degree of flow resistance for the oil due to the presence of irreducible water saturation. When water is injected into a reservoir, it cannot flush out all the oil from the pores, leaving behind residual oil saturation at water injection (Sorw).

Injecting gas above the minimum miscibility pressure (MMP) results in the formation of a miscible plug, which efficiently displaces the remaining oil. The residual saturation at the injection of miscible fluids (Sorm) is the fraction of the oil that remains, typically composed of heavy hydrocarbon molecules. As gas injection proceeds, the gas effectively moves the miscible plug, flowing around the water fixed on the walls of the pores and the residual oil **[17]** .

I.4.5 WAG oil recovery efficiency

The primary goal of the WAG technique is to enhance the recovery of oil, which can be accomplished by refining the Recovery Efficiency (RF) factor (as shown in Figure **II.4**).

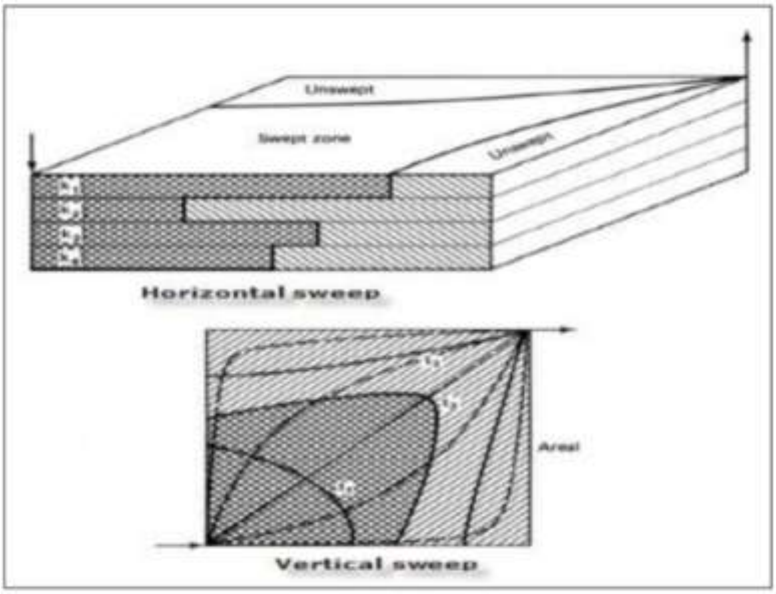


Figure I-7 : WAG Recovery Efficiency Vertical and Horizontal [17]

Furthermore, the contribution of the recovery factor can be described

by simple relations as below:

$$RF = EV \ x \ EH \ x \ Em \qquad (I.1)$$

Where:

RF : Oil recovery

EV : Vertical sweep efficiency

EH : Horizontal sweep efficiency

Em : Microscopic sweep efficiency

It's evident that increasing any factor will lead to an improvement in oil recovery. The vertical and horizontal sweep efficiencies multiplied together make up the overall macroscopic displacement efficiency. When implementing a miscible displacement, residual oil saturation tends to approach zero in flooded areas. Even with an immiscible displacement, the remaining oil saturation after gas flooding is typically lower than after waterflooding, indicating that the microscopic displacement efficiency of gas is superior to that of water .

I.4.5.1 Horizontal Efficiency

The stability of the front, which is determined by the mobility of the fluids, has a significant impact on the horizontal displacement efficiency (Ehis). The equation (I-2) expresses the mobility ratio (M).

$$M = \frac{Krg/\mu g}{Kro/\mu o} \qquad \textbf{(I-2)}$$

krg :Relative gas permeability. μg: gas viscosity

kro : Relative oil permeability μg: oil viscosity

I.4.6 Vertical Efficiency

The vertical efficiency Evis influenced by the relationship between gravitational forces and gravitational forces the relationship between viscosity and gravity is expressed by equation (I-3)

$$R_{v/g} = \left(\frac{V\mu_o}{kg\Delta\rho}\right)\left(\frac{L}{H}\right) \qquad \textbf{(I-3)}$$

Where :

v: The speed of darcy.

L: is the distance between two wells.

g: the force of gravity.

$\Delta\rho$: The difference in density between fluids.

μ_o: The viscosity of the oil.

K: the oil permeability.

H: the height of the scanned area.

The main reservoir properties affecting vertical displacement efficiency are dip angle, variation in permeability and porosity. Normally porosity and permeability increase going down, this is advantageous for WAG injection, since this combination will increase front stability. In general the sweep by the WAG will be optimized if the mobility ratio is favorable (M<1), the reduction of the mobility ratio can be achieved by increasing the viscosity of the gas and reducing the relative permeability of the fluids. Gas mobility can be reduced by injecting water and gas alternately **[19].**

I.4.7 WAG injection problems

The WAG process offers benefits like improved displacement efficiency but faces operational difficulties during production.

Early breakthrough in producing wells is a common issue in WAG fields, caused by gas migration through thief zones or fractures.

Understanding reservoir heterogeneity and perforation set is crucial to avoid early breakthrough.

Corrosion can occur during WAG injection, especially on the injection side, and can be mitigated with high-quality steel and coating of pipes.

Reduction of injectivity can occur due to various factors, affecting the miscibility and pressure maintenance of the WAG process.

Limescale deposits can form due to changes in temperature, pressure, or chemical composition, and prevention methods include chemical inhibitors and adjusting production parameters.

Formation of hydrates and asphaltenes can cause issues in oil fields, but they can be resolved through solvent treatment or temperature management.

Temperature difference between injected phases can lead to tubing failures, but adjustments in injection design can prevent such problems. **[17].**

I.4.8 Analytical solutions provided by wag

I.4.8.1 Gravity Effect

The effect of gravity plays a crucial role in the success of WAG (Water-Alternating-Gas) injection for oil recovery. When gas is injected into the reservoir, gravity segregation causes it to move upwards while water moves downwards, limiting the efficiency of the process. However, the efficiency of WAG injection can be improved by optimizing the injection rates based on the spacing between wells. This results in better vertical efficiency and improves oil recovery, which is determined by the viscosity/gravity ratio.

I.4.8.2 Displacement Efficiency And WAG Ratio

To improve the sweeping efficiency of WAG injection, gas must be injected at a rate corresponding to the volume of gas trapped in front of the front by the water bank, which reduces the saturation of residual oil from water injection. Therefore, optimizing the WAG ratio can significantly improve the displacement efficiency.

I.4.8.3 Displacement Of Fronts During WAG Injection

The allocation of water/gas banks and recycling are crucial to tune the injection pattern for specific reservoir conditions during WAG injection. Decreasing the volume of the gas bank injected in cycles alternating with water in the high permeability layer increases the volume of gas trapped in the latter, limiting the amount of separated gas that can enter the upper layer. This improves recovery from the high permeability layer, but it comes at the expense of recovery from the lower permeability top layer.

The formation of the front is determined by viscous and gravitational forces, and the shape of the front depends on the ratio of horizontal and vertical velocities in the cross-section. In the case of segregated flow, the increased gas flow can lead to rapid and premature breakthrough. However, the water injected afterwards can trap all the gas ahead of the front as well as the oil not swept away by the gas.

Overall, the success of WAG injection for oil recovery depends on optimizing the injection rates, WAG ratio, and allocation of water/gas banks to improve displacement efficiency and minimize the negative effects of gravity segregation **[17].**

CONCLUSION

To conclude, the Water Alternating Gas (WAG) injection process is a promising enhanced oil recovery technique that has been successfully applied in several oil fields around the world. The literature review has provided an overview of the key principles, mechanisms, and factors affecting the success of the WAG injection process. However, to fully assess the effectiveness of the WAG injection process, it is necessary to evaluate its performance in specific reservoirs under different operating conditions.

Therefore, the next chapter will focus on the evaluation of the WAG injection process in the Hassi Messaoud field in zone 19. The chapter will provide a detailed analysis of the field's geology, reservoir properties, and operating conditions to assess the performance of the WAG injection process in enhancing oil recovery. This evaluation will provide valuable insights into the practical application of the WAG injection process in a real-world scenario and identify potential areas for optimization. Overall, the evaluation of the WAG injection process in the zone 19 of Hassi Messaoud field will contribute to our understanding of the effectiveness of this technique in enhancing oil recoveryin

CHAPTER II: HASSI MESSAOUD WAG PILOT APPLICATION IN ZONE 19

INTRODUCTION:

Hassi Messaoud field is a significant oil and gas field located in the eastern part of Algeria; it is one of the largest oil fields in the country and has been an important contributor to its oil production. The field was discovered in the 1950s and has played a vital role in the country's energy sector. As it’s shown in chapter one, every reservoir depletes at a certain point, HMD reservoir needed a new technique to extract the maximum amounts of oil contained in the pores. Therefore, the application of WAG (Water Alternating Gas) was crucial to enhance the oil recovery.

This chapter provides the application of WAG technique in zone 19 in HMD field. First, zone 19 of HMD field description, followed by WAG technique application in the zone, and finally discussing the results.

II.1 Description of Zone 19:

a. Zone 19 History:

Zone 19 is a vaporizing gas drive recovery area located in the South central part of the Hassi Messaoud Field. The 11,400 acre (46 MM m²) zone is developed by 33 producers (27 active) and 9 Gas injectors (8 active) as illustrated on the Base Map. The total Zone production averaged 3911 scm/day in 2009 and had produced a total cumulative of 97.7 MM scm of oil at May 2010. Production was 5043 scm/day in May of 2010. Production began in 1960 and gas injection was initiated in 1972. Cumulative Oil Production and Cumulative Gas Injection are exhibited in **Figure 01**. These very quickly illustrate the areas of higher cumulative production and cumulative injection volumes.

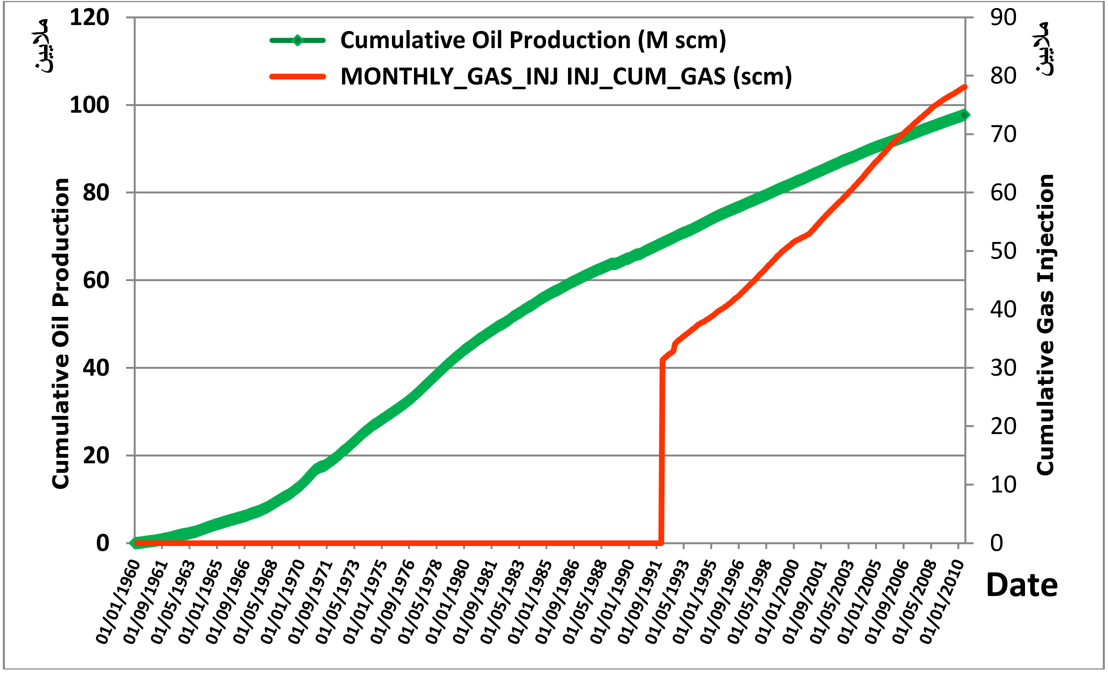


Figure II-1 : Cumulative Oil Production and Gas Injection of Zone 19 vs. Time

B. Geologycal description of zone 19

The D2 is the main pay drain; production above the D3 was so sparse. Below the D2, the D1, ID and ZPG all contribute. The permeabilities, both areally and vertically are much better than in other areas of the Hassi Messaoud Field. The presence of the D4 and D5 drains is negligible as they have been eroded off throughout most of the Zone. The R2 was not included either as it did not appear to be significant in this Zone. The D3 Structure Map

(EXHIBIT 1 in appendix) illustrates the high area around the well MD111 and the eroded areas in the north of the Zone. Effects of erosion are only slight in the D2 and have no effect in the lower drains. The Gross Isopach (EXHIBIT 2 in appendix) from the Discordance to the top of the ID illustrates the thinning to the north in the D2 and D3 drains.

- The permeability distribution had a median of 4.7 md with 5% of the permeabilities greater than 100 md and 5% less than 0.1 md (Courtesy Sonatrach Document).
- The permeability-thickness (KH) map for all drains is shown on EXHIBIT 3 (appendix). This map illustrates the high KH that runs East-West in the center of the zone. This is further confirmed by the production bubble map (EXHIBIT 4 in appendix). There is some good KH in the north where development is less regular. This area could be infilled because it is away from the main gas injection areas. Gas injection, as can be seen on the "Cumulative Gas Injection" bubble map (EXHIBIT 5 in appendix), tends to be adjacent to the E-W high KH area in the center of the Zone. The lower KH running E-W in the very southern part of the Zone is confirmed by lower productivity and injectivity in this area. No fringe developable locations were found in the western area of the Zone; we are bounded by dry wells. The faults shown are usually accompanied by adjacent areas of low permeability which provide barriers to flow and may inhibit the flooding process on the wide spacing employed in HMD. EXHIBIT 6 through 10 (appendix are the KH maps for the D3, D2, ID, D1 and ZPG. All seem to have similar better areas in common.
- Porosity is oriented in a Northeast-Southwest trend and its distribution for all wells was normal with a range from 0 to 15% with a maximum frequency of 7.5%; about 5% of the porosity values were above 11.5% and 5% were below 3% porosity. Thus, the median porosity of all points is about 7.5% (Courtesy Sonatrach Document).
- The porosity-thickness map for all drains is shown on EXHIBIT 11(appendix; the strong NE-SW trend is observable. Porosity-thickness maps for the D3, D2, ID, D1, and ZPG are shown in EXHIBITS 12 through 16 (appendix) (Courtesy Sonatrach Document).

II.2 WAG pilot application in zone 19 of HMD field:

II.2.1 Hmd WAG Project implementation

Later, in 2005, zone 19 at Hassi Messaoud field was chosen for implementation of WAG project in order to reduce the gas injection volume requirement, increase gas sweeping efficiency and improve oil production. Zone 19 has been on production since 1960 and undergoing gasflood since 1973. The current gas-oil-ratio (GOR) is approximately 2500 cubic meters per cubic meters (m^3/m^3), increased from the initial GOR of approximately 220 m^3/m^3 (**Figure 02**):

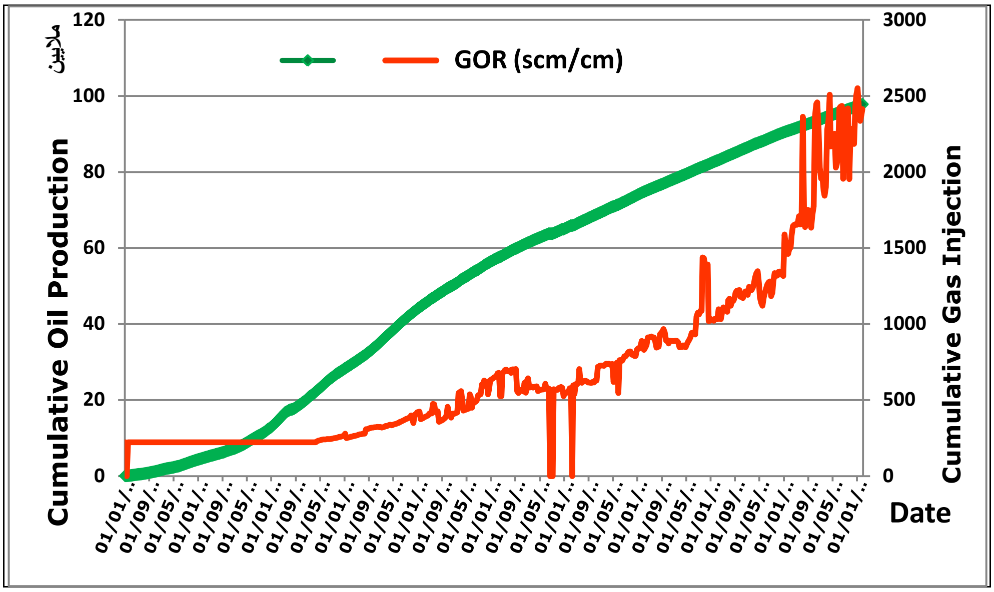


Figure II-2Cumulative Oil Production and Average GOR evolution in Zone 19 vs. Time

II.2.2 Zone 19 production challenges

The production challenges that Sonatrach is fighting in zone 19 are: on the one hand, how to maintain or increase the production oil rate; on the other hand, the limited injection gas local availability. The current daily gas-injection is about 4.7 MM sm^3 in zone 19 with a daily oil production of 3900 sm^3 (Figure 07).

During the year 2000, a simulation study done on Hassi-Messaoud has showed that 10 MM sm^3 could be produced during the forthcoming 8~10 years from the zone 19 by using the current gasflood. However, the gas injection rate needed have to reach 13MM sm^3/d for a GOR equal to 3000 sm^3/sm^3. Thus, this amount of gas is out of the field capacity.

II.2.3 Design of WAG pilot in zone 19:

II.2.3.1 Criteria for selecting WAG injection:

It is recommended that the injector for the WAG pilot program meet the following criteria:

1. Located inside the zone 19 (this rules out the injectors at or near the boundary of zone 19),
2. Acceptable petrophysical properties necessary for reaching desired injectivity (able to inject significant volume of gas at high rate to have desired injectivity),
3. Located away from known faults,
4. Surrounded by sufficient offset producer for capturing response to the WAG injection (for monitoring program purpose),
5. Some remaining oil volume around the injector.

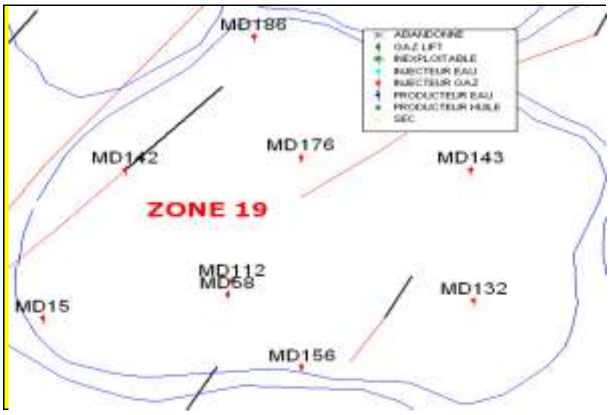


Figure II-3 : Injector Gas Wells situation in Zone 19

II.2.3.2 Recommendation of the MD112 results and discussion

Nine gas injector wells are counted in zone 19: MD112, MD132, MD142, MD143, MD15, MD156, MD176, MD186 and MD58 (Figure 04).

Three wells, MD15, MD156 MD186 were quickly ruled out of consideration because of their situation at the boundary of zone 19 and likewise MD142 because of location near a fault.

Injectors MD112 and MD58 are very close to each other, and hence, only one of them needs to be considered. The MD58 well was stricken off because its injection rate has been lowest among all injectors in zone 19. The injector MD176 was also ruled of because two existing potentially faults to the east and south of this well. For MD132, most of its offset producers, MD11, MD45, MD118, MD193, MD278, MD471, MD526 and MDZ534 have relatively low productivity (Figure 05) and low BHP from the historical production data (Figure 06).

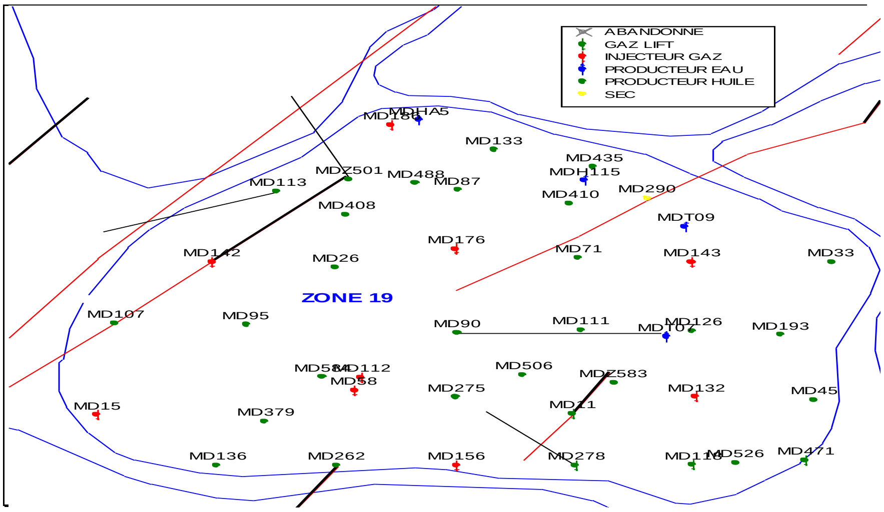


Figure II-4 : ZONE 19 Location Map

From the preceding analysis, it appears that only two injectors in zone 19, MD112 and MD143, might be suitable for the WAG injector for the pilot program. The production data-calibrated reservoir model was then used to finalize the Wag injector selection for the WAG pilot program in zone 19.

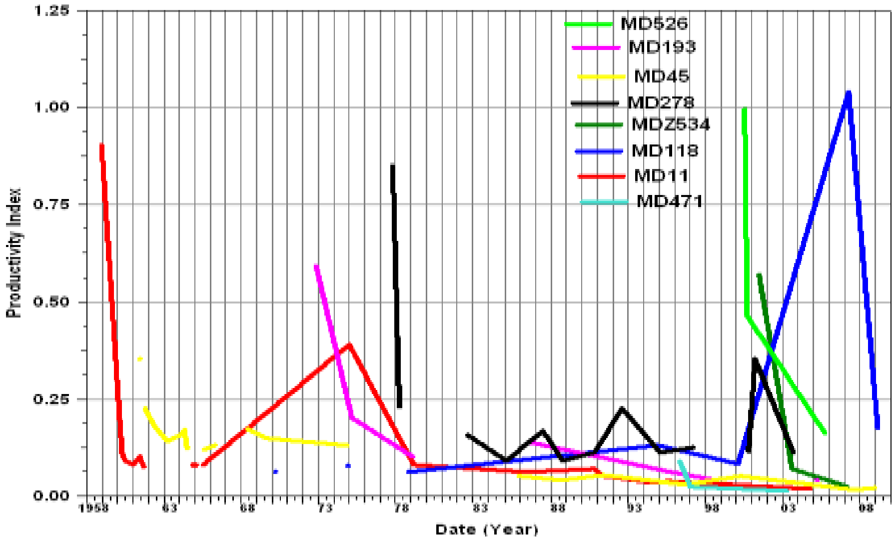


Figure II-5 : Productivity Index of Offset Oil Producer Wells around MD132

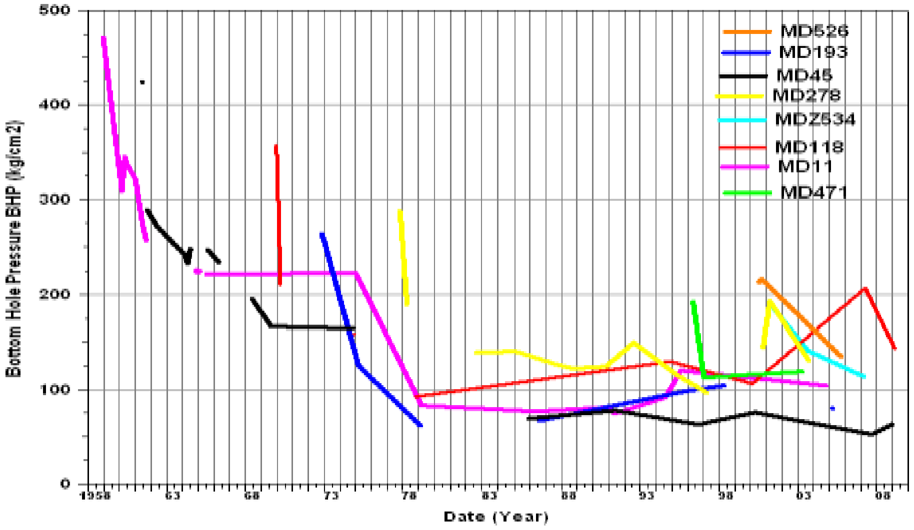


Figure II-6 : BHP of Offset Oil Producer Wells around MD132

Petrophysical properties of rock at the MD112 and MD143 wells, as shown on Table, indicate that the injectivity of the MD112 should be higher than that of the MD143. This has been verified by the historical gas-injection data at these two wells: the MD112 can generally inject approximately 30% more gas than that of MD143 (Figure 12).

table II-1Rock Petrophysical Properties of MD112 and MD143

Drain	Cores Interpretation Results MD112				Cores Interpretation Results MD143			
	Top (m)	**Top (m)**	**K (md)**	**ϕ (%)**	**Top (m)**	**Btm (m)**	**K (md)**	**ϕ (%)**
D5	3318	3329	0.77	1.95	3294	3301	.94	.15
D4	3329	3334	27.18	6.82	3301	3322	2.48	5.22
D3	3334	3348	7.25	6.85	3301	-	-	-
D2	3348	3373	39.77	7.54	3322	3347	8.72	5.32
ID	3373	3404	27.49	8.99	3347	3378	7.36	7.32
D1	3404	3428	35.26	9.65	3378	3401	12.54	7.96
Z-PSG	3428	3434	27.11	10.22	3401	3405	5.28	8.02
R2	3434	3438	2.09	4.79	3405	3425	2.64	8.45

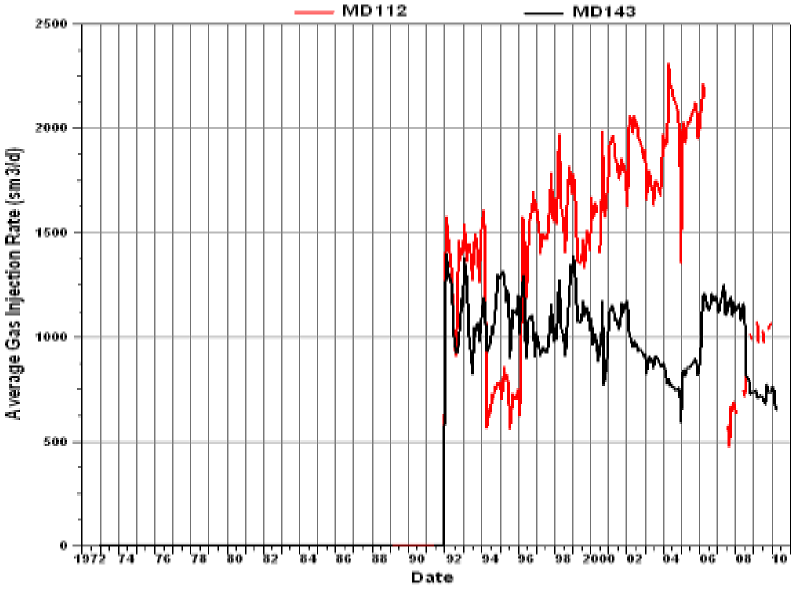


Figure II-7 : Daily Gas Injection Rate of MD112 and MD143

II.2.3.3 Simulation Results and Discussion

Figures 08 through 12 show the model-estimated results of three production scenarios for zone 19: continuous gas injection, WAG injection at MD112 and WAG injection at MD143. It appears that both WAG and continuous gas-injection processes produce similar volume of oil (Figure 09), but the WAG process requires much less gas-injection volume (Figure 11) and produces much less gas (Figure 10). Therefore, for the same volume of oil produced, the WAG process is much more efficient in terms of gas usage. However, the gas process does produce water: the water-production rate might increase as the process continues, depending on the WAG parameters.

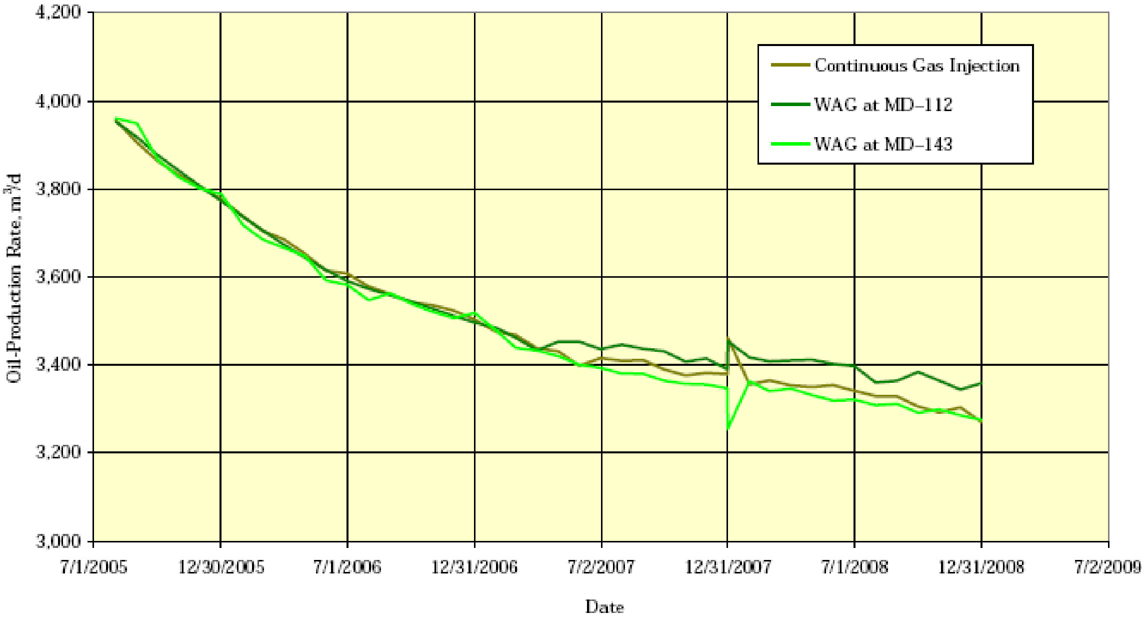


Figure II-8 : Estimated Oil Production Rate

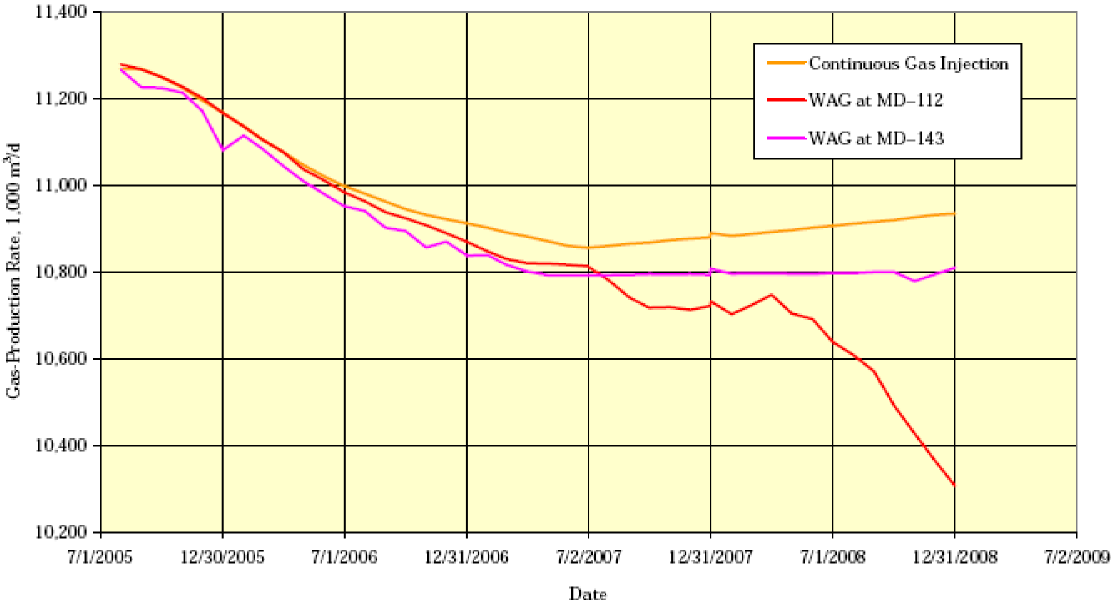


Figure II-9 : Estimated Gas Production Rate

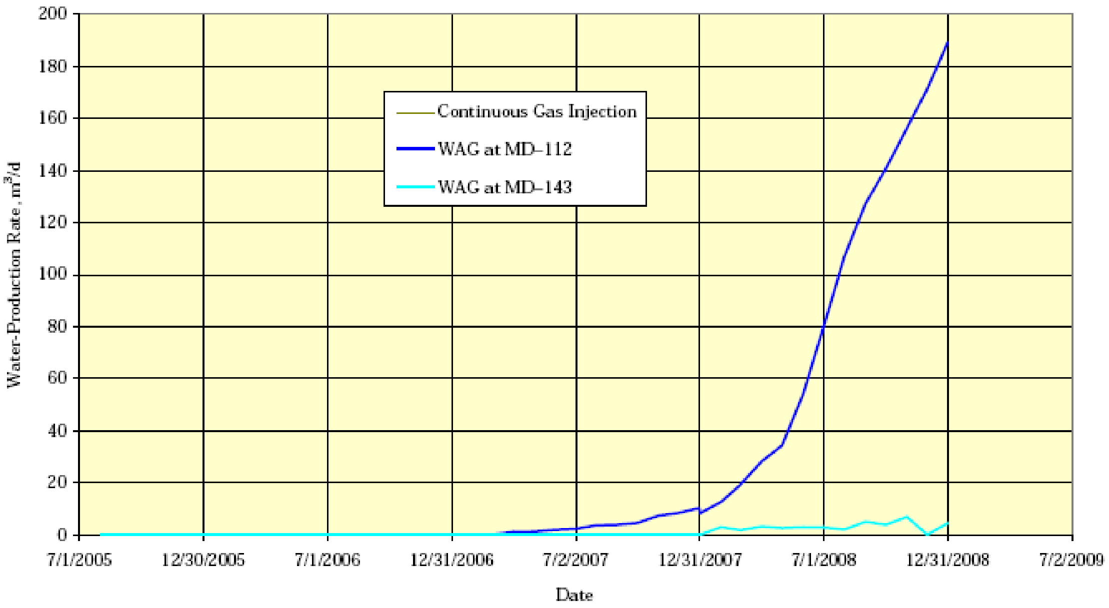


Figure II-10 : Estimated Water Production Rate

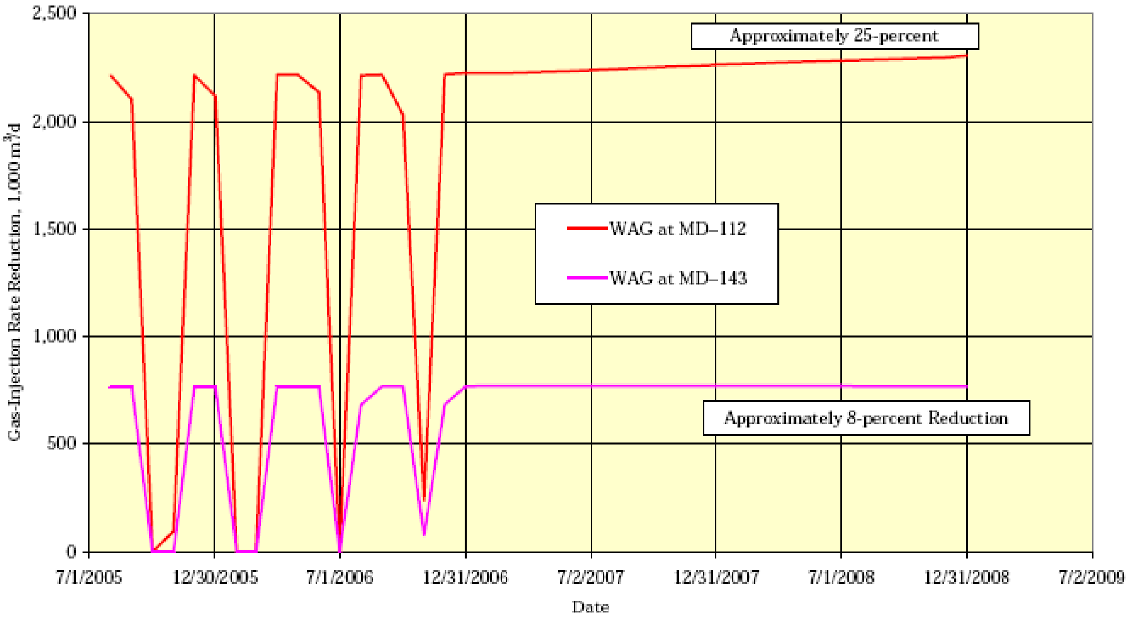


Figure II-11 : Estimated Gas Injection Reduction

Figures 13 through 17 show the oil, gas and water production of WAG and continuous gas-injection processes from wells around Wag injectors. The model estimates that the wells around MD112 show earlier and much more significant response to the WAG injection than those around the MD143. For the pilot program, the earlier response to the WAG process is important for the collection and interpretation of data in a timely fashion.

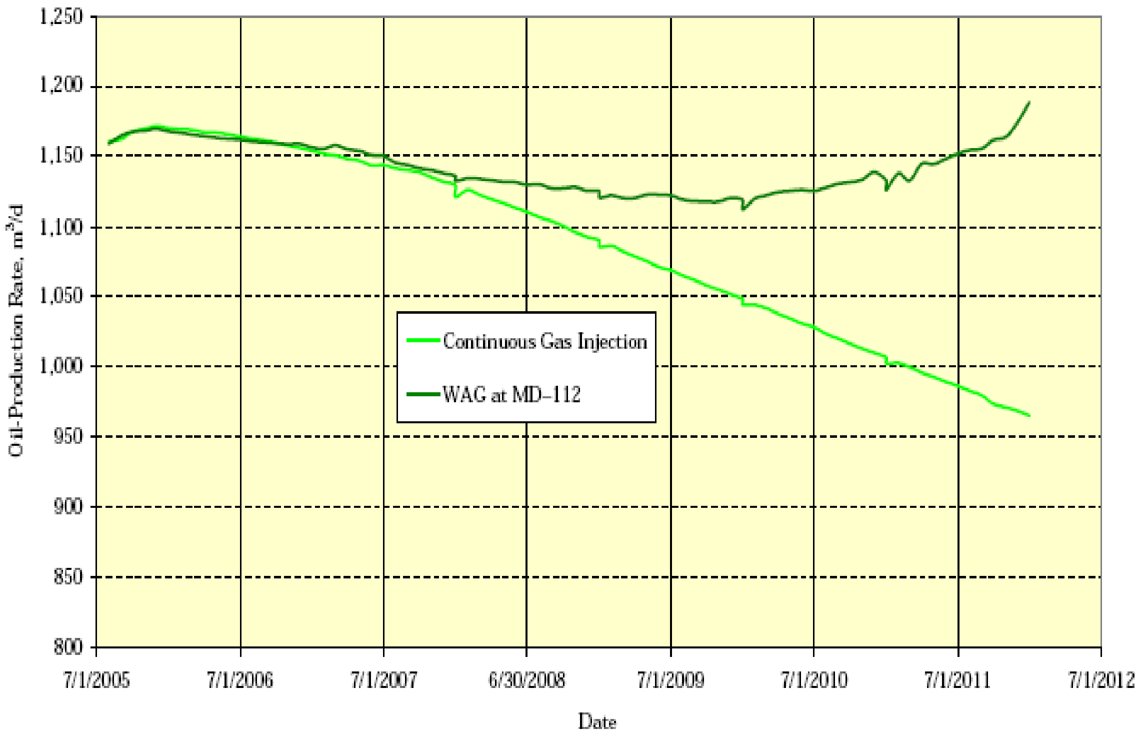


Figure II-12 : Oil Production rate for Offset Producer Wells around MD112

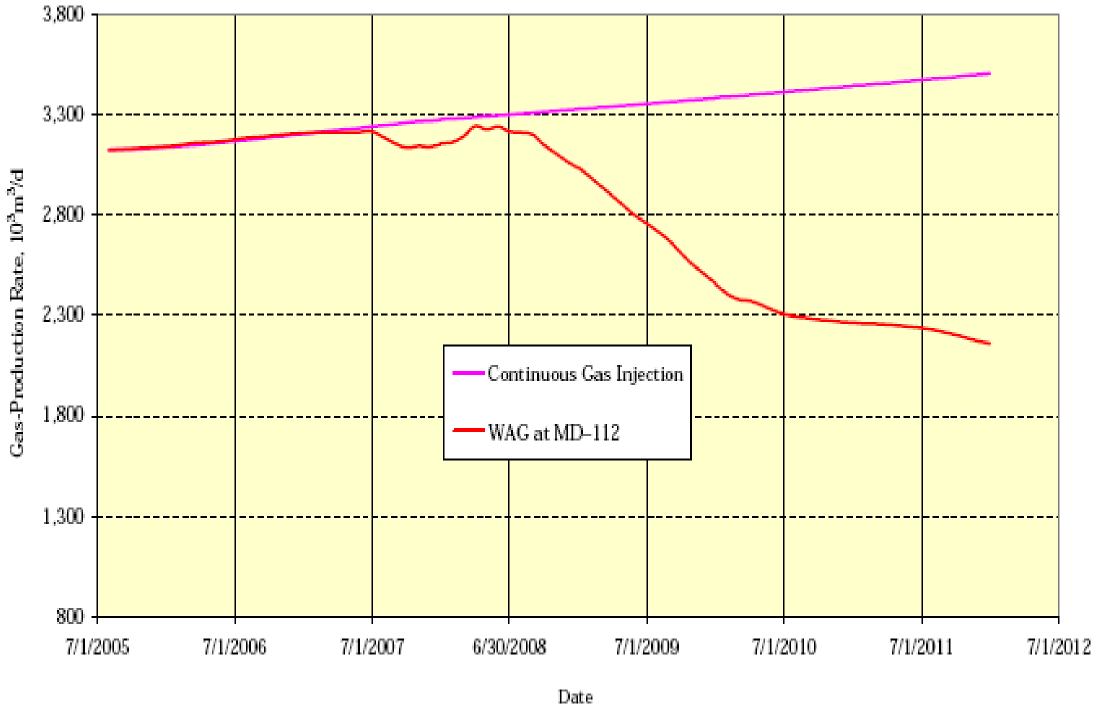


Figure II-13 : Gas Production rate for Offset Producer Wells around MD112

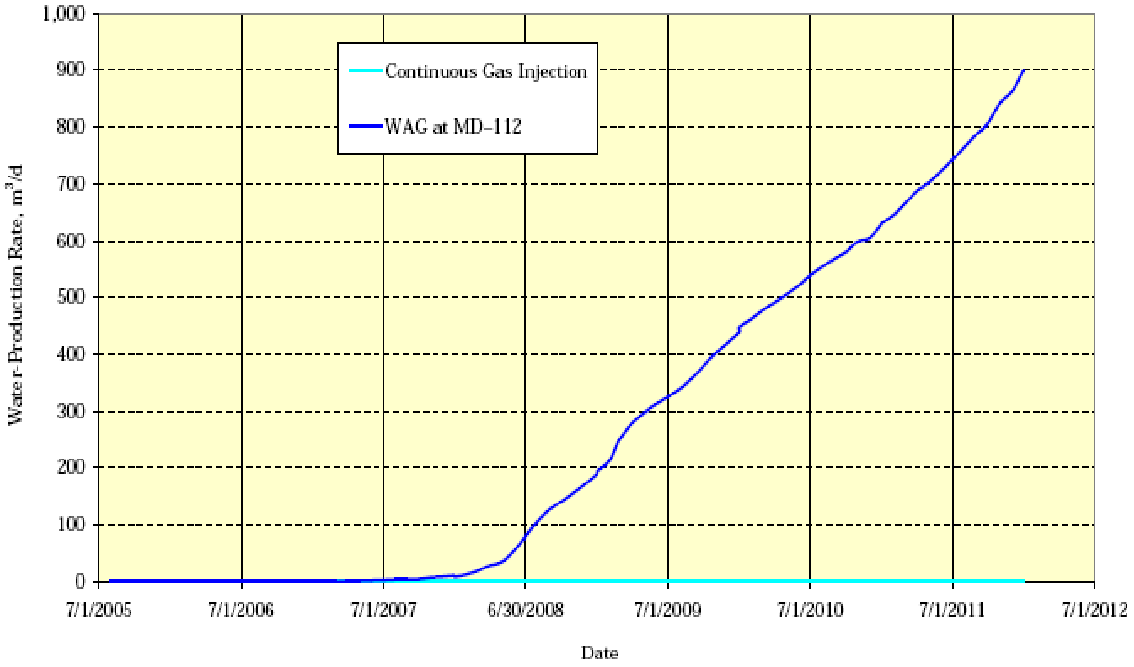


Figure II-14 : Water Production rate for Offset Producer Wells around MD112

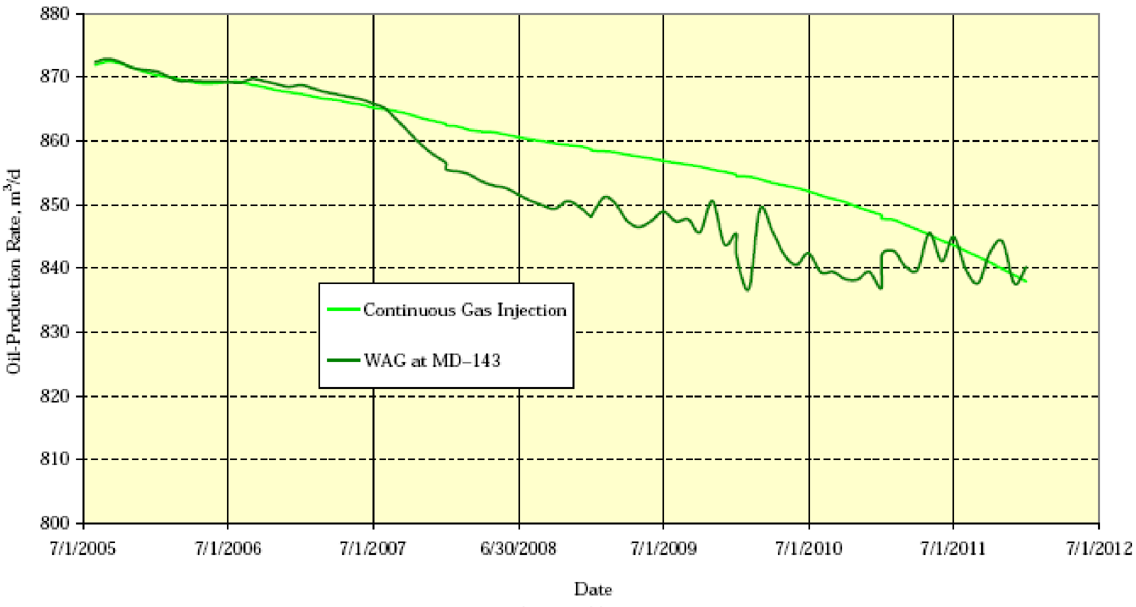


Figure II-15 : Oil Production rate for Offset Producer Wells around MD143

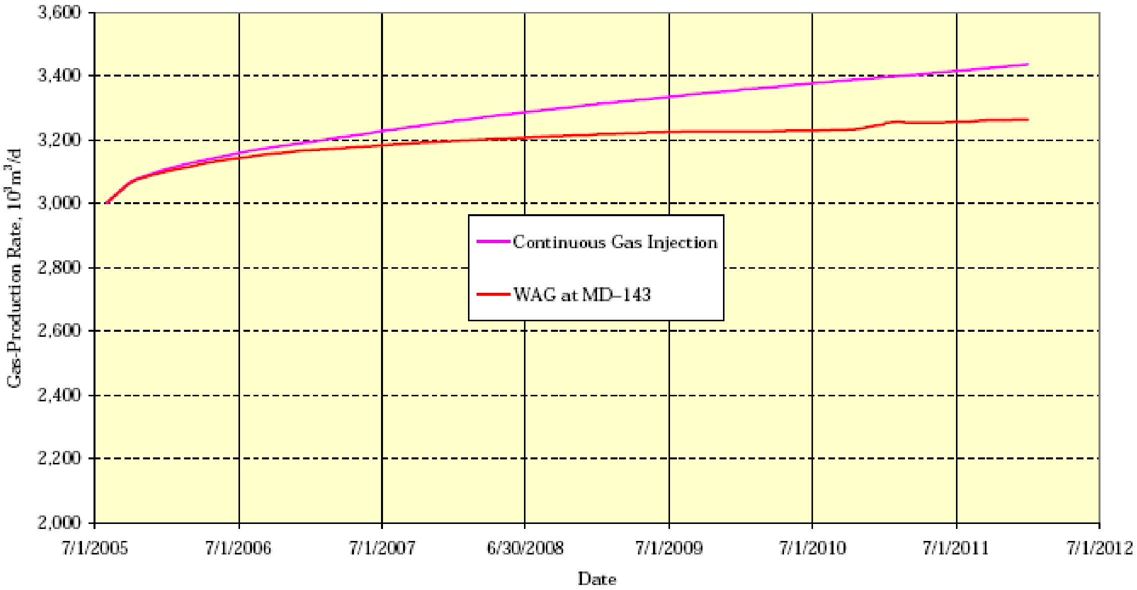


Figure II-16 : Gas Production rate for Offset Producer Wells around MD143

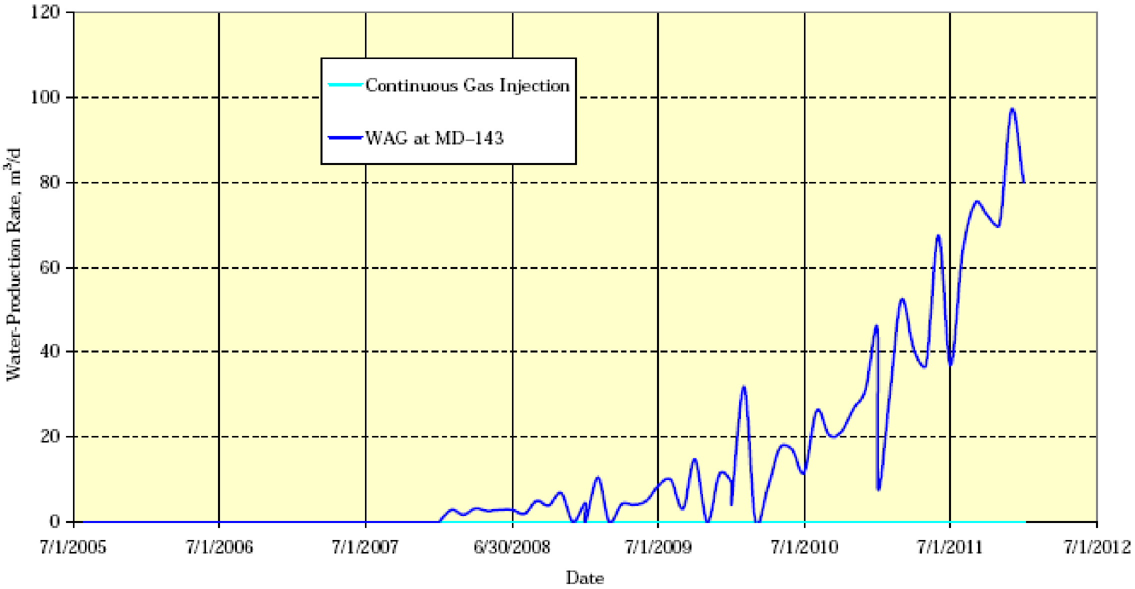


Figure II-17 : Water Production rate for Offset Producer Wells around MD143

II.3 WAG pilot area:

II.3.1 Construction of fine-grid model for md112 well area:

A model with a geologically refined area around MD112 (Figure 18) was used to finalise the design of WAG pilot parameters, location of an observation well and program for monitoring the WAG pilot progress. The dimension of the fine-grid model is 48 by 40 by 60 with a cell size of approximately 60 by 60 by 3 meters. This cell is about one-eighth of the cell size of the original simulation model.

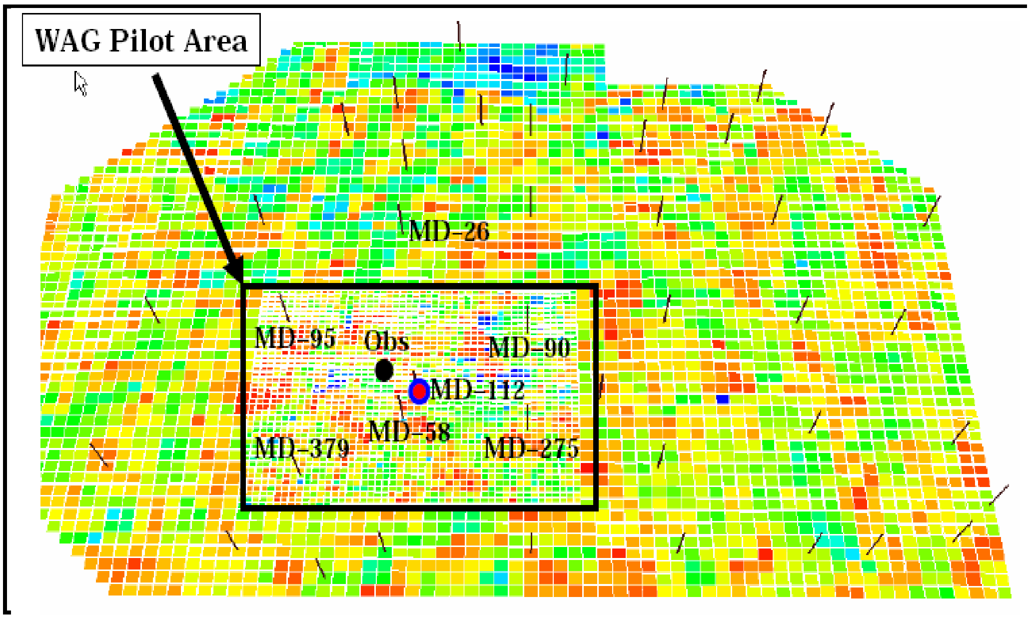


Figure II-18 : Fine-Grid Model around MD112 Well

II.3.2 Observation well concept:

The objective of the observation well are to quickly monitor the reservoir response to the WAG process at the observation well to ensure the success of the WAG pilot program (Figure 19). The response might include:

- Timing of water breakthrough
- Fluid saturation profile change with time
- Remaining oil saturation to WAG process (to waterflood in lower drains and gasflood in upper drains)
- Water slumping because of gravity if injection only occurs in the Ra sand
- Data from the pilot needed quickly to be collected and interpreted

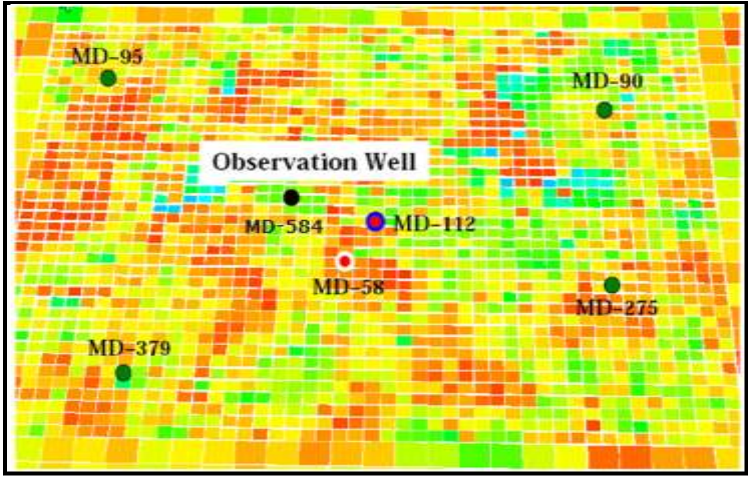


Figure II-19 : Observation Well Location

Subsequently, an observation well MD584 was drilled later in November 2005 at 400m northwest of MD112. This well is used for quickly collecting pilot data and well monitoring project promotion.

II.4 WAG pilot injection rates and timing:

To start the WAG injection, water is recommended to be injected first. The water injection rate is expected to be around 3500 m^3/d. Injection should convert to gas at a rate similar to the current gas-injection rate of approximately 2.2 MM m^3/d. When the water breaks through at the observation well or the water injection continues for 60 days, whichever comes at the beginning. Therefore, two months injection period for each fluid is recommended for the first two WAG cycles (Table 02).

After the first two WAG injection cycles, the time length for water increases (Figure 20), which leads to a gradual increase in WAG ratio.

table II-2 :Schedule of WAG Injection Cycles

WAG Cycle	Water Injection		Duration (days)	Gas Injection		Duration (days)
	Start day	End day		Start day	End day	
1	01-Jul-2005	31-Aug-2005	61	31-Aug-2005	31-Oct-2005	61
2	31-Oct-2005	31-Dec-2005	61	31-Dec-2005	01-Mar-2006	60
3	01-Mar-2006	30-May-2006	90	30-May-2006	30-Jun-2006	31
4	30-Jun-2006	29-Sep-2006	91	29-Sep-2006	28-Oct-2006	29

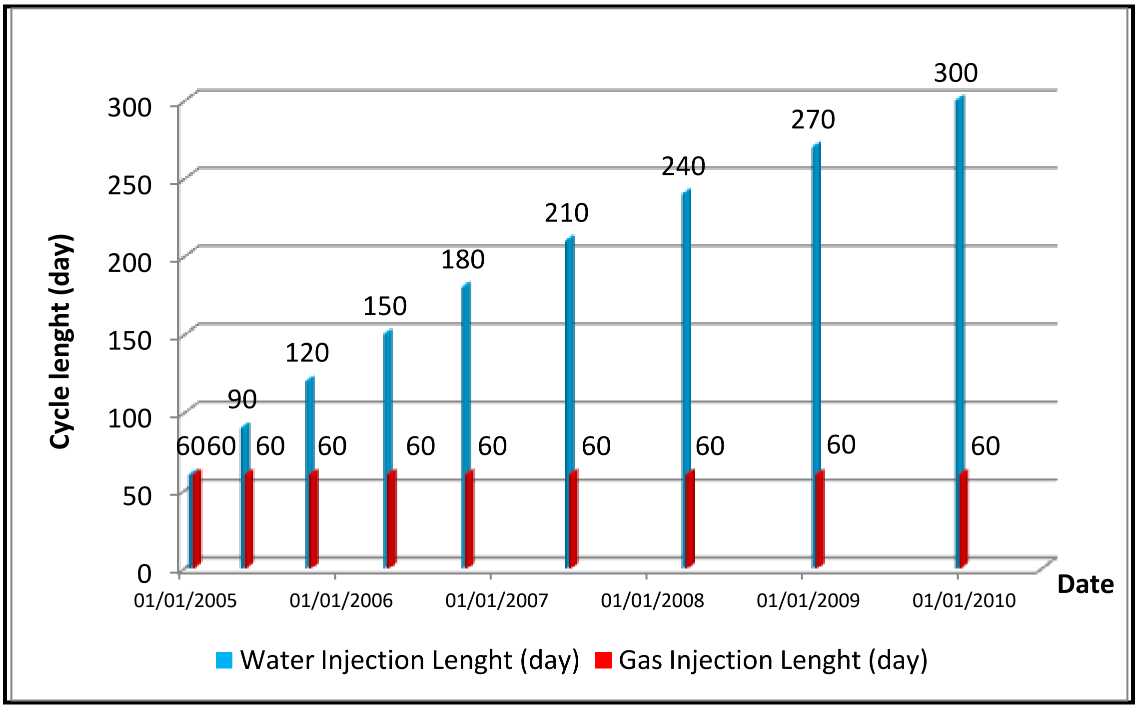
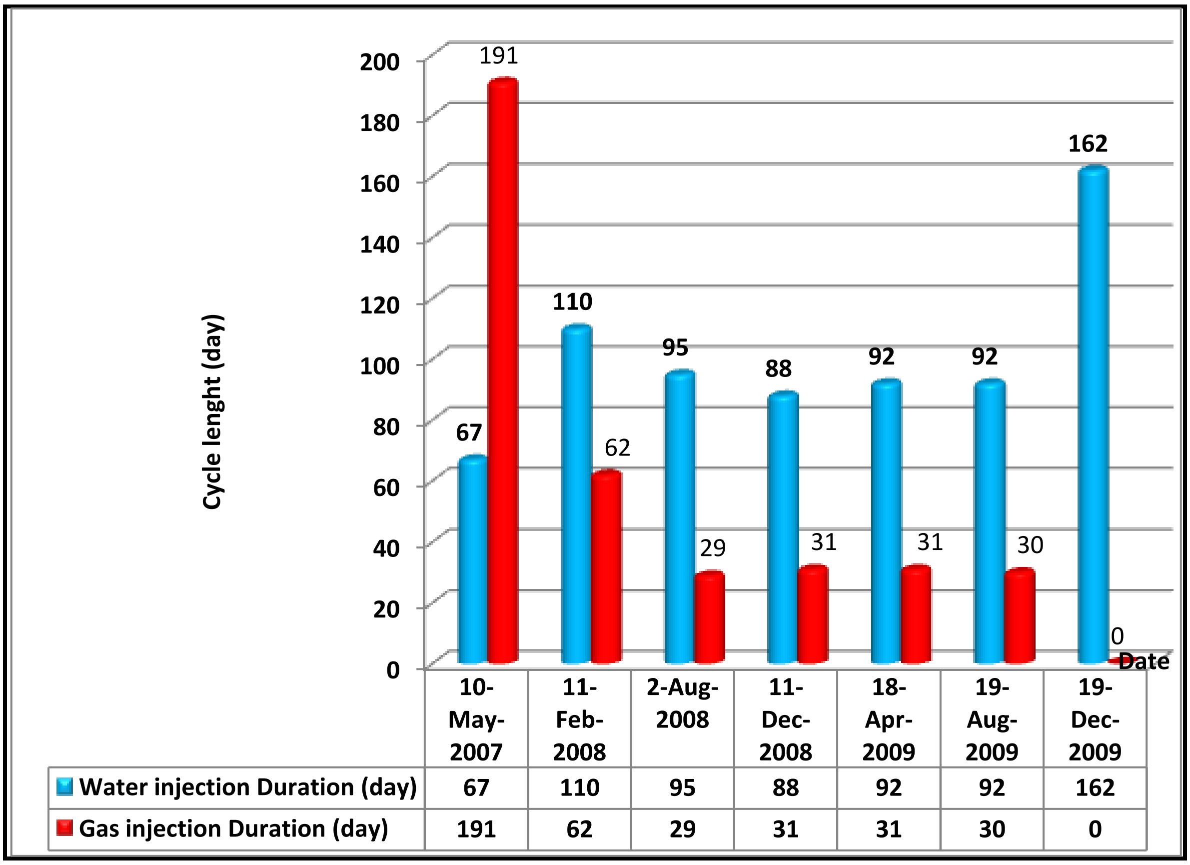


Figure II-20 : Schedule of WAG Injection Cycles

Unfortunately, the schedule implementation of starting WAG pilot injection was not respected due to operation constraints such as the drilling delay of the observation well MD584 (November 2005) and the workover intervention (December 2006) done on MD112 itself for recompletion with a cemented perforated liner instead of slotted liner. The table 03 below shows the ongoing WAG injection progress:

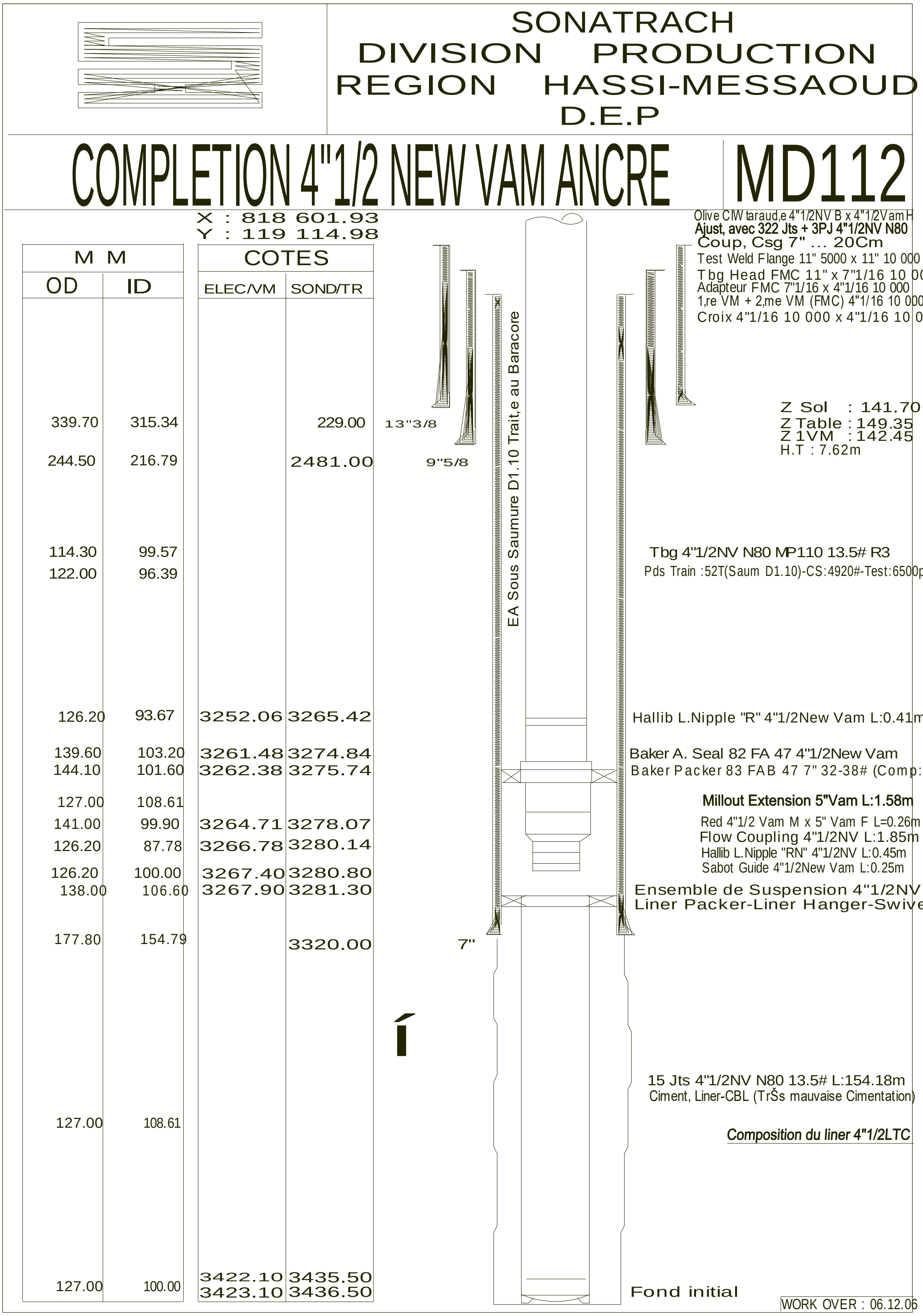
table II-3: Timing of WAG Injection Progress

WAG Cycle	**Water injection**			**Gas injection**		
	Start day	**End day**	**Duration**	**Start day**	**End day**	**Duration**
1st	10/05/2007	16/07/2007	67	02/08/2007	09/02/2008	191
2nd	11/02/2008	31/05/2008	110	01/06/2008	02/08/2008	62
3rd	02/08/2008	05/11/2008	95	05/11/2008	04/12/2008	29
4th	11/12/2008	09/03/2009	88	16/03/2009	16/04/2009	31
5th	18/04/2009	19/07/2009	92	19/07/2009	19/08/2009	31
6th	19/08/2009	19/11/2009	92	19/11/2009	19/12/2009	30
7th	19/12/2009	30/05/2010	162	30/05/2010	In progress	-



	10-May-2007	11-Feb-2008	2-Aug-2008	11-Dec-2008	18-Apr-2009	19-Aug-2009	19-Dec-2009
🟦 Water injection Duration (day)	67	110	95	88	92	92	162
🟥 Gas injection Duration (day)	191	62	29	31	31	30	0

Figure II-21 : Timing of WAG Injection Progress



M M		COTES	
OD	ID	ELEC/VM	SOND/TR
339.70	315.34		229.00
244.50	216.79		2481.00
114.30	99.57		
122.00	96.39		
126.20	93.67	3252.06	3265.42
139.60	103.20	3261.48	3274.84
144.10	101.60	3262.38	3275.74
127.00	108.61		
141.00	99.90	3264.71	3278.07
126.20	87.78	3266.78	3280.14
126.20	100.00	3267.40	3280.80
138.00	106.60	3267.90	3281.30
177.80	154.79		3320.00
127.00	108.61		
127.00	100.00	3422.10 3423.10	3435.50 3436.50

Figure II-22 : MD112 Technical Sketch

II.4.1 Water injection Cycles

WAG injection in its water phase began on 09/05/2007 with an average flow of 2670 m3/d. In the first cycle, we were able to reach the flow rate predicted by the simulation (3000 m3/d). From the third cycle, a decrease in water injectivity was observed compared to the first two cycles.

To increase the injection of water, acidification operations were carried out as the injection was reduced. The cumulative water injection at the end of the seventh cycle is: 1,207,001 m3.

The table 04 summarizes the cumulative water injected and the average daily water rates during the seven accomplished water cycles.

table II-4Water Injection Rates and cumulative Volumes

Cycle	Start day	End day	Average injected rate (m^3/d)	Injected Volume (m^3)
1st	10/05/2007	16/07/2007	2670	171 093
2nd	11/02/2008	31/05/2008	2107	186 994
3rd	02/08/2008	05/11/2008	1549	128 994
4th	11/12/2008	09/03/2009	1829	160 956
5th	18/04/2009	19/07/2009	1640	150 927
6th	19/08/2009	19/11/2009	2200	162 836
7th	19/12/2009	30/05/2010	1471	216 466
			Total	1 178 266

II.4.2 Gas injection Cycles

Gas injection began on 02/08/2007, or 15 days after the first phase of water injection. During this shutdown period, various operations (scraping, clean tube, nitrogen cleaning, and neutralization of a casing leak) took place in the MD112 well.

The average flow rate at the start of the gas injection phase was 622,103 m3/d. during the seven WAG injection cycles the average flow rate of the gas injected was between 800 - 1000 103 m3/d.

The cumulative gas injected and the average daily gas rates during the seven gas cycles are recapitulated in table 05.

table II-5 : Gas Injection Rates and cumulative Volume

Cycle	Start day	End day	Average injected rate (M m^3/d)	Injected Volume (M m^3)
1st	02/08/2007	09/02/2008	623	116 920
2nd	01/06/2008	02/08/2008	731	45 287
3rd	05/11/2008	04/12/2008	939	28 180
4th	16/03/2009	16/04/2009	1 021	31 651
5th	19/07/2009	19/08/2009	986	30 569
6th	19/11/2009	19/12/2009	1 020	31 639
7th	30/05/2010	In progress	-	-
			Total	**284 246**

II.5 The pilot program monitoring:

II.5.1 Monitoring program summary:

During the first cycle of the WAG pilot, several measurements are recommended to be made to help improve the knowledge of the WAG process behaviour in zone 19. Table 09 shows the recommended timeline for measurements of Production Logging Tool (PLT) and Reservoir Saturation Tool (RST). The WAG parameters for the subsequent WAG cycles need to be determined from the detailed reservoir simulations based on the history match the first WAG cycle data. If the gravity segregation of gas and water is not observed at observation well during the first WAG cycle, the injection rate might need to be reduced. It is important for the pilot program to capture the gravity effect to calibrate the simulation model.

table II-6 : Monitoring Program Summary

	MD584	**MD112**	**MD90 & MD58**	**Producers 6 Wells**
Baseline	XPT MDT Resistivity Log PLT DH Pressure Gauge	Surface Pressure Injection rate DH Pressure Gauge PLT		Vx every 2 Weeks PLT
Water Injection Phase (2 months)	Vx every 2 Weeks PLT Resistivity Log when water Breakthrough	Surface Pressure Injection rate DH Pressure Gauge PLT	Vx every 2 Weeks PLT when water Breakthrough	Vx every 2 Weeks PLT when water Breakthrough
Gas Injection Phase (2 months)	Vx every 2 Weeks PLT Resistivity Log when water Breakthrough	PLT for water invasion Surface Pressure Injection rate DH Pressure Gauge PLT		Vx every 2 Weeks PLT when water Breakthrough
Rest of WAG (12 months)	Vx once a month PLT Resistivity Log when water Breakthrough	Surface Pressure Injection rate DH Pressure Gauge	Vx once a month PLT when water Breakthrough	Vx once a month PLT when water Breakthrough
End of WAG	Resistivity Log PLT	PLT		PLT

II.5.2 Evaluation of miscible wag pilot:

The observatory well MD584 was drilled in November 2005 in order to evaluate the impact of WAG injection from MD112. As illustrated in Figure 29, the production data gathered form MD584 has shown a considerable increase of oil rate **~50%** (4 to 6 scm/h) between 2007 and 2010. However, the GOR has recognised a considerable decrease from **~2500 scm/cm** to **~1200 scm/cm**. The reservoir pressure has still maintained stable around **260 kg/cm^2**.

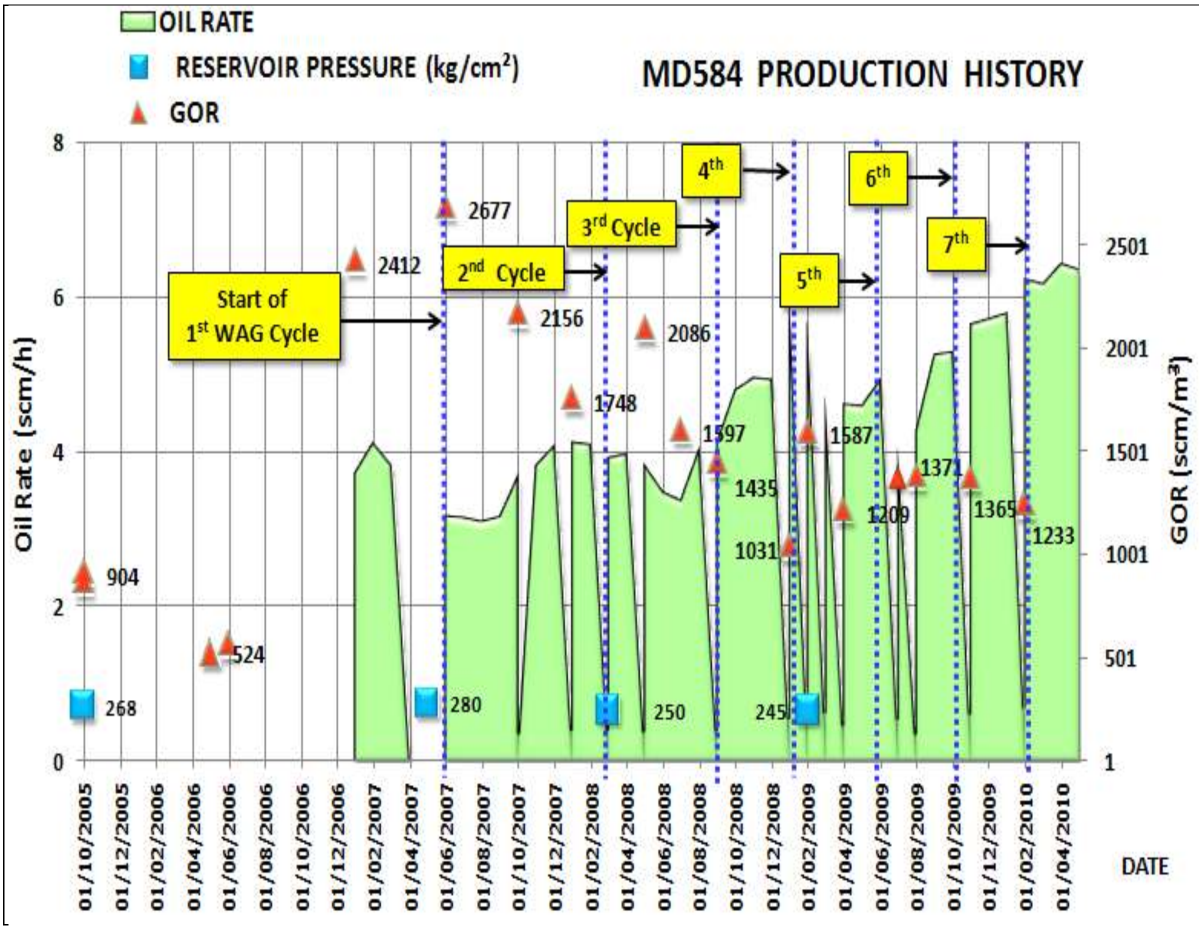


Figure II-23 : MD584 Evolution of Oil Rate Production, GOR and Reservoir Pressure with WAG cycles vs. Time.

In addition, several logging measurements were recorded on MD584 in order to evaluate the oil and gas contributions of each layer and the impact of WAG injection from MD112. The table 07 summarizes the results of PLTs' interpretation:

table II-7 : Interpretation Results of MD584 PLTs'

OPERATION TYPE	DATE	Oil Rate (scm/h)	Gas Rate (scm/h)	Water Rate (scm/h)
PSP/GHOST/DEFT	07/06/2006	5.4	4 000	0.04
PSP/GHOST/DEFT	17/01/2007	3.77	11 538	0.03
PSP/GHOST	19/01/2008	3.60	6 594	0
PSP/GHOST	31/05/2008	3.50	7 000	0

II.6 Results of WAG Pilot Program

As it is exhibited in Figure 24, six WAG cycles have been completed, whereas the seventh cycle is underway injection (7th gas cycle started on May 30, 2010).

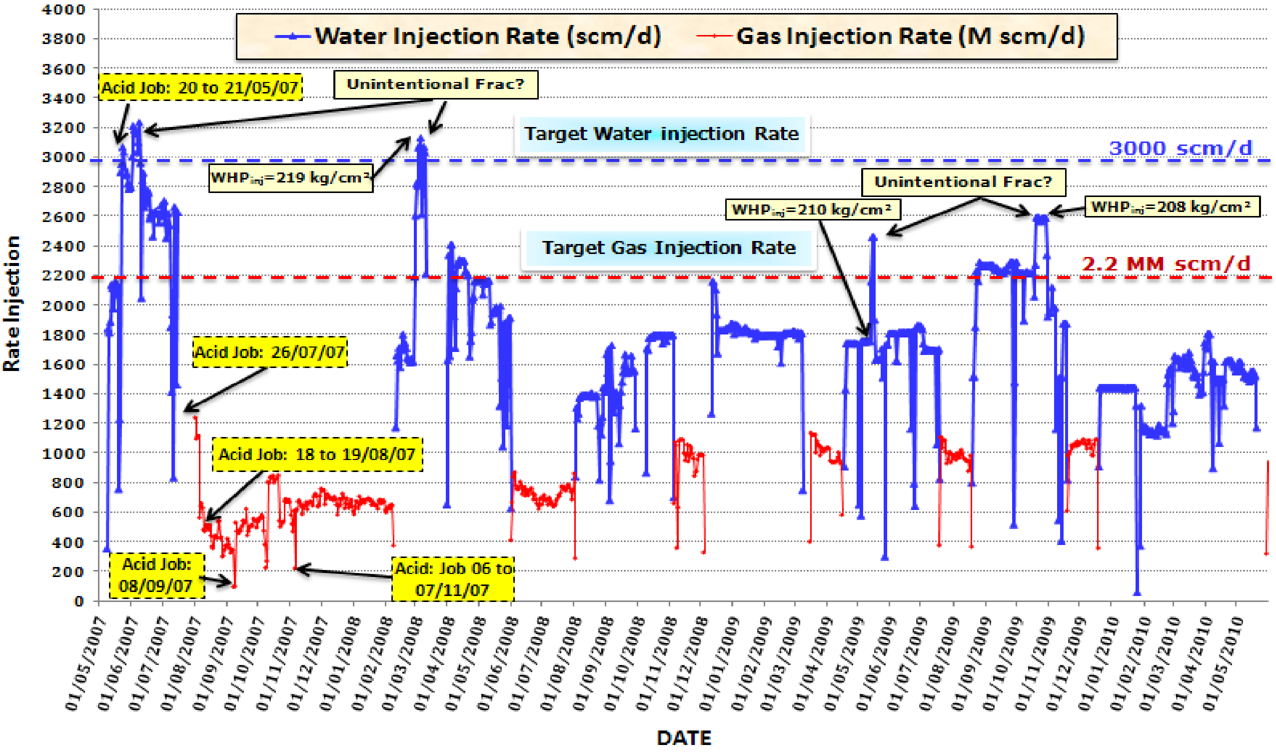


Figure II-24 : Water and Gas Injection Rates in MD112 vs. Time

The injection behavior of the pilot test is significantly different of what was predicted by the simulation model. The daily volumes of gas and water injected in MD 112 are significantly below their targets (2.2 MM scm/d for gas and 3000 scm/d for Water). Thus, as shown in Table 08, gas and water injections are 66% and 40%, respectively under-predicted injection plan. In fact, it is partially due to the fact that MD112 injectivity for both water and gas is lower than simulated, i.e., the injection rates are unable to reach their desired rates without exceeding the **fracturing pressure** estimated to **530 kg/cm²** for MD112.

table II-8 : WAG Injection Deviations

	Average Gas Inj (M scm/d)	**Average Water Inj (scm/d)**
WAG injection	747	1799
Simulation Plan	2200	3000
Deviation (%)	**66**	**40**

Furthermore, several reasons can stay behind this injections gaps including:

- Inaccuracy set of relative permeability curves used in the model,
- Changes in relative permeabilities due to three-phase flow, wettability dynamically changing, and precipitates (salts, asphaltenes) formed in the near well zone.
- However, reduction of gas injectivity could be also due to the fact that injected water is saturating the most permeable zones. As a consequence, gas flood may be diverted towards less permeable zones.

In return, and regarding the positive face of WAG implementation in Hassi-Messaoud field where the reduction of gasflood volume is among the primary objectives. Thus, Figure 25 illustrates the reduction of gas injection in Zone 19. By comparing the monthly gas injection between April 2007 (219 MM scm) and May 2010 (140 MM scm), which represent a gap of 56%, meanwhile the monthly oil productions are ~115 M scm and 121 M scm, respectively.

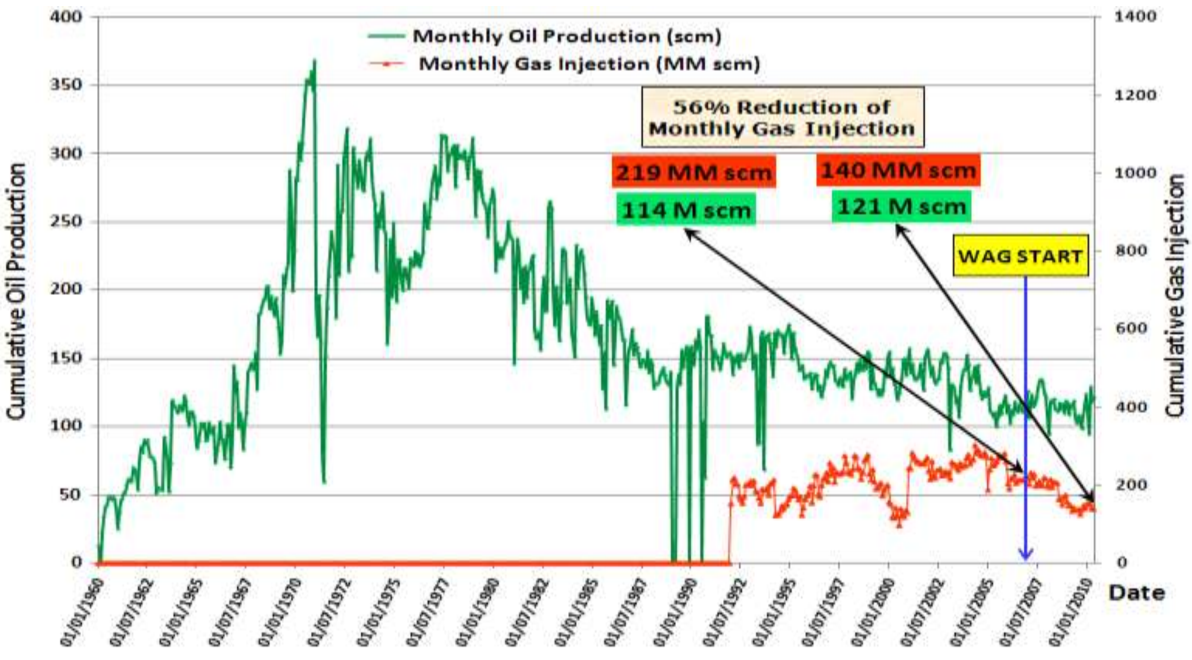


Figure II-25 : Cumulative Gas Injection and Oil Production of Zone 19

The Figure 26 shows the evolution of cumulative oil contribution and the wells count in zone 19 with time. The last well drilled in zone 19 was MD584 (WAG observation well) which has only a monthly contribution ~3100 scm.

Then, aside the MD584 there was no gain of production through new drilled wells after starting the WAG injection in zone 19.

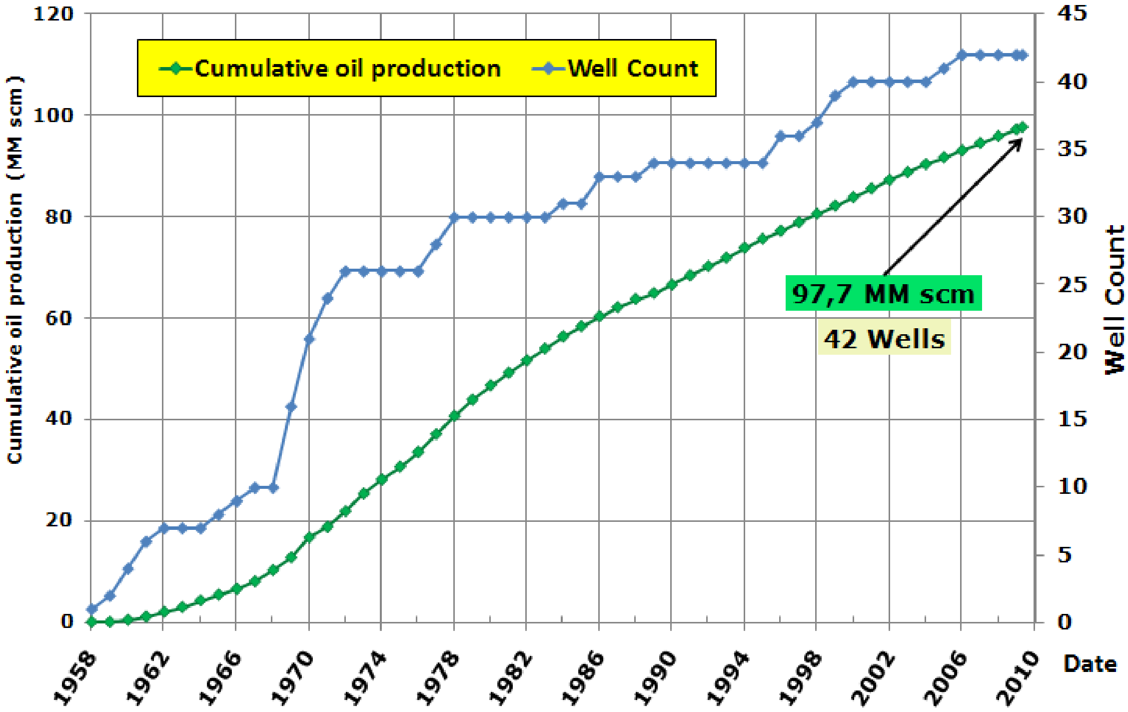


Figure II-26 : Cumulative Oil production & Well Count in Zone 19 vs. Time

II.7 Impact of wag pilot on the observation wells area:

The below Figure 27 exhibits the production rate behavior of offset wells surrounding the WAG pilot MD112. For gasflood consequence of MD112 and MD58, the production rate of this area was increasing considerably till January 1994 where reached its highest daily rate of 1643 scm/d. However, since this date, the oil production did not stop declining till 1999. Furthermore, in December 2005 the oil production rate dropped to its lowest value 316 scm/d.

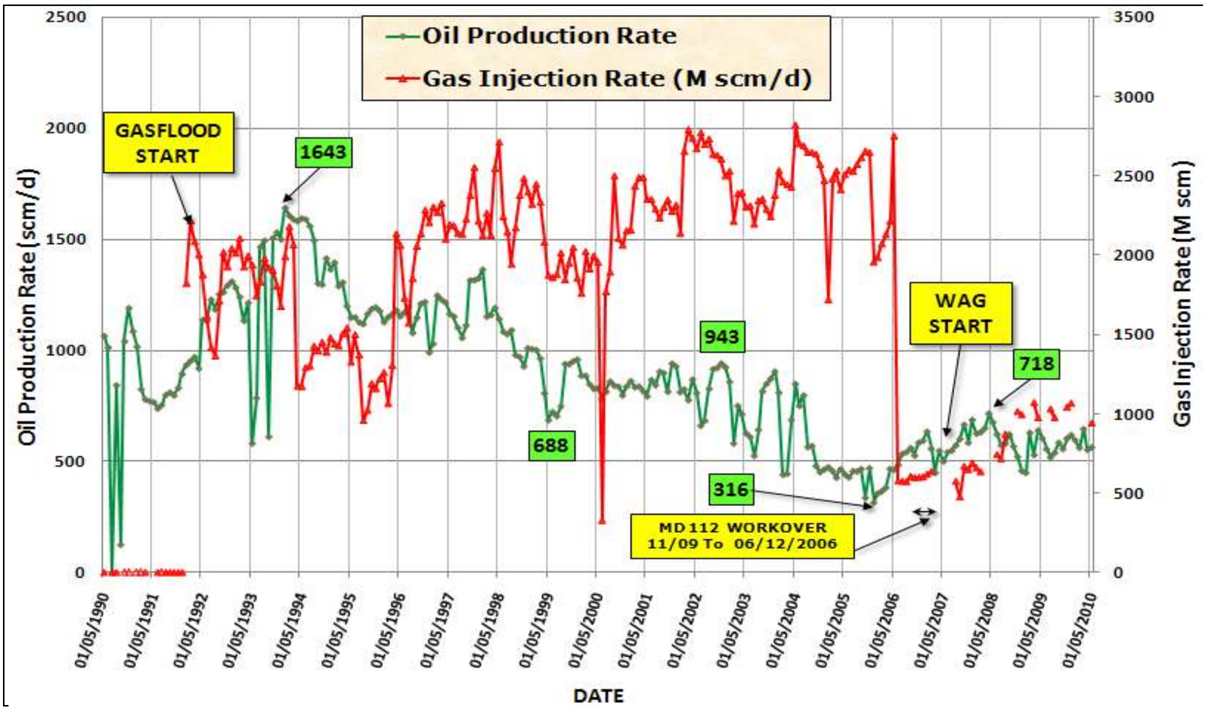


Figure II-27 : Offset MD112 Oil production Rate before WAG starting vs. Time

In addition, the Figure 28 highlights the performance of these wells within this area. In fact, The GOR was increasing since 1992 while the oil production rate was increasing too due to modest breakthrough (indirect gas-lift), whereas the GOR carried on rising while the oil production rate was significantly decreasing owing to gas breakthrough. Therefore, the current average GOR of this area is about 4700 scm/scm with oil production rate ~580scm/d.

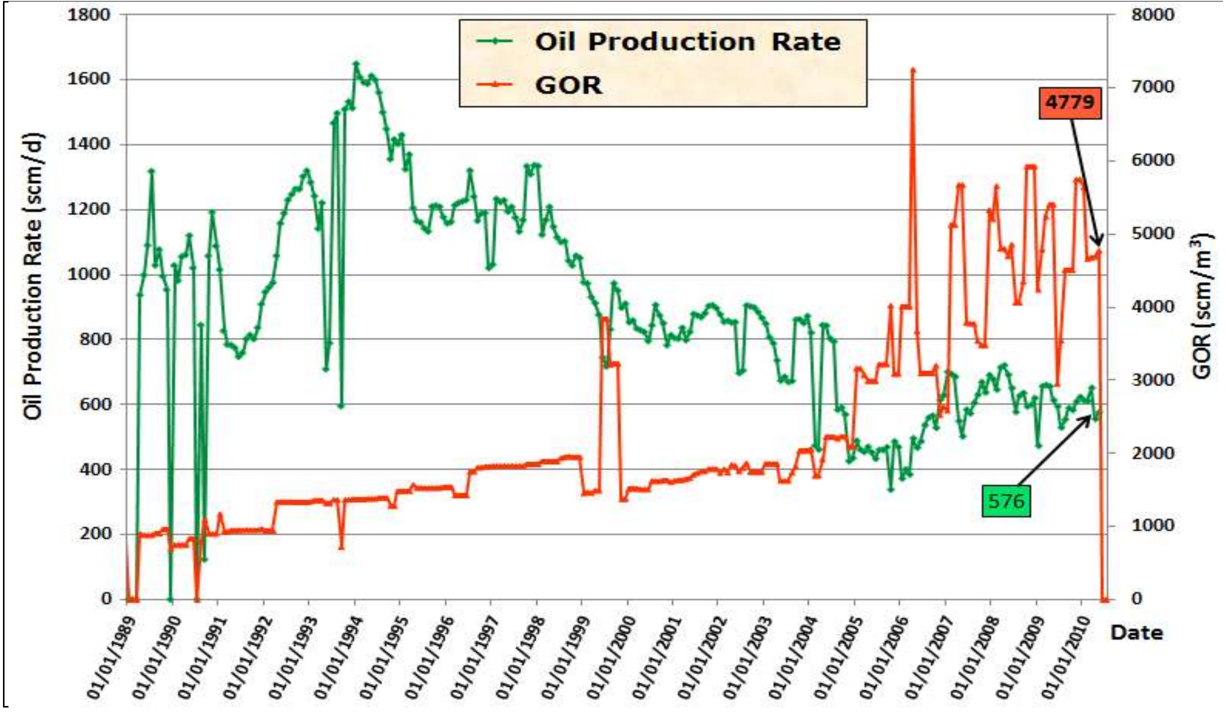


Figure II-28 : Oil Production Rate and GOR evolution of Offset MD112 Producing Wells vs. Time

The figure 27 illustrates the impact of the well MD112 as gas-injector and the same well as WAG injector on the offset wells observation area. Before WAG starting, the gas-injection rate was more than 2.6 MM scm/d with oil production rate sinking from 940 scm/d to 316 scm/d between 2002 and 2006, respectively. However, this considerable leak of oil production rate was referred to closing the well MD379 (~120 scm/d) between October 2004 and April 2006, and afterwards the production start increasing at the beginning of WAG injection in MD112. However, the reason of that oil production is due to the contribution of the new drilling well MD584 (~100 scm/d).

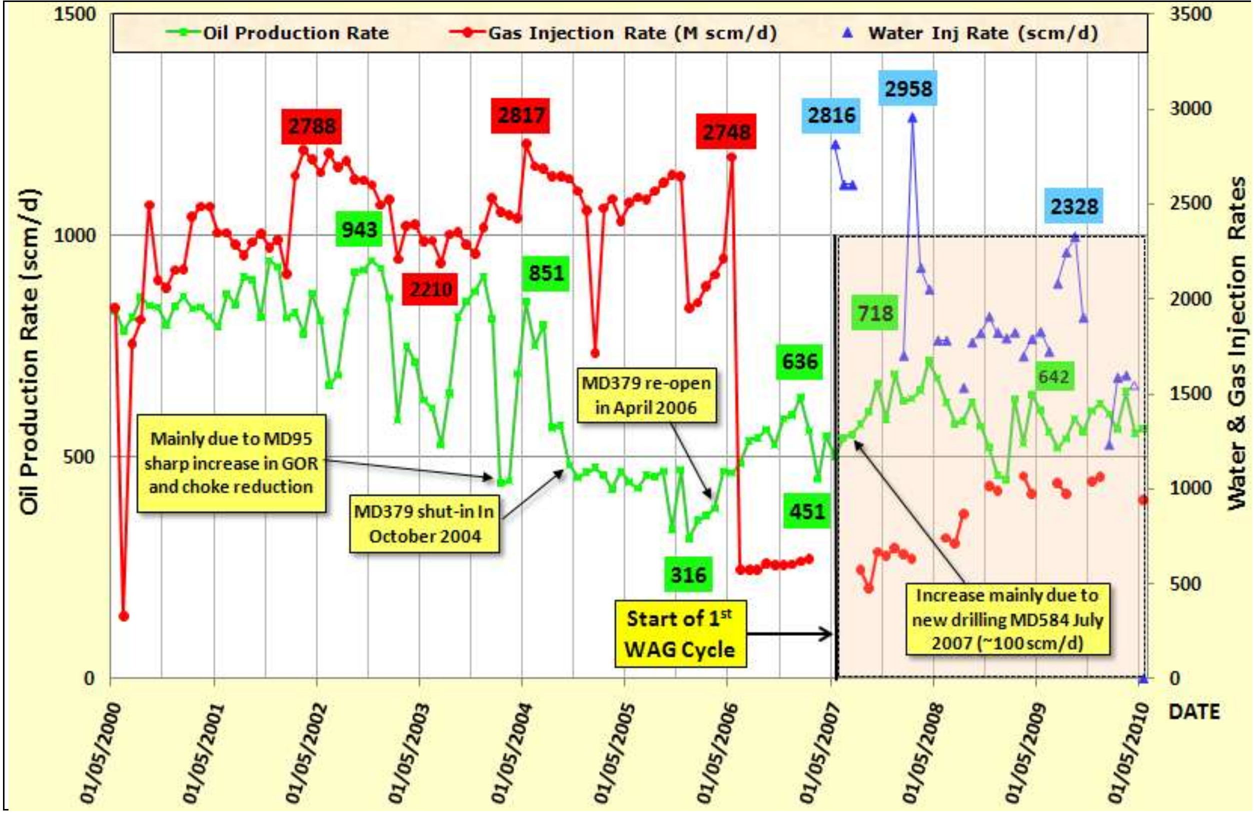


Figure II-29 : Oil Production Rate of Offset Wells surrounding MD112 vs. Time

In addition, the reservoir pressure behaviour is highlighted in Figure 27 which shows the sharply falling period of pressure between 1968 and 1974 from virgin pressure ~370 kg/cm² to ~260 kg/cm². This decline trend could be related to lack of injection support and the wild exploitation of the field by choke-less production, i.e. producing without carrying about reservoir interests. For this purpose, gas injection started by converting the two oil producer wells MD58 and MD112 into gas injectors in January and March of the year 1973, respectively. Since, the reservoir pressure was maintained at the majority of the wells at ~250 kg/m².

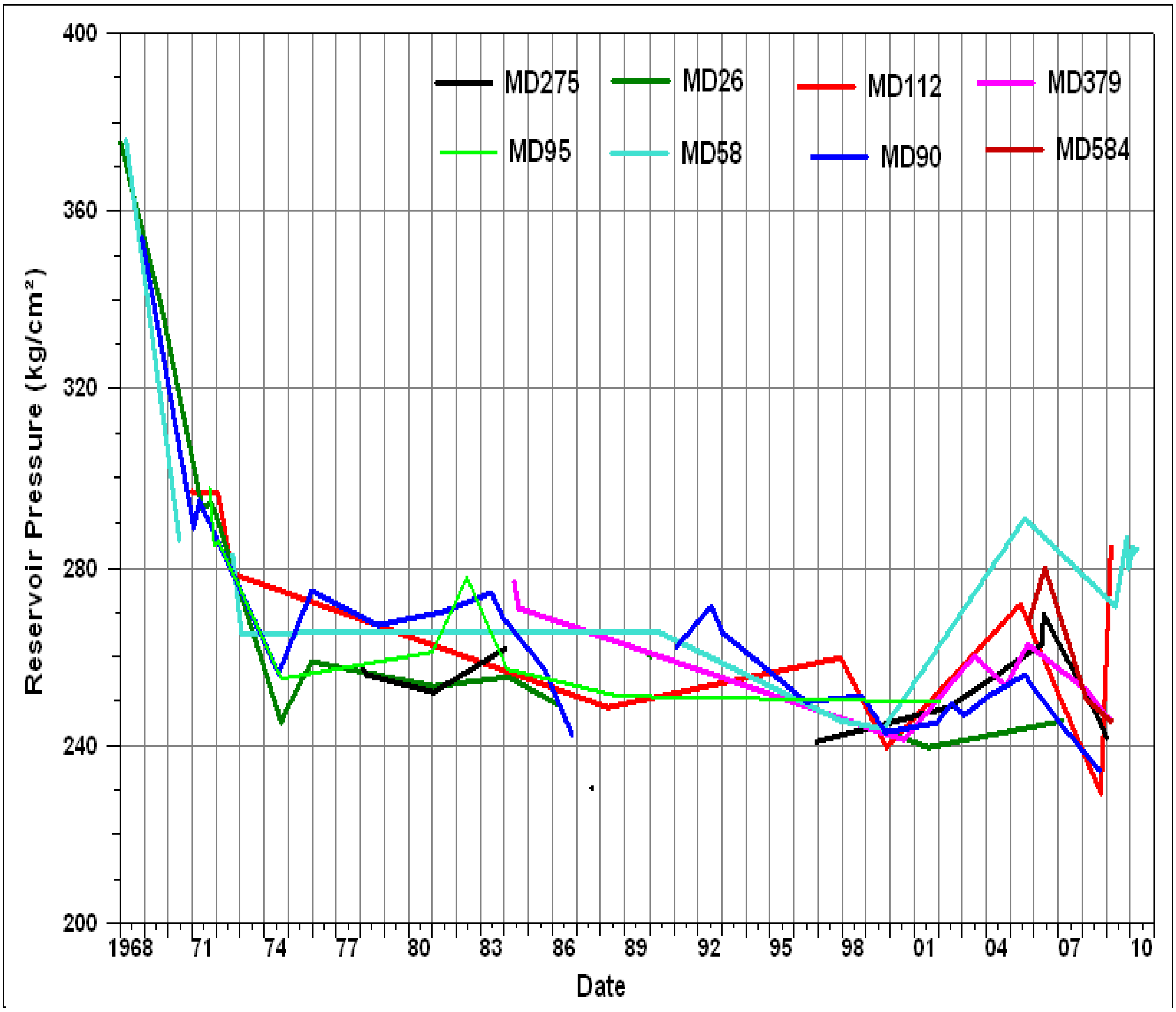


Figure II-30 : Reservoir Pressure of Offset Wells surrounding MD112 vs. Time

II.8 WAG performance study aimed at gas injection

A performance study focused on gas injection in WAG (Water Alternating Gas) was conducted. Consequently, a simulation model was constructed and adjusted. To achieve the objectives of the study, a simulation was created to analyze the progression of WAG benefits in comparison to continuous gas injection. The process unfolded in the following manner:

II.8.1 Continuous Gas Injection Case:

In this scenario, the current injection regime is continued. Within area 19, there are five gas injectors named MD-58, -112, -132, -143, and -176. These injectors are expected to maintain injection rates similar to the historical average rate.

II.8.2 WAG Injection Case:

For the WAG injection case, the five gas injectors have been divided into two groups. Group 1 consists of wells MD-112 and -143, while group 2 includes wells MD-58, -132, and -176. Each group alternates between water and gas injections simultaneously, creating the WAG effect. The gas injection rate remains the same as in the continuous gas injection case. However, two levels of water injectivity are considered: 3000 m3/d and 5000 m3/d. These rates are estimated based on the historical water injection rates in area 17 of the HMD field.

It is worth noting that the assumed water injection rates are significantly lower than the gas injection rate under reservoir conditions. Group 1 wells, at water injection rates of 3000 m3/d and 5000 m3/d, inject approximately 35% and 60% (respectively) of the volume equivalent to the reservoir gas injection. On the other hand, group 2 injection wells inject around 50% and 82% (respectively) of the volume.

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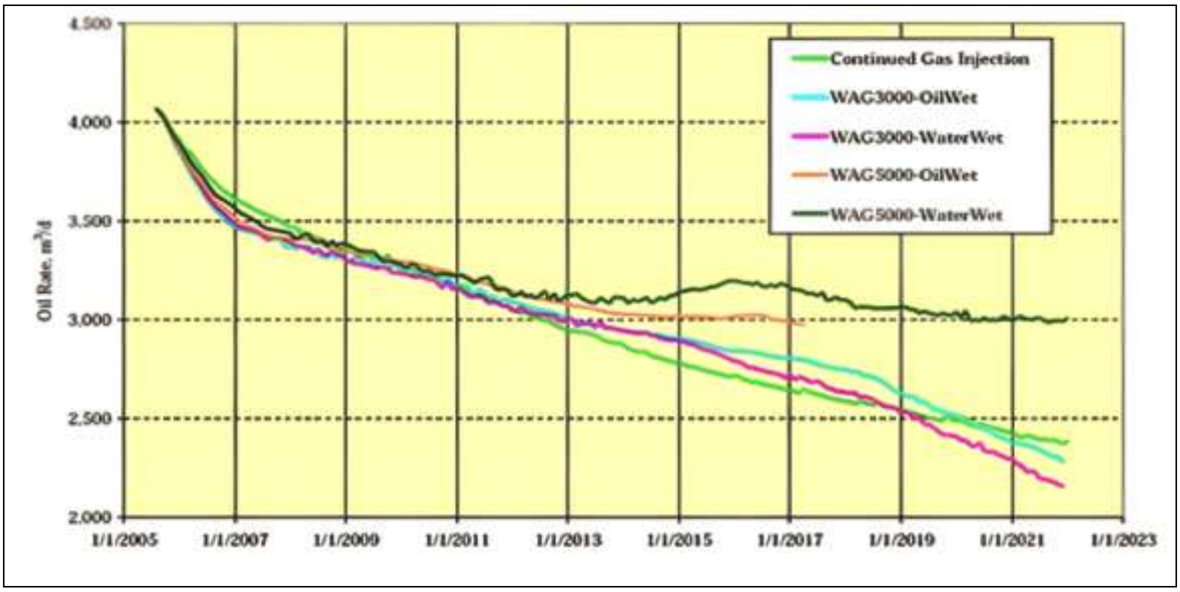

Figure II-31 : The production of oil for the various seniors of injection

NOTE (Figure-II -31):

- If a sufficient volume of high-flow water could be injected into area 19, oil production is estimated to increase

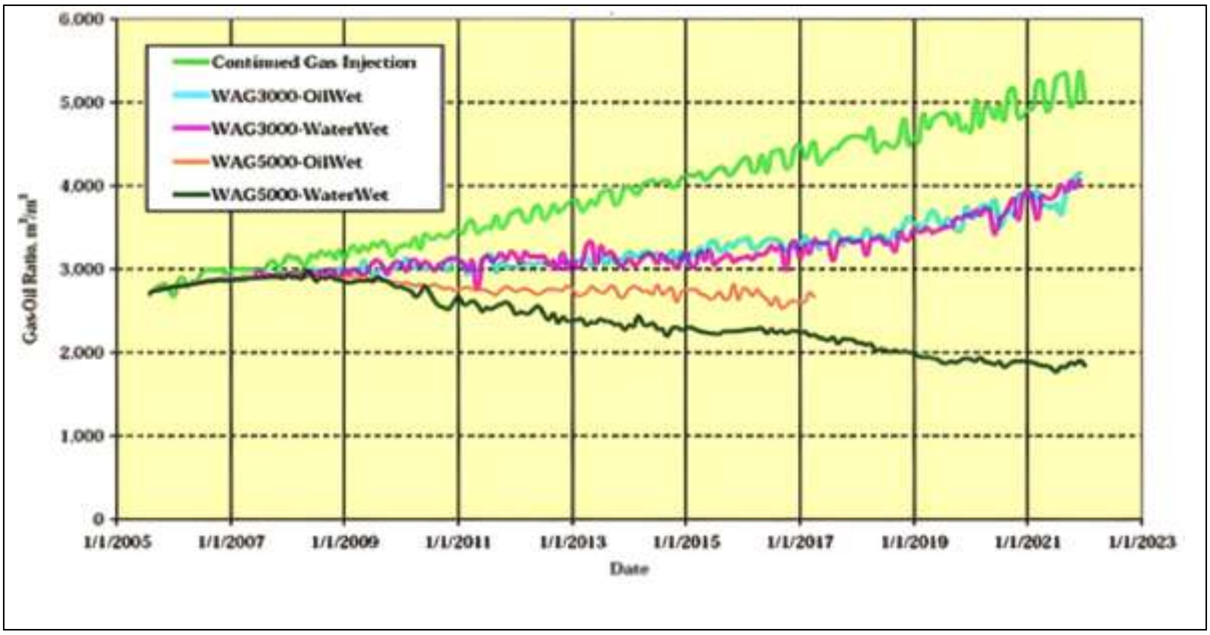

Figure II-32 : GOR estimation for different injection seniors

NOTE (Figure-II-32):

-Indicates that the GOR of the WAG process becomes lower than that of the gasflood about 1 year into the WAG injection.

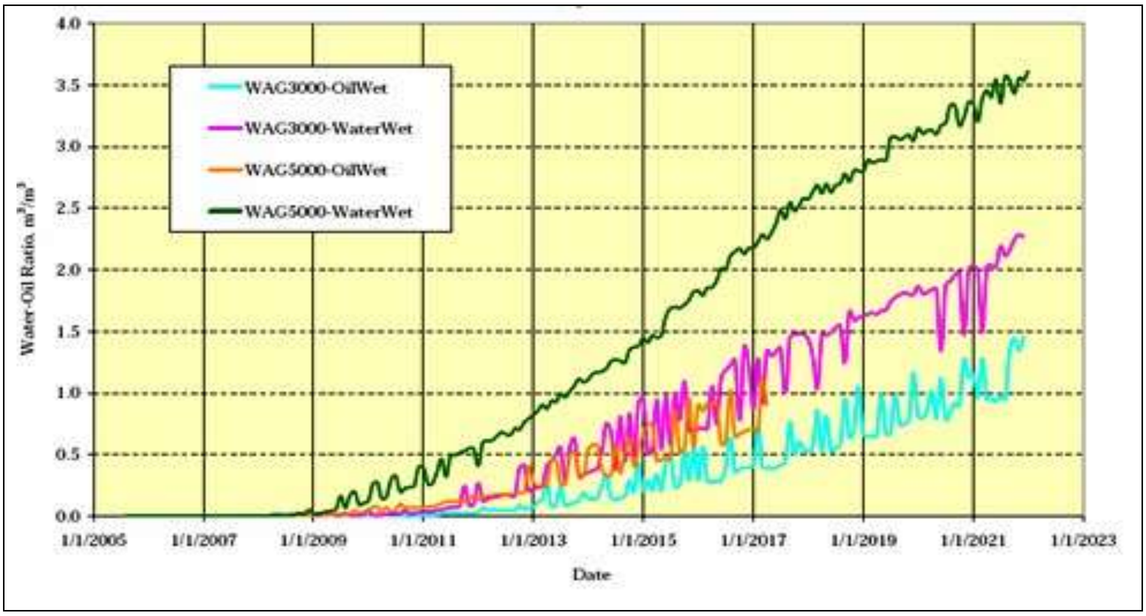

Figure II-33 : The production of water for the various WAG injection seniors

NOTE (Figure-II-33):

- Production wells begin to produce water approximately 20 months into WAG injection

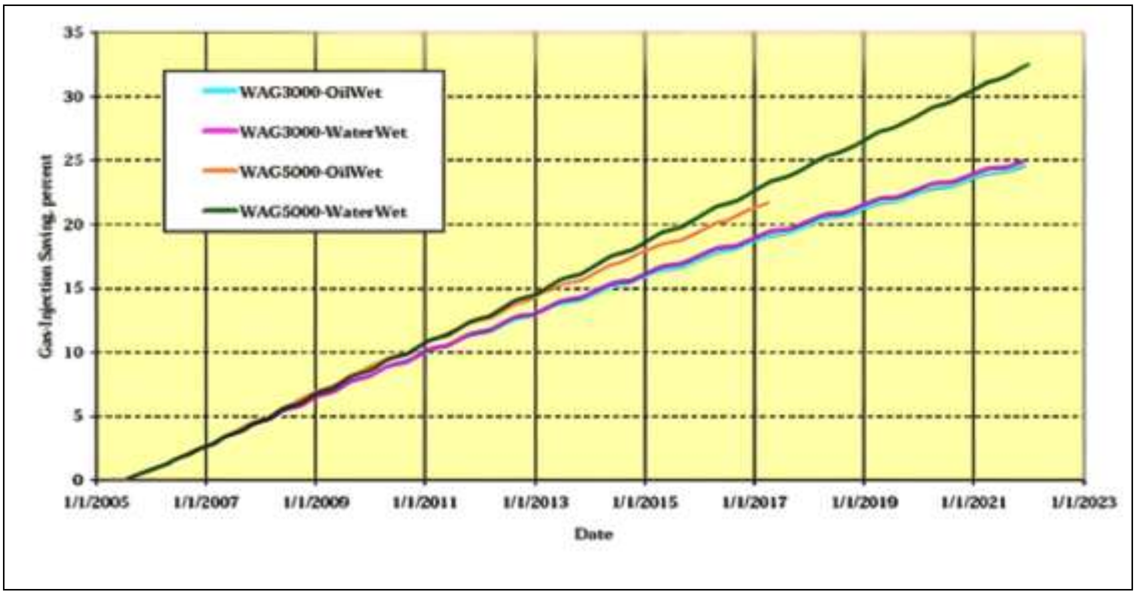

Figure II-34 : Comparison of gas injection accumulation for the different injection seniors

NOTE (Figure-II-34):

- It seems that the WAG process can significantly reduce the volume of gas injection

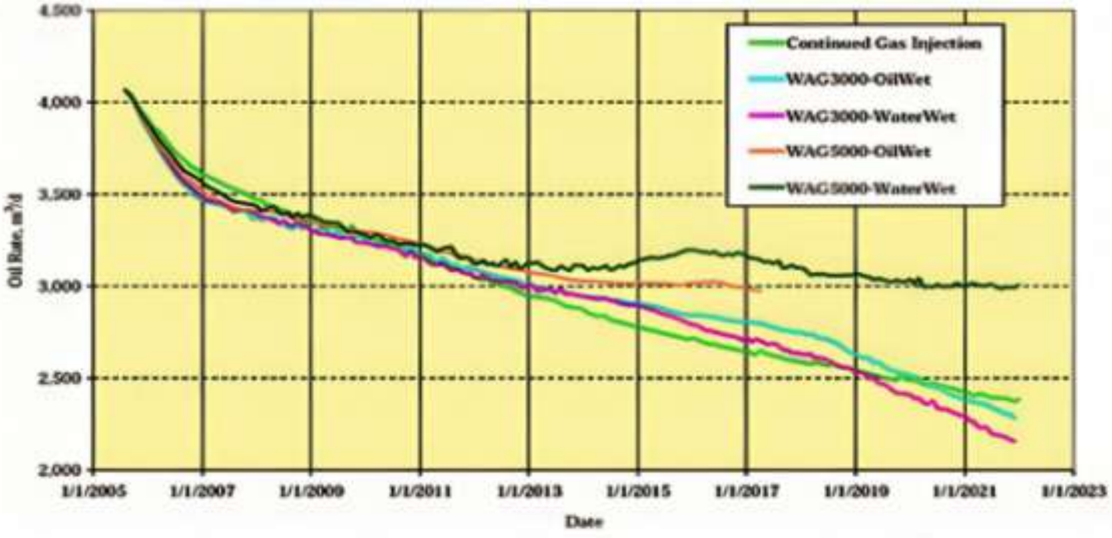

Figure II-35 : The gain in percentage volume of injected gaS

NOTE (Figure-II-35):

- For the cases tested, the WAG process is estimated to be able to replace approximately 25 percent of gas injection without reducing the volume of oil production

II.8.3 Interpretation

Based on the simulation results, it is evident that implementing the WAG process in Zone 19 of the HMD field can significantly reduce the amount of gas injection required without compromising oil production. The success of the WAG process in this zone heavily relies on water injectivity.

In the case of assumed low water injectivity, the pressure in Zone 19 after 15 years of WAG injection is estimated to be approximately 170 kg/cm2 . To increase the volume of water injection, it may be necessary to convert wells with high gas-to-oil ratios, such as MD-90, into WAG injectors or drill new wells specifically for WAG injection. This approach aims to expand the WAG process and achieve higher overall efficiency.

II.9 WAG different methods and Technologies used around the world

Water Alternating Gas (WAG) injection is a well-established enhanced oil recovery (EOR) technique, and while there might not be entirely "new" technologies, there are ongoing advancements and variations in WAG implementation. Here are a few notable technologies and techniques used in WAG injection around the world.

II.9.1 Smart Water Alternating Gas (SWAG)

Smart Water Alternating Gas (SWAG) injection is a technique used in enhanced oil recovery (EOR) to improve the production of oil from reservoirs. It involves injecting a combination of water and gas into the reservoir to displace the oil and increase its mobility, allowing for improved recovery.

Here's a brief description of the process:

Water Injection: In the initial stage, water is injected into the reservoir to displace the oil and push it towards the production wells. This process helps maintain reservoir pressure and sweep the oil towards the wellbore.

Gas Injection: In the next stage, gas, typically carbon dioxide (CO2), is injected into the reservoir. The gas helps further displace the oil by reducing its viscosity and improving its mobility. It also acts as a sweep agent to push the oil towards the producing wells.

Smart Water Injection: The term "smart water" refers to modified or customized water that contains specific additives or chemicals to enhance its effectiveness in interacting with the reservoir rock and oil. These additives can alter the wettability of the rock, increase the ionic strength of the water, or modify the interfacial tension between water and oil. The goal is to improve the displacement efficiency and the recovery factor.

The combination of water and gas injections in a cyclic manner (water-gas-water-gas) is referred to as Smart Water Alternating Gas (SWAG) injection. It is a technique that aims to optimize oil recovery by utilizing the synergistic effects of water and gas injection **[24].** . (figureII-0-6)

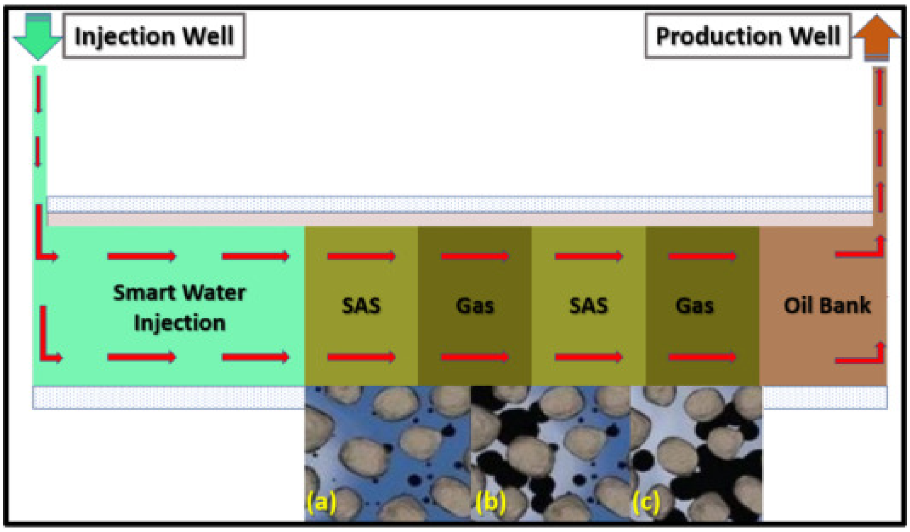

Figure II-36 : Smart Water Alternating Gas (SWAG) [24].

II.9.2 Nanotechnology Water alternating Gas injection

Nanotechnology can be employed to enhance the effectiveness of WAG injection by modifying the properties of the injected fluids and improving the displacement of oil from the reservoir. Here is a detailed mechanism of how nanotechnology can be incorporated into WAG injection:

Nanomaterial synthesis: The first step involves synthesizing nanomaterials that will be used in the WAG injection process. Nanomaterials commonly employed in this context include nanoparticles, nanofluids, and nanoemulsions. These materials are typically engineered to have specific properties such as stability, surface charge, and size distribution.

Fluid modification: The nanomaterials are then added to the injection fluids to modify their properties. For example, nanoparticles can be dispersed in water to form a nanofluid, or they can be incorporated into gas to form a nanoemulsion. The choice of nanomaterial and its concentration depends on the specific reservoir conditions and the desired enhanced oil recovery outcomes.

Interfacial tension reduction: One of the key advantages of nanotechnology in WAG injection is its ability to reduce the interfacial tension between the injected fluid and the oil in the reservoir. Nanoparticles or nanofluids can be designed to adsorb onto the oil-water interface, effectively reducing the tension and allowing better oil displacement. This leads to improved sweep efficiency and enhanced recovery rates.

Mobility control: Nanomaterials can also be used to control the mobility of injected fluids. By adjusting the concentration and properties of nanoparticles, it is possible to increase the viscosity of water or gas, thereby improving the sweep efficiency. This is particularly useful in reservoirs with high permeability or channels that allow the injected fluids to bypass the oil-bearing zones.

Selective targeting: Nanotechnology can facilitate selective targeting of oil-rich zones within the reservoir. Functionalized nanoparticles can be designed to preferentially interact with oil molecules, allowing for a more efficient displacement of oil. By modifying the surface properties of nanoparticles, they can be made to exhibit affinity towards oil, enhancing the recovery process.

Reservoir monitoring: Nanosensors and nanoprobes can be used to monitor the progress of WAG injection in real-time. These tiny devices can be injected into the reservoir along with the fluids and provide valuable information about fluid flow, pressure, and temperature. This data can then be used to optimize the injection parameters and improve recovery efficiency **[25].**.(Figure II-07) (Figure II-08)

Overall, incorporating nanotechnology into WAG injection offers several advantages such as reduced interfacial tension, improved mobility control, selective targeting, and enhanced reservoir monitoring. These advancements can lead to increased oil recovery and greater efficiency in the oil and gas industry.

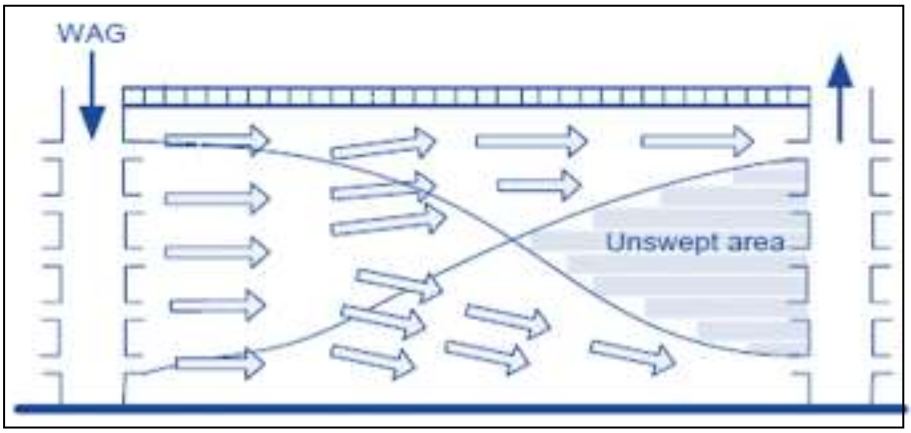

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Figure II-37 : A review on nanofluid water alternating gas application [25].

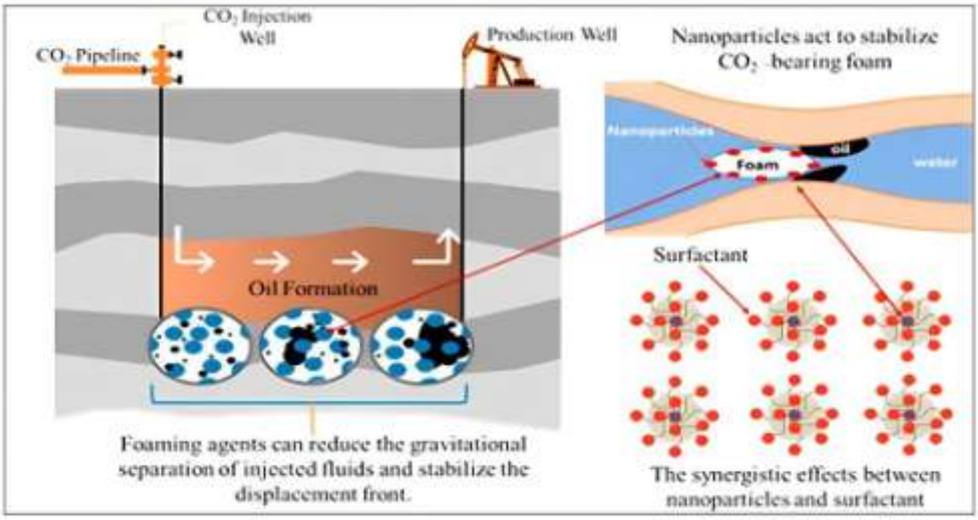

Figure II-38 : Nanotechnology Water alternating Gas injection [25]

II.9.3 Surfactant-Aided Water Alternating Gas Injection mechanism and Applications

Surfactant-aided water alternating gas (SAWAG) injection is an enhanced oil recovery (EOR) technique that combines the benefits of surfactants and gas injection to improve oil recovery from reservoirs. This mechanism involves the injection of a mixture of gas and surfactant solution into the reservoir, followed by water injection. The alternating injection of gas and water helps mobilize and displace the trapped oil, enhancing the overall recovery efficiency. This essay aims to provide a detailed understanding of the SAWAG mechanism, its underlying principles, and its applications in the oil and gas industry **[26].** (Figure II-10)

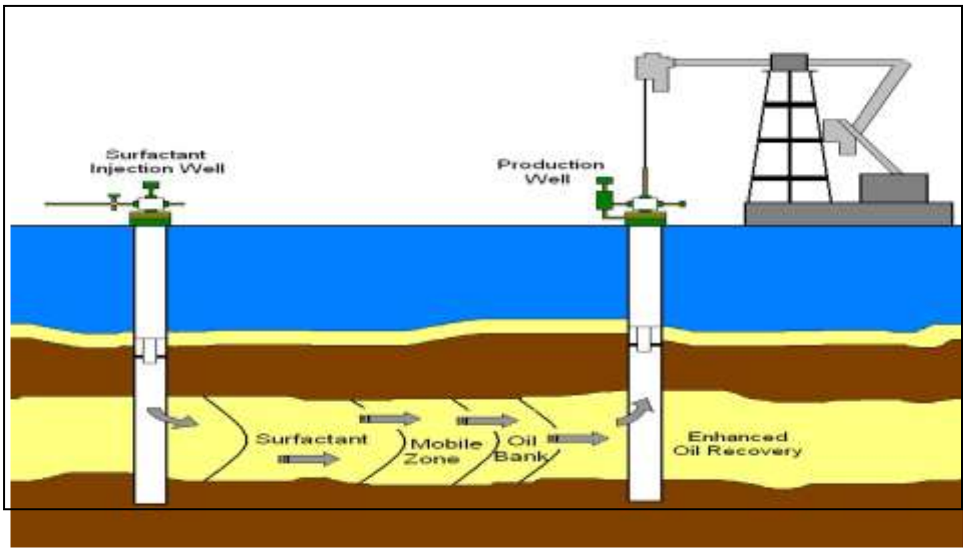

Figure II-39 : Surfactant-Aided Water Alternating Gas Injection [26].

II.9.4 Low Salinity Water Alternating Gas Injection (LS-WAG)

Low Salinity Water Alternating Gas Injection (LS-WAG) is an enhanced oil recovery (EOR) method that involves the injection of low salinity water and gas into an oil reservoir. The primary objective of LS-WAG is to improve oil recovery by altering the interfacial properties between the reservoir rock, the injected fluids, and the oil.

The mechanism of LS-WAG involves several processes that work synergistically to enhance oil displacement and recovery. Here's a detailed explanation of each step:

Initial Water Flooding: The LS-WAG process typically follows a primary water flooding stage, where water is injected into the reservoir to displace and mobilize oil. Water flooding helps to sweep the oil towards production wells, but it is often not efficient in recovering all the oil due to various factors, including high reservoir heterogeneity and unfavorable rock-fluid interactions.

Salinity Alteration: In LS-WAG, the salinity of the injected water is modified to a lower value compared to the formation water present in the reservoir. Lower salinity water alters the electrical properties of the reservoir rock, leading to changes in the wettability of the rock surface. This alteration reduces the oil-water interfacial tension and promotes the release of oil trapped in the rock matrix.

Wettability Modification: The lower salinity water preferentially displaces the high salinity formation water, altering the wettability of the reservoir rock from oil-wet to more water-wet conditions. This wettability modification improves the capillary forces, reducing the oil trapping and improving the sweep efficiency of subsequent displacing fluids.

Interfacial Phenomena: The altered wettability and reduced interfacial tension between oil and water facilitate the mobilization and flow of oil from the rock matrix. The lower interfacial tension allows for better displacement of oil droplets, reducing the capillary trapping and increasing the microscopic sweep efficiency.

Gas Injection: The next phase involves injecting gas, such as nitrogen or carbon dioxide (CO2), alternately with the low salinity water. Gas injection helps to further mobilize and displace the remaining oil by several mechanisms, including the swelling of the oil phase, viscosity reduction, and pressure maintenance. The injected gas can expand the volume of the remaining oil, reduce its viscosity, and create pressure to drive it towards production wells.

Hysteresis Effects: The alternating injection of low salinity water and gas introduces hysteresis effects in the reservoir. This means that the rock wettability and fluid distribution change in response to the fluid composition and sequence of injection. These hysteresis effects enhance oil recovery by improving the sweep efficiency and displacing oil from previously bypassed regions.

Overall, the LS-WAG mechanism involves a combination of interfacial tension reduction, wettability alteration, capillary force modification, and gas mobility improvement. These mechanisms work together to improve the displacement and mobilization of oil, thereby increasing the overall oil recovery from the reservoir. (Figure II-11)

It's worth noting that the effectiveness of LS-WAG can vary depending on reservoir conditions, such as rock type, fluid properties, reservoir heterogeneity, and operational parameters. Therefore, detailed reservoir characterization and laboratory studies are often conducted to optimize the LS-WAG process for specific reservoirs before implementation **[27].**

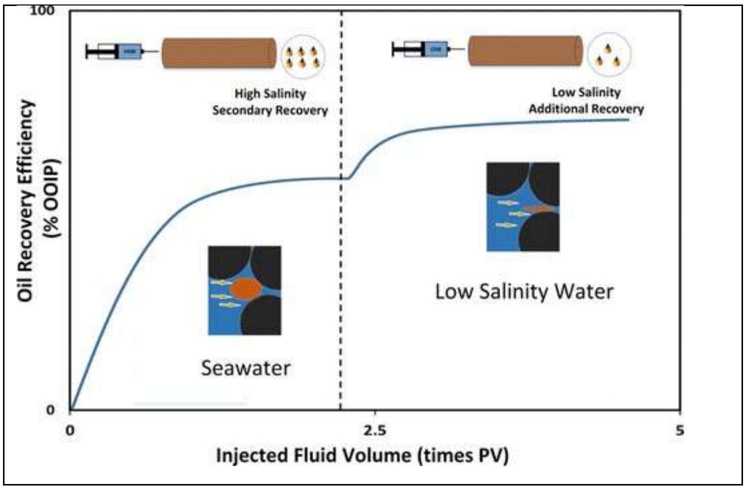

Figure II-40 : Low Salinity Water Alternating Gas Injection (LS-WAG) [27].

II.10 Proposed solution for WAG Application in zone 19 in Hassi Messaoud field

II.10.1 Foam water alternating gas (FWAG) injection

Foam water alternating gas (FWAG) injection is an enhanced oil recovery (EOR) technique that involves the injection of a combination of foam, water, and gas into an oil reservoir. It is designed to improve the sweep efficiency of injected fluids and increase oil recovery. This mechanism is particularly suitable for reservoirs with high-permeability channels or fractures, where conventional water flooding may bypass significant volumes of oil.

Here's a detailed explanation of the FWAG mechanism:

Injection of Foam: The process begins with the injection of a foam-forming solution into the reservoir. This solution typically consists of a surfactant mixed with water. The surfactant reduces the interfacial tension between oil and water, facilitating the formation of stable foam. The injected foam fills the high-permeability channels or fractures, which would otherwise allow gas or water to flow through rapidly, bypassing the oil. (Figure II-12)

Water Injection: After the foam injection, a water slug is introduced into the reservoir. The purpose of the water slug is to displace the remaining foam and drive it further into the reservoir. Water is the primary fluid for displacing oil, and by injecting it after foam, the sweep efficiency is enhanced.

Gas Injection: Following the water slug, a gas, such as nitrogen or carbon dioxide, is injected into the reservoir. The gas helps push the remaining foam and water deeper into the reservoir, displacing more oil in the process. Gas injection aids in reducing the oil viscosity, improving the mobility of oil, and enhancing oil recovery **[28].**

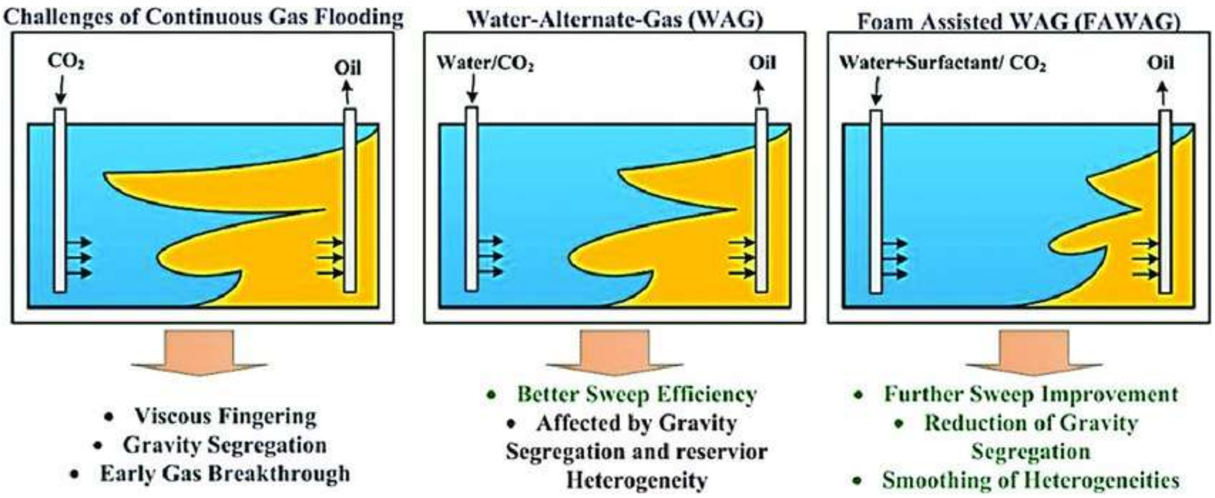

Figure II-41 : Foam water alternating gas (FWAG) injection [28]

1) Advantages of Foam Water Alternating Gas (FWAG) Injection:

Improved Sweep Efficiency: The primary advantage of FWAG injection is its ability to improve the sweep efficiency of injected fluids. By using foam, the high-permeability channels or fractures in the reservoir are filled, forcing the fluids to flow through the low-permeability zones and contact a larger portion of the oil in place. This leads to higher oil recovery compared to conventional water flooding.

Selective Channel Blocking: FWAG injection selectively blocks the high-permeability channels or fractures, which would otherwise allow fluids to flow through them quickly. This diversion of fluids helps distribute them more evenly throughout the reservoir, ensuring better contact with the oil and reducing the likelihood of bypassing significant oil volumes.

Enhanced Displacement: The use of foam followed by water and gas injection helps to displace oil effectively. Foam improves the sweep efficiency, water displaces the remaining foam and drives it further, and gas aids in reducing oil viscosity and increasing oil mobility. This combination of actions leads to enhanced displacement of oil from the reservoir.

Reduced Gas Mobility Ratio Effects: In conventional gas injection methods, the mobility ratio between gas and oil can result in gas fingering and channeling, limiting the effectiveness of gas flooding. However, in FWAG injection, the foam and water slugs help reduce the mobility ratio effects. The foam acts as a mobility buffer, preventing the gas from fingering and channeling, and ensuring a more uniform displacement of oil.

Versatility: FWAG injection can be applied in various reservoir types, including those with high-permeability channels, fractures, or heterogeneous formations. It can be tailored to the specific characteristics of the reservoir, such as the oil and water properties, reservoir temperature, and permeability distribution.

Overall, Foam Water Alternating Gas (FWAG) injection offers improved sweep efficiency, selective channel blocking, enhanced displacement, reduced gas mobility ratio effects, and versatility as an EOR mechanism. By effectively addressing the challenges associated with high-permeability reservoirs, FWAG injection has the potential to increase oil recovery and maximize the utilization of hydrocarbon resources **[28].**

II.11Prosper Production optimization scenario in zone 19 in HMD field

Prosper software, can provide a detailed estimation of a suitable new technology for Water Alternating Gas (WAG) Injection in Zone 19 in Hassi Messaoud. Based on the information provided, implementing an advanced foam-assisted WAG injection technique could be a promising option. Here's a breakdown of the estimation and the rationale behind.

II.11.1 Criteria of choosing Foam-Assisted WAG Injection in zone 19 in Hassi Messaoud

Foam-assisted WAG injection involves the injection of foam into the reservoir along with water and gas. The foam acts as a mobility control agent, improving the gas sweep efficiency and enhancing oil recovery. It has several advantages that make it a suitable technology for Zone 19:

a. Mobility Control:

Foam has the ability to reduce gas mobility and improve sweep efficiency. By generating a stable foam in the reservoir, it can divert the injected gas into unswept zones, increasing oil recovery and reducing the reliance on high gas injection rates.

b. Gas Conservation:

Foam-assisted WAG injection requires lower gas injection rates compared to traditional WAG methods. This addresses the challenge of limited gas availability mentioned in the Zone

19 production challenges. By conserving gas, it allows for optimal use of available resources and mitigates the risk of exceeding the field's capacity.

c. Foam Stability:

Advancements in foam formulation and stabilization techniques have led to more stable foams that can withstand reservoir conditions. Stable foams can maintain their mobility control properties over extended periods, ensuring consistent performance and improved oil recovery over the lifespan of the project.

d. Reservoir Compatibility:

A comprehensive reservoir characterization and simulation study should be conducted to assess the suitability of foam-assisted WAG injection in Zone 19. Factors such as reservoir permeability, heterogeneity, and fluid properties should be evaluated to ensure compatibility with foam injection and its effectiveness in improving oil recovery.

e. Field Implementation:

Prior to implementing foam-assisted WAG injection, laboratory-scale experiments and pilot tests should be conducted in representative reservoir conditions to assess its performance and validate the estimated benefits. Proper design and monitoring of the foam injection process should be implemented to optimize results.

The estimation provided above is based on the information available and the potential advantages of foam-assisted WAG injection in Zone 19. It is recommended to conduct a comprehensive feasibility study and consult with reservoir engineering experts and specialized foam technology providers to further evaluate the suitability and potential implementation of this technology in the specific context of Zone 19 in Hassi Messaoud.

Conclusion

Depends on the recent studies we should know that Wag injection is successful than continuous gas injection in enhancing oil recovery in zone 19 but there still some other challenges. So that foam assisted WAG technique should be considered and tried to see better results.

In the third chapter, we studied the implementation of the WAG technique in the zone 19 of HMD field. Moreover, the results obtained did not confirm the success of this technique in the enhancement of oil recovery but it showed a slight amelioration in the production perform

General Conclusion

Based on the analysis of various cell parameters such as injection, production, GOR, water breakthrough, and reservoir pressure, the following conclusions can be drawn:

The connection between the injector well MD112 and the producer wells in the cell is not definitively established.

The injection behavior observed in this pilot significantly differs from the simulation predictions. Due to injectivity issues, we were able to inject less than 45% of the recommended volumes of gas and water.

At this point, it is uncertain whether the WAG technique will improve or weaken the oil sweep. The overall oil production in the cell is unstable, except for MD262's production, which notably improved in 2008.

One advantage of the WAG technique is a considerable reduction in the gas injection rate required to produce 01 m3 of oil. This reduction occurred after implementing WAG and decreasing the amount of gas injected via MD112 and closing MD58 well.

The occurrence of water breakthrough contradicts the simulation results, which predicted it to happen in 2008. On the other hand, the gas breakthrough remains persistently high even after implementing WAG.

The pilot has completed its 9th injection cycle, which began on 05/12/2011, focusing on the water phase. This cycle will continue until water breakthrough to understand the behavior of the producing wells during this phase.

The gas recycling rate exceeds 15% due to the production of gas from outside the cell through other injectors in the area.

New WAG Technology should be considered as an advanced production solution to enhance residual oil recovery in zone 19 in HMD field

RECOMMENDATIONS

- The complexity of the training parameters in the HASSI MESSAOUD region has a negative impact on the effectiveness of the WAG project.
- It is necessary to assess the impact of other water injection wells or gas in the area on the WAG cell.
- MD90 well produces a significant amount of free gas, with a Gas-Oil Ratio (GOR) fluctuating between 5000 and 50000 m3/m3. Specifically, during the gauging conducted on 17/08/2011, a GOR of 48411 m3/m3 was recorded, resulting in a total gas production of approximately 744,000 Sm3/d. By shutting down this well, the gas recycling rate may decrease, ultimately enhancing the efficiency of fluid displacement.
- To determine the water and gas breakthrough or the well level within the cells, the utilization of multicolored or phosphoric materials can be employed.

Based on the provided geological description of Zone 19 in Hassi Messaoud Field, we can provide some general recommendations for WAG injection technologies that can be explored in Zone 19:

- Reservoir Simulation Studies: Conduct comprehensive reservoir simulation studies to evaluate the potential benefits of WAG injection in Zone 19. These studies will help in assessing reservoir heterogeneity, fluid properties, and identifying the optimal WAG injection parameters for enhanced oil recovery.
- Water and Gas Compatibility: Assess the compatibility of injected water and gas with the reservoir fluids to avoid potential formation damage or unfavorable interactions. Laboratory tests should be conducted to determine the best water chemistry and gas composition suitable for WAG injection in Zone 19.
- WAG Injection Timing and Ratio: Optimize the timing and ratio of water and gas injection cycles. Based on reservoir simulation studies, determine the appropriate WAG injection pattern, which may involve alternating between shorter or longer injection cycles, depending on the reservoir characteristics and desired results.
- Gas Selection: Analyze the available gas sources and their composition to determine the most suitable gas for WAG injection. The gas should have adequate miscibility

with the reservoir oil to achieve efficient displacement. If required, gas treatment processes such as gas sweetening or conditioning can be considered to improve its suitability for WAG injection.

- Advanced Well and Surface Facilities: Evaluate the need for well and surface facility modifications or upgrades to accommodate WAG injection operations. Consider implementing advanced well completion techniques, such as intelligent completions or inflow control devices, to optimize fluid distribution and injection efficiency.
- Monitoring and Surveillance: Develop a comprehensive monitoring and surveillance plan to track the performance of the WAG injection process. Implement techniques such as production logging, pressure monitoring, and tracer studies to evaluate the effectiveness of WAG injection and make any necessary adjustments during field operation.

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APPENDIX

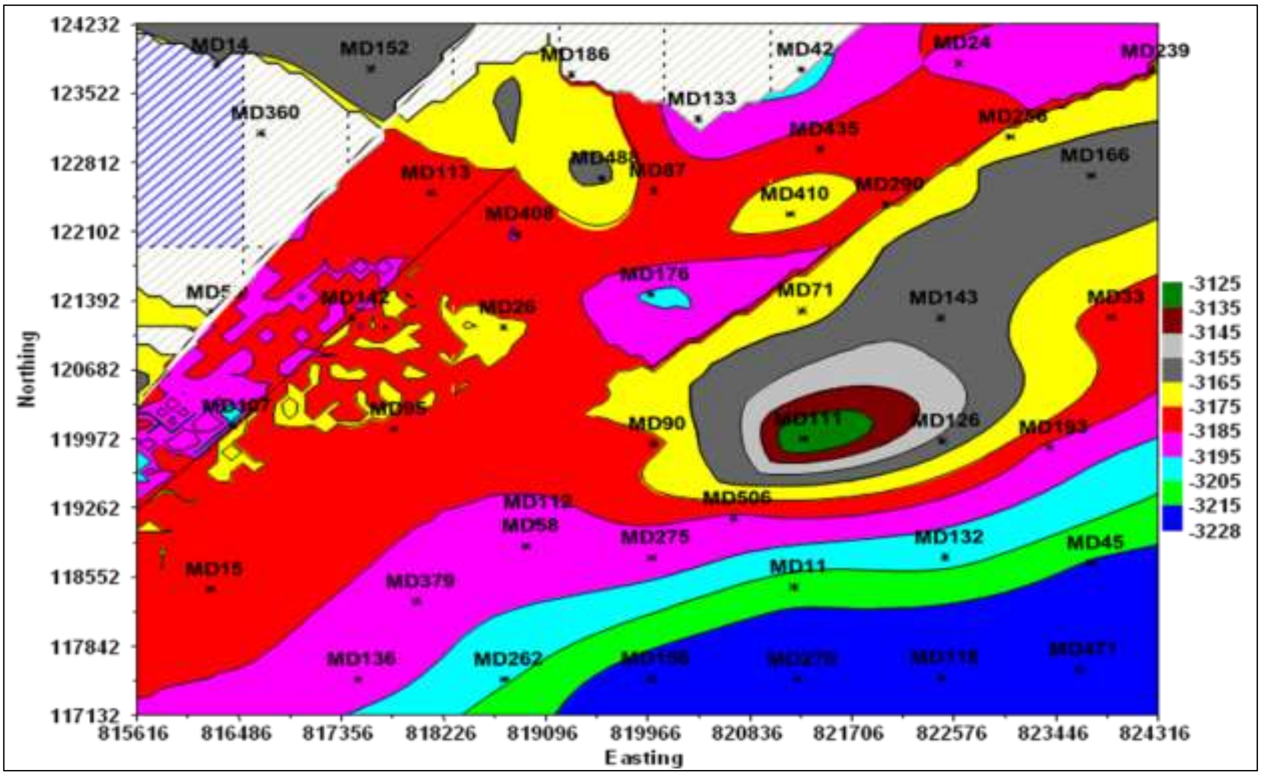

Exhibit 1 : Structure top of D3 with the effects of erosion added. Hatched areas indicate where D3 has been completely eroded

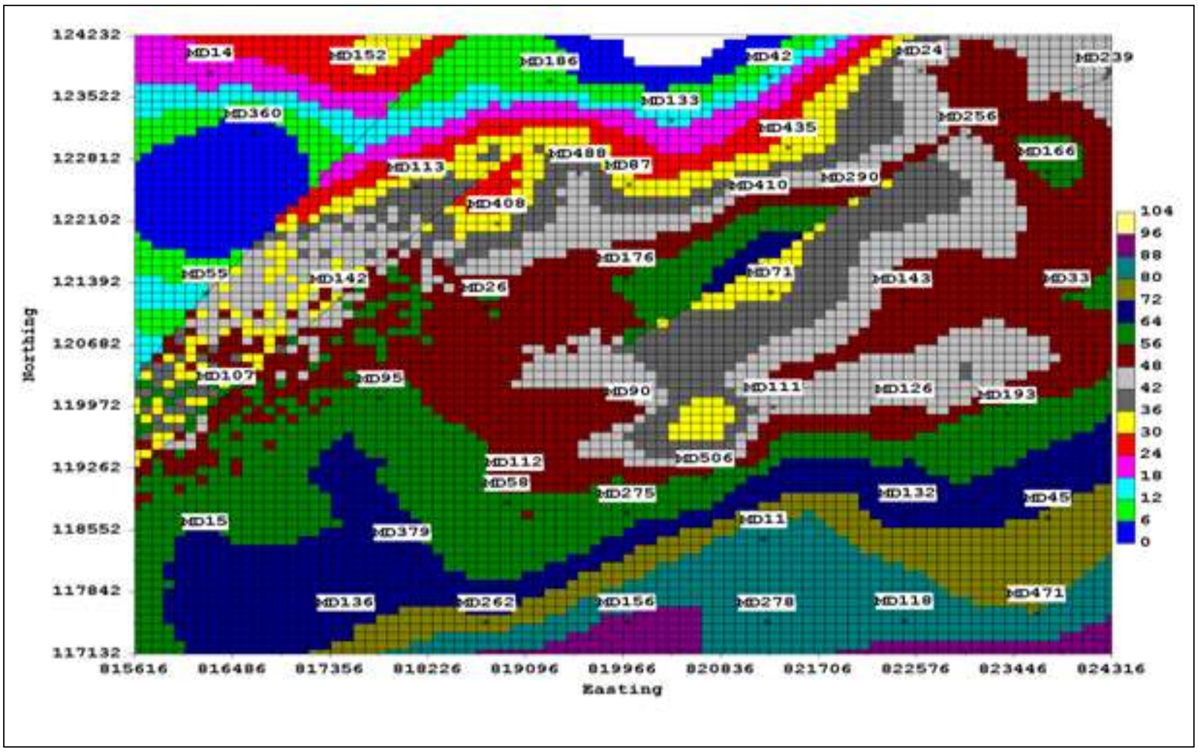

Exhibit 2 : Gross isopach from Discordance to top of ID.

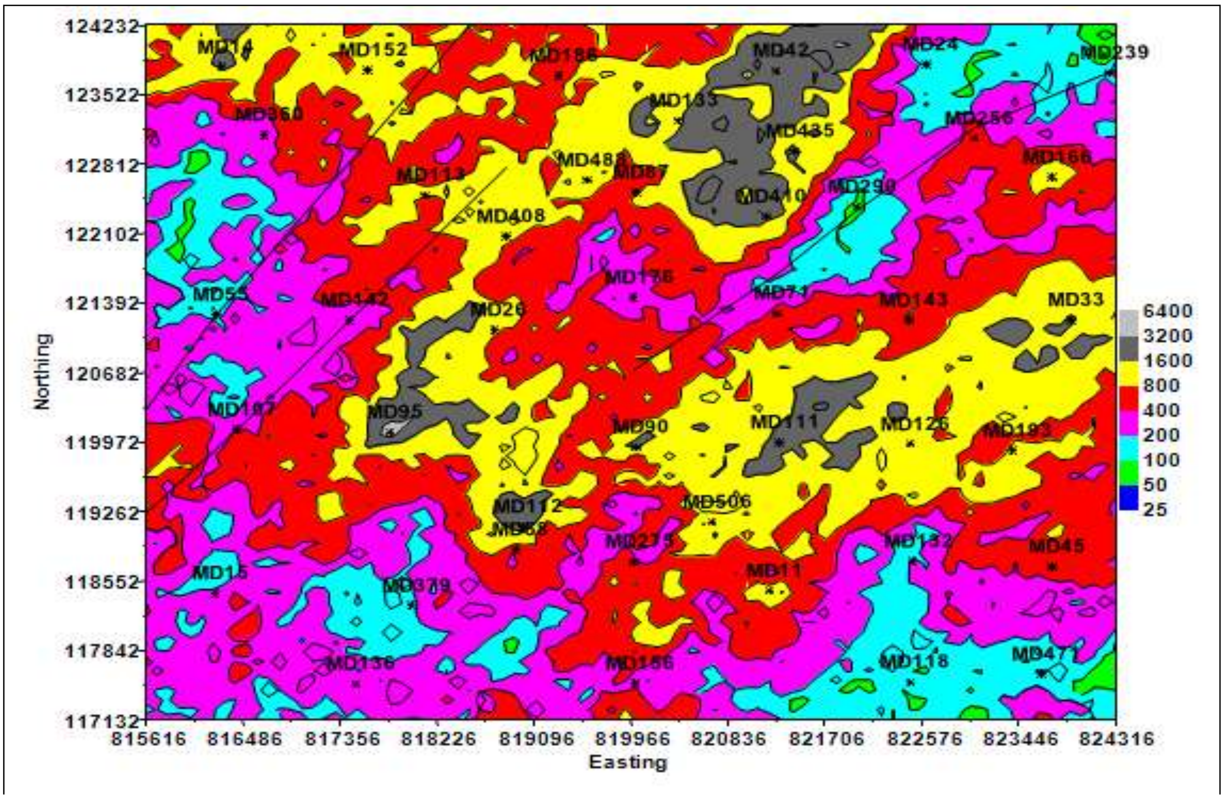

Exhibit 3 Total reservoir Kh

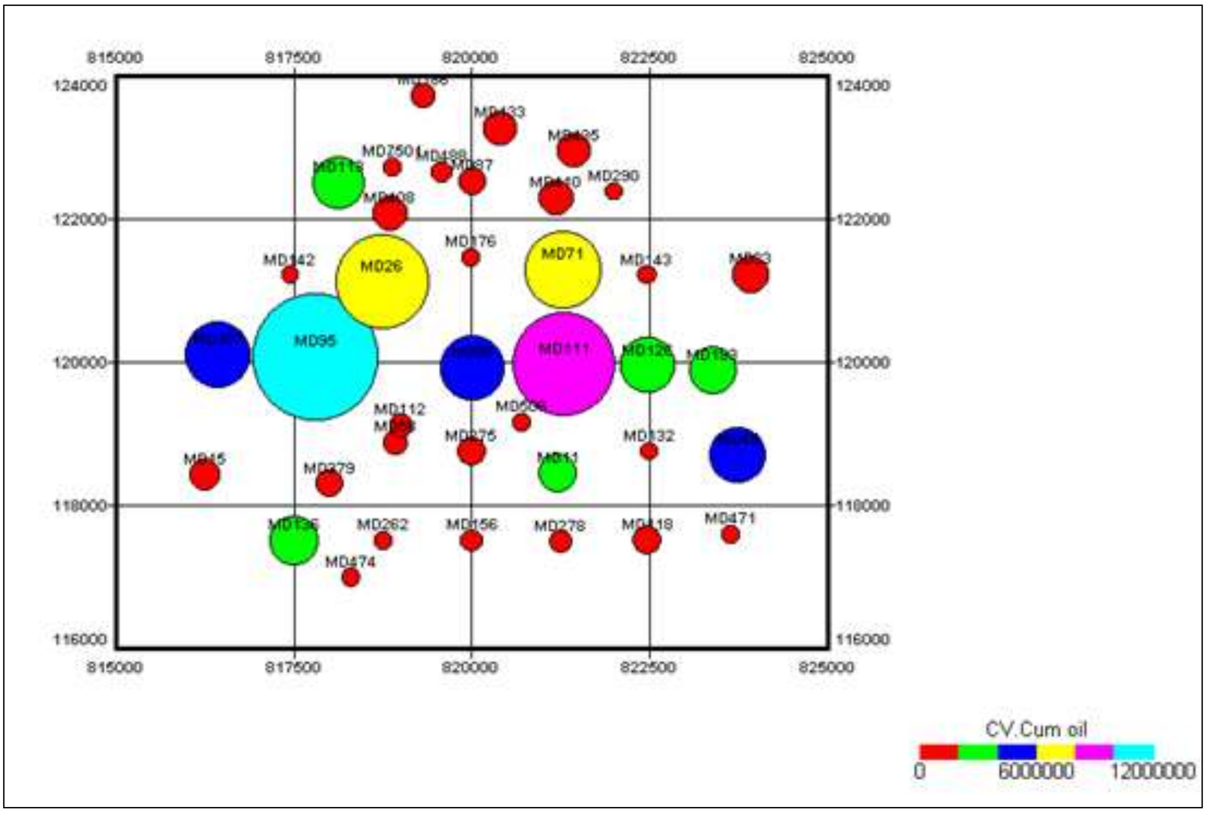

Exhibit 4 : Cumulative Oil Production

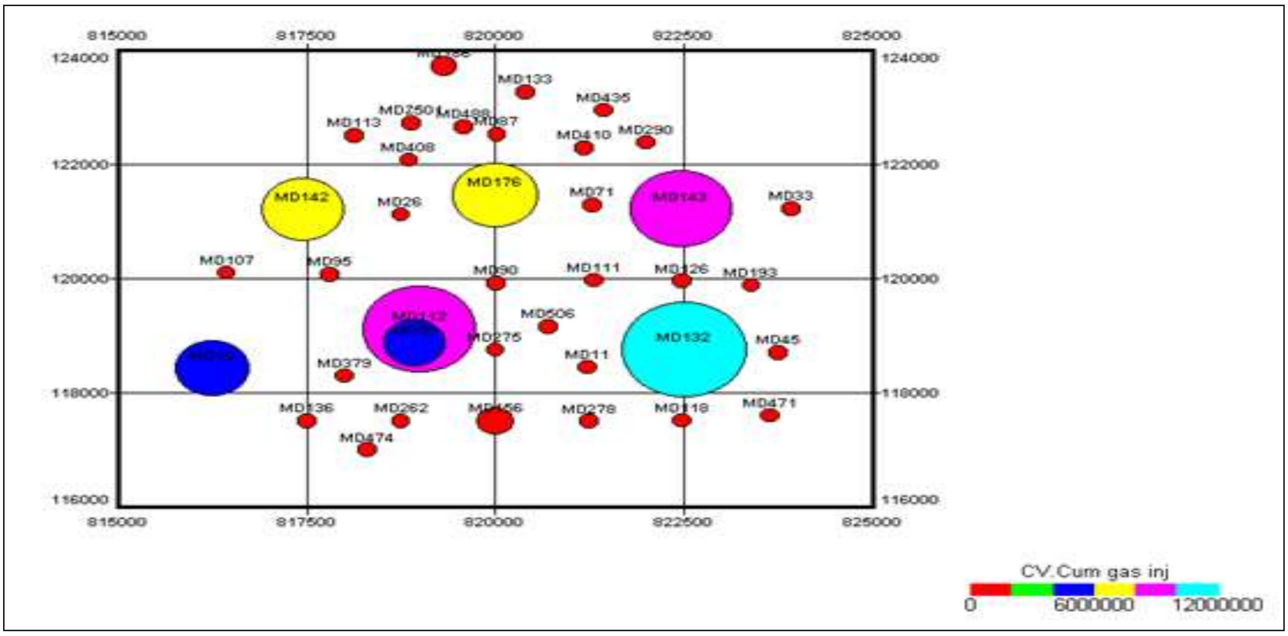

Exhibit 5 : Cumulative Gas Injection Bubble Map

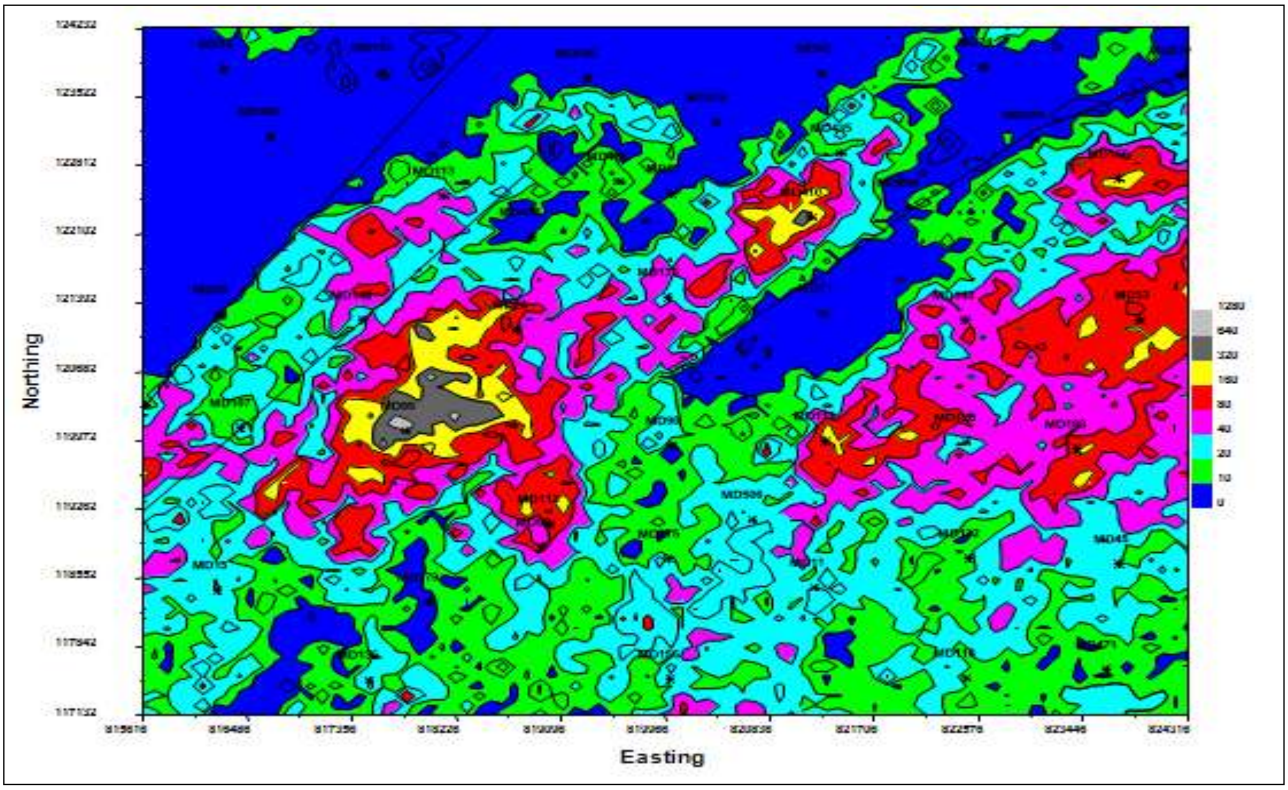

Exhibit 6 : Kh of D3

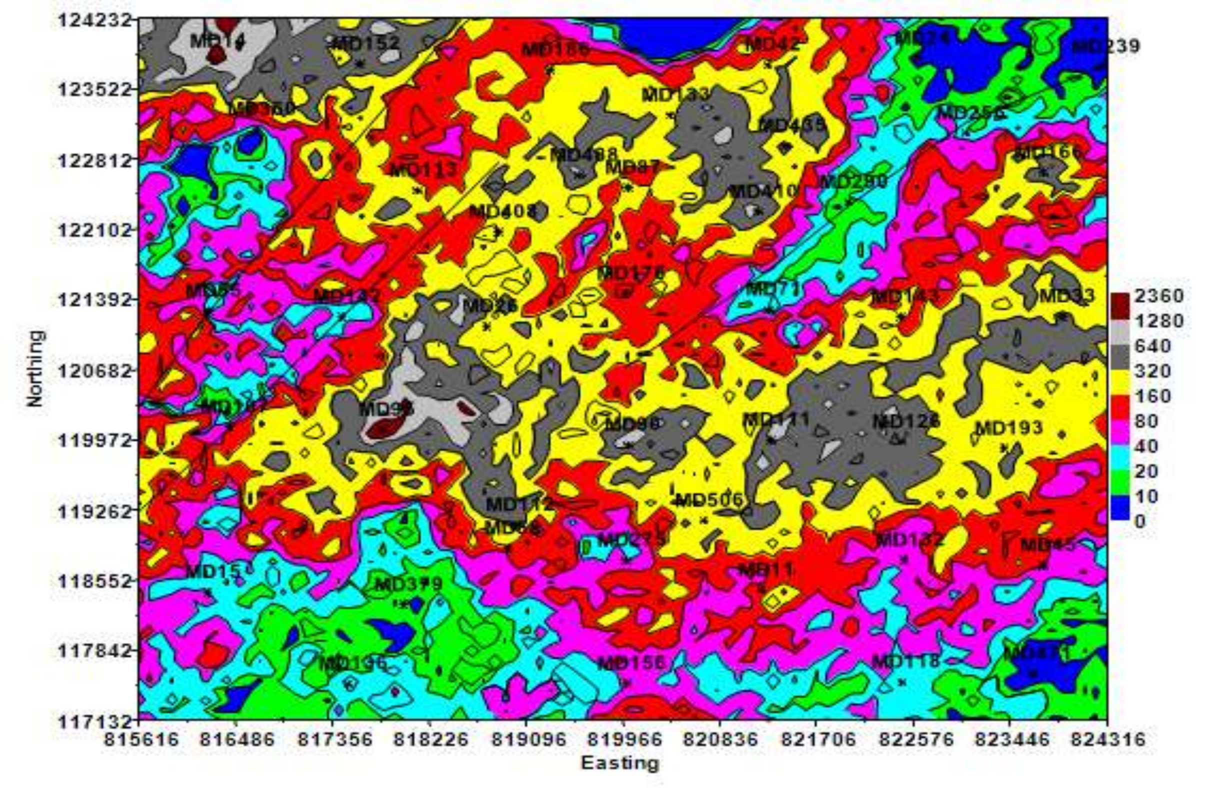

Exhibit 7 : Kh of D2

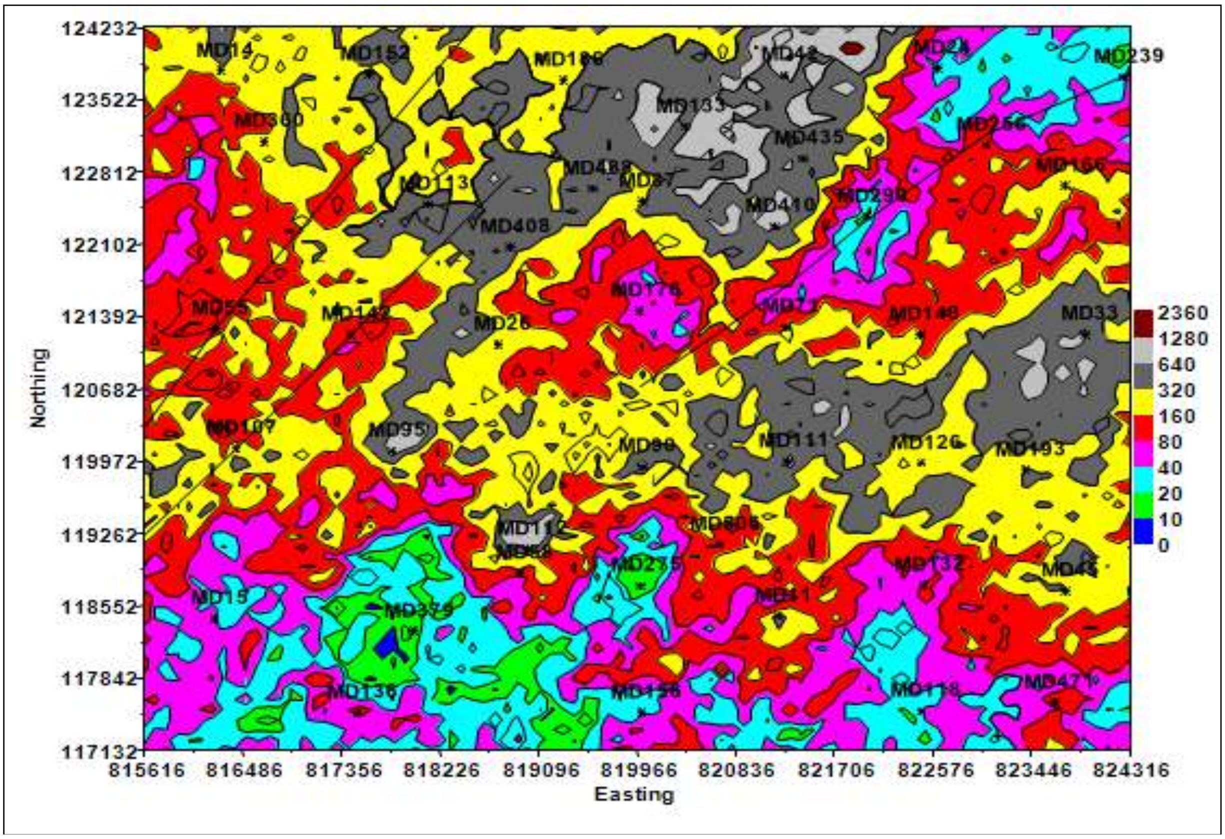

Exhibit 8 : Kh of ID

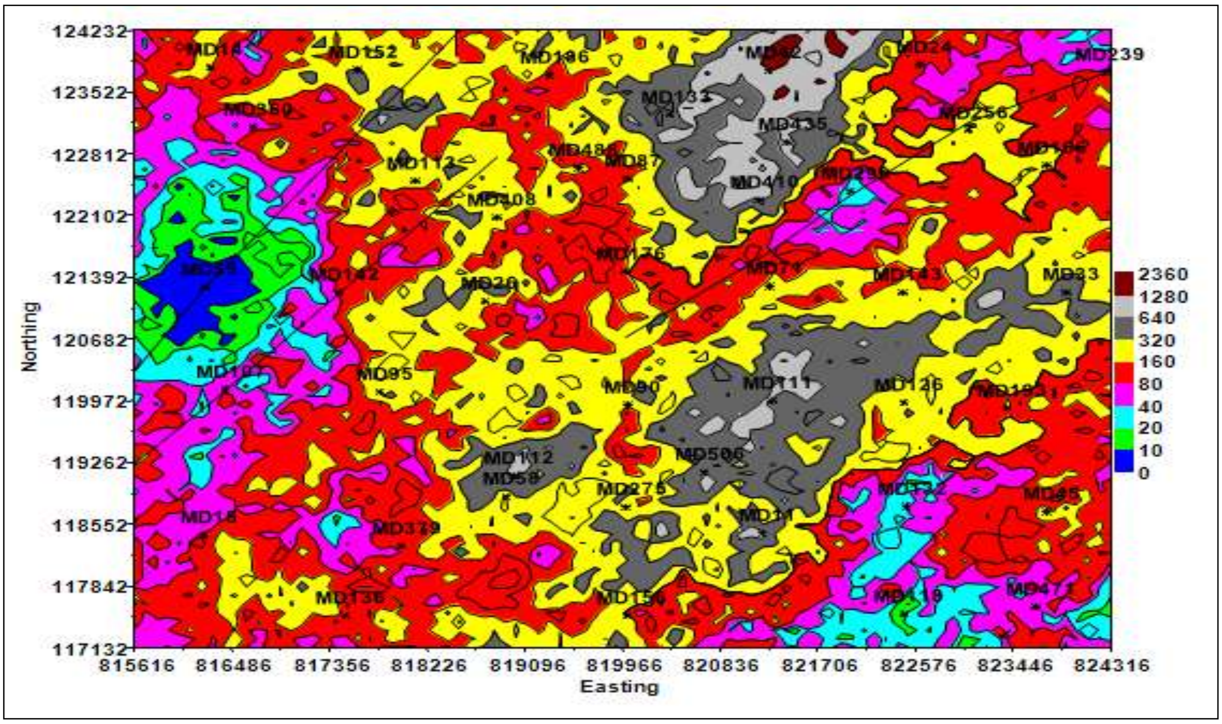

Exhibit 9 : Kh of D1

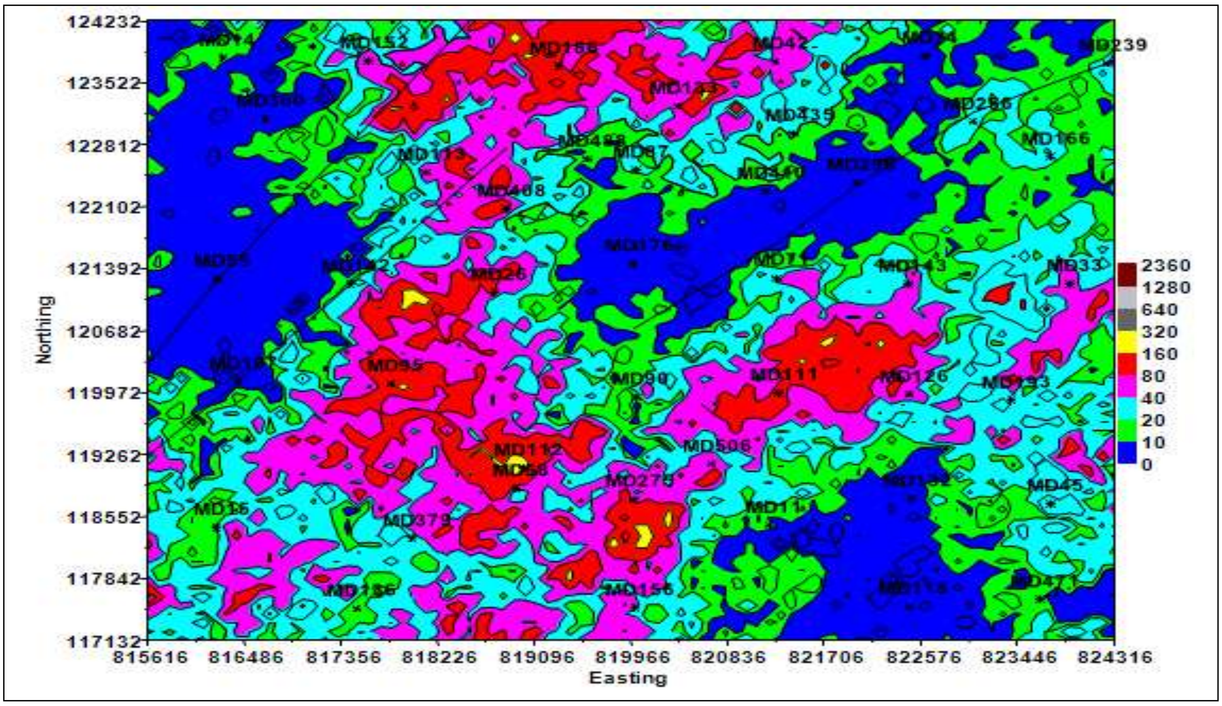

Exhibit 10 : Kh of ZPG

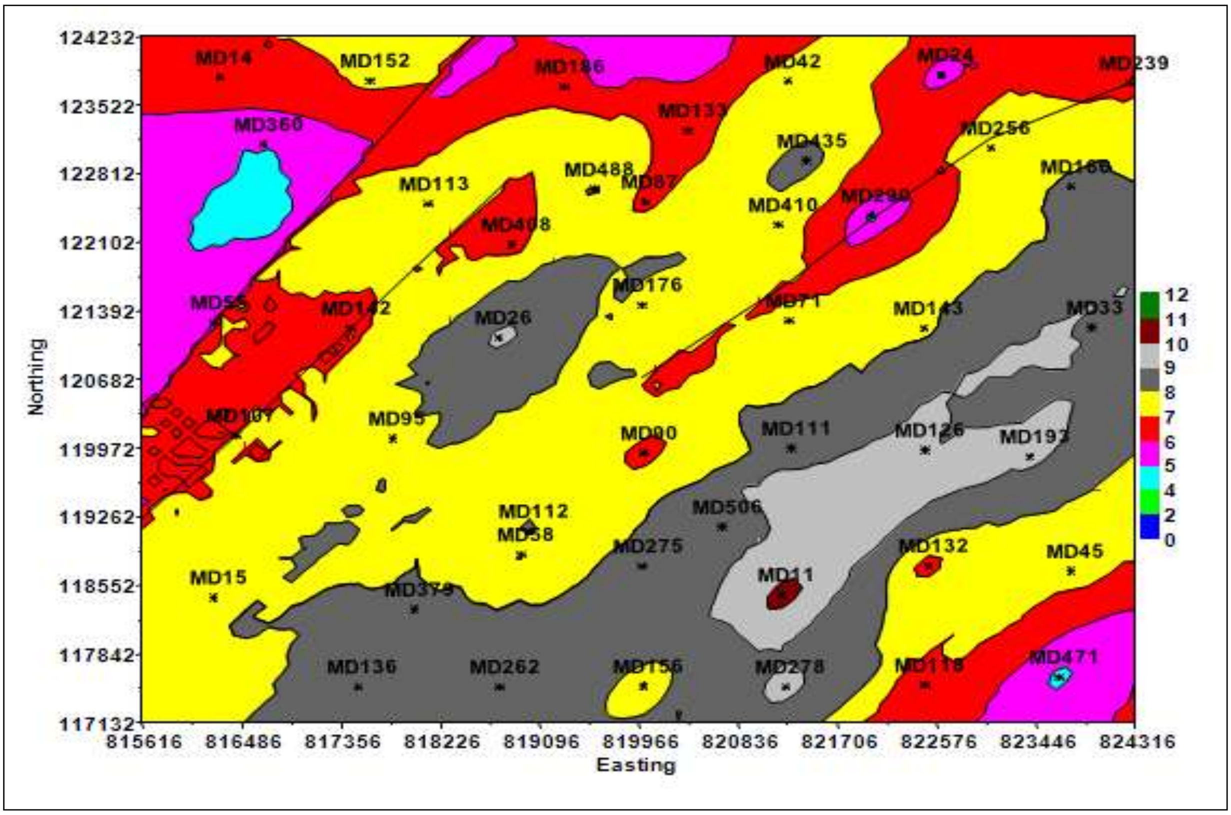

Exhibit 11 : Total reservoir volume (phi*h) for all drains (m).

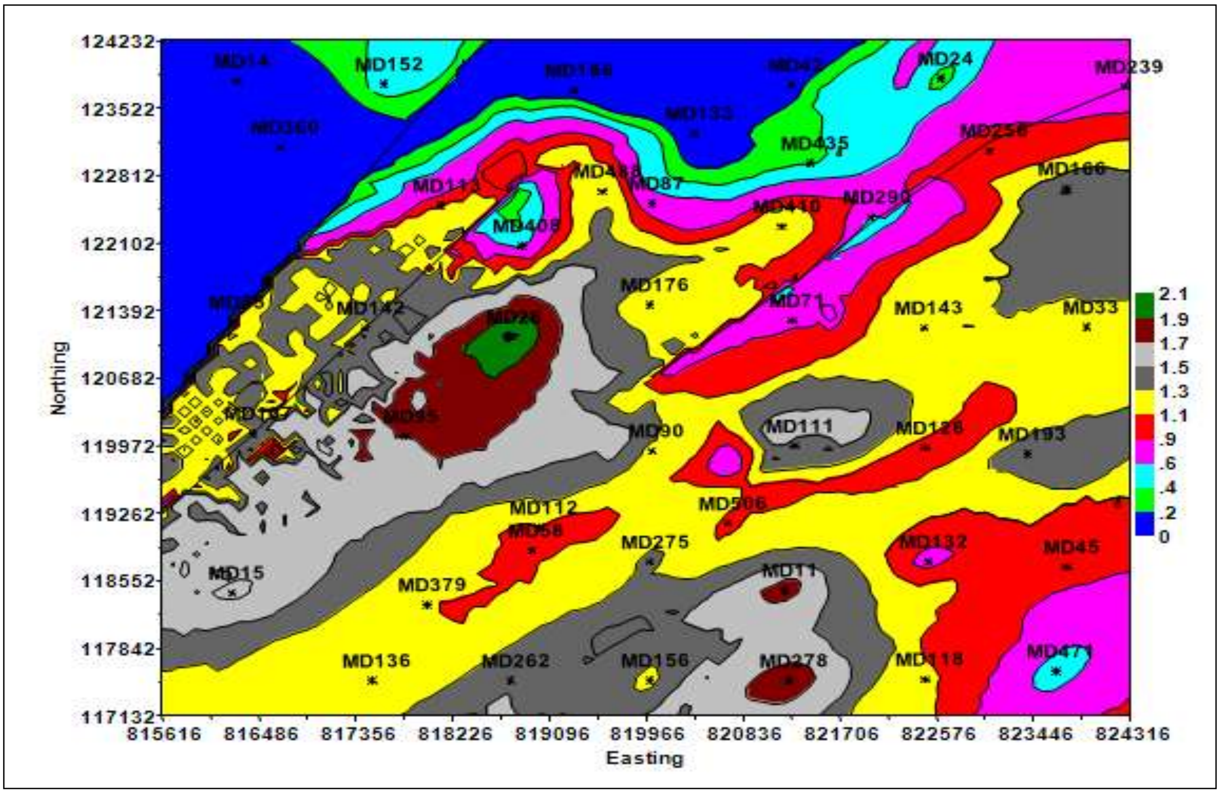

Exhibit 12 : Reservoir volume (phi * h) for D3.

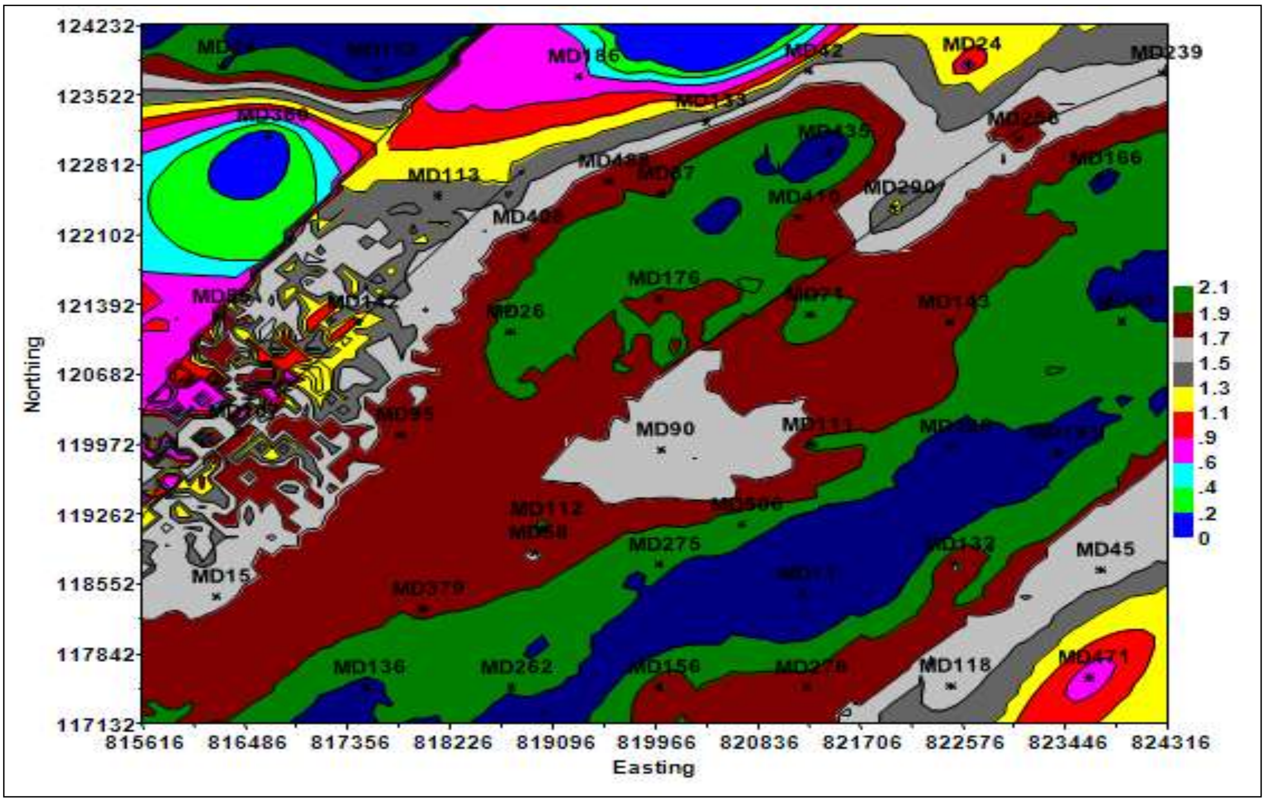

Exhibit 13 : Reservoir volume (phi*h) for D2.

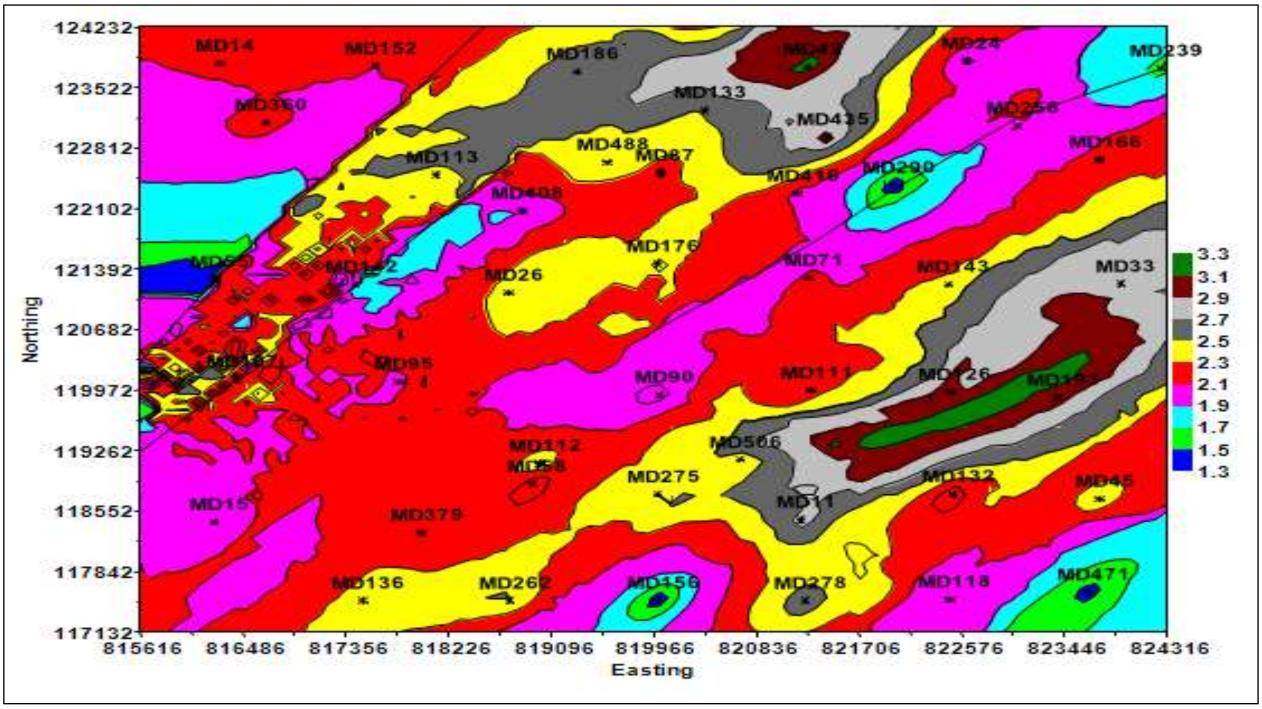

Exhibit 14 : Reservoir volume (phi*h) for ID.

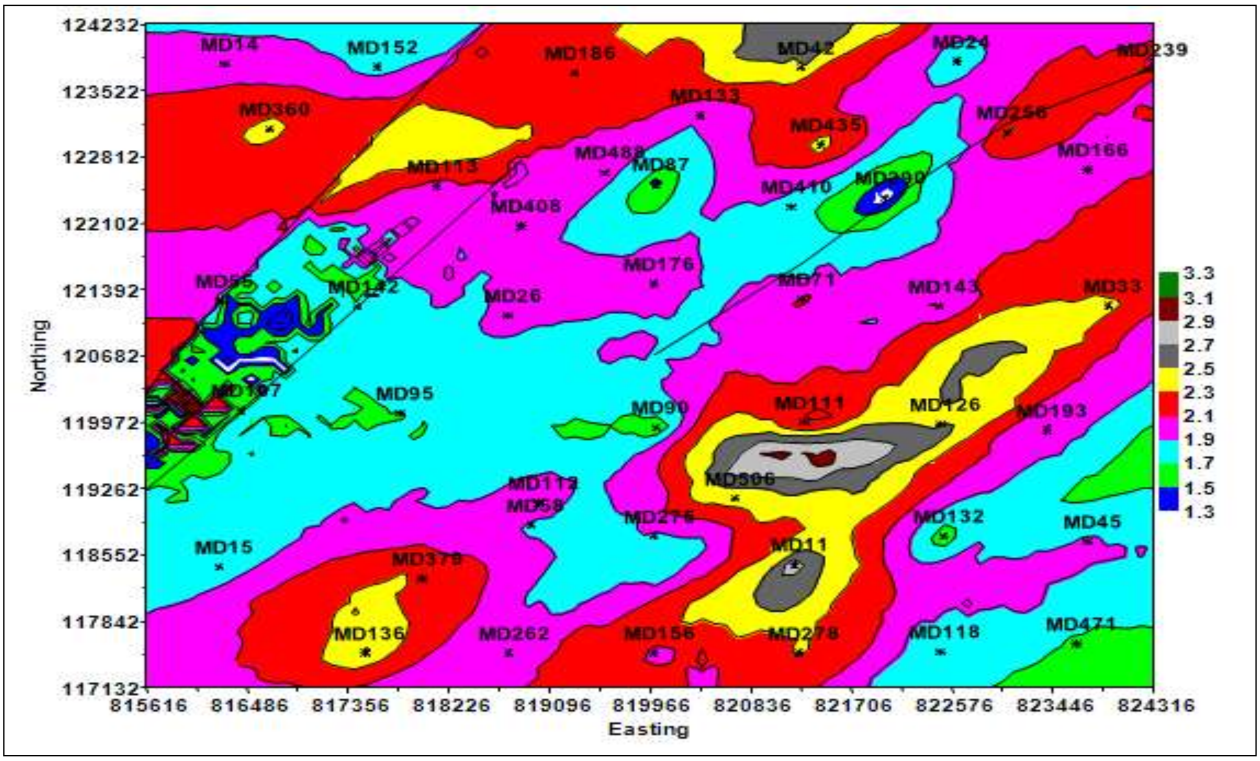

Exhibit 15 : Reservoir volume (phi*h) for D1 (m).

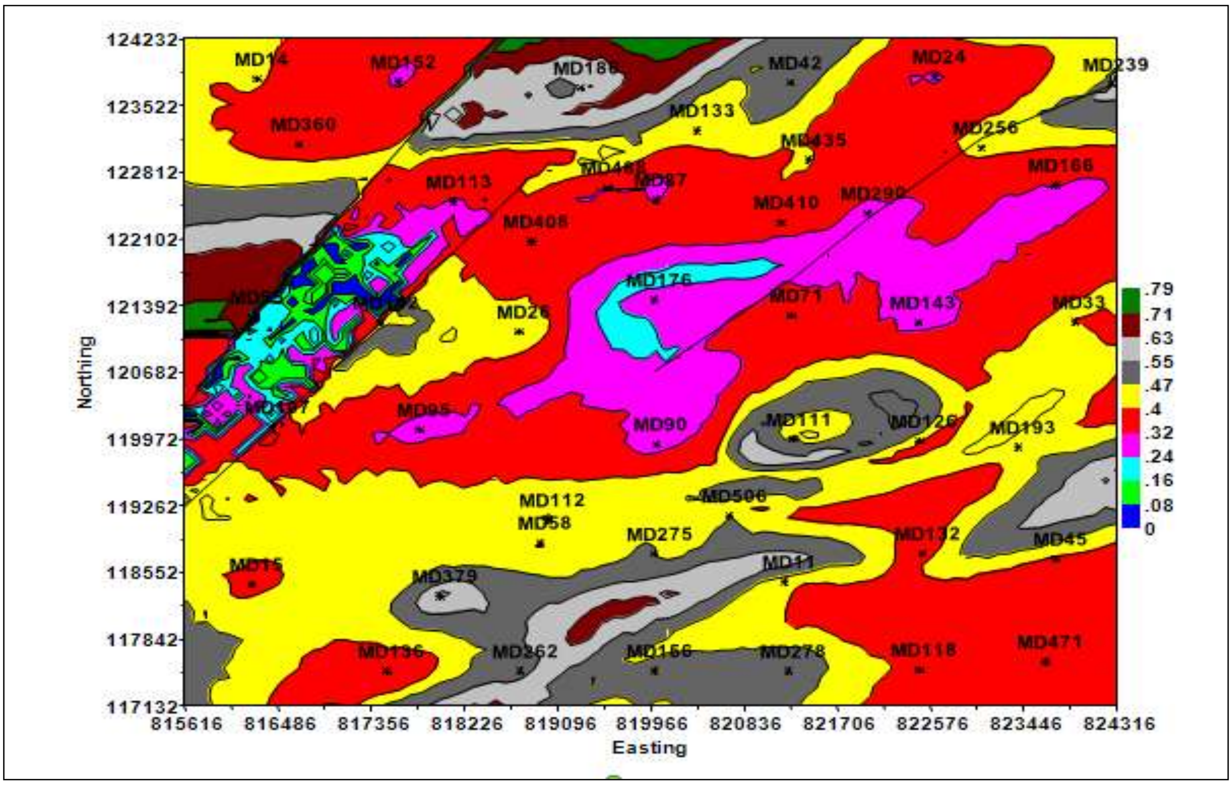

Exhibit 16 : Reservoir volume (phi*h) for ZPG