ENHANCED OIL RECOVERY BY WAG PROCESS IN A MATURE OIL FIELD

A THESIS SUBMITTED TO THE INSTITUTE OF GRADUATE STUDIES OF NEAR EAST UNIVERSITY

By
SARKASH NAEB FAIDHALLA

In Partial Fulfilment of the Requirements for the Degree of Master of Science in Petroleum and Natural Gas Engineering

NICOSIA, 2021

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Approval of Director of Institute of Graduate Studies

Prof. Dr. K. Hüsnü Can BAŞER

We certify that this thesis is satisfactory for the award of the degree of Masters of Science in Petroleum and Natural Gas Engineering

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my family…

ABSTRACT

The most significant oil production method in the petroleum industry is EOR, which endeavors to deliver the last drop of oil. There are a few techniques for upgraded oil recovery; their determination relies upon the reservoir fluid and rock properties. In the viscous mature oil fields with only water or gas injection alone, the ideal recovery proficiency can't be accomplished on the grounds that the issue with superseding and under riding phenomenon. In this way in the examination the practicality of upgraded oil recovery by WAG will be researched with intend to accomplish a piston-like uprooting and improve the recovery productivity.

One of the EOR strategies that has been utilized in oil industry since the mid of the previous century is (WAG). This strategy is favored over different techniques for EOR in light of the fact that give superior recovery effectiveness as well as it is profitable in economic prospective (Afzali et al., 2018). As of late, there have been many intrigues and studies on WAG measure as an EOR strategy in matured oil fields through both miscible and immiscible dislodging which assists with augmenting the volumetric displacement productivity and recover more oil. This technique is an extraordinary preferred position over different strategies in light of the fact that the delivered gas and water can be reused through re-injection them back to the reservoir.

The purpose of this research is to investigate the influence of WAG injection in matured oil fields. Sensitivity study of certain WAG injection variables, such as injection cycle and injection fluid, has been performed, and their influence on cumulative oil and water output, water-cut, and gas-oil ratio has been evaluated.

The study concluded that injecting gas first then water over 360 days' injection period produce the highest amount of oil of around 6 million barrels been produced and less water and gas been produced. However, the simulation result illustrated that injecting water then gas over 90 days period have produced the minimum oil production of 2.83 million barrels and highest amount of water of around 4.5 million barrels of water.

***Keywords*:** Water-Alternating-Gas; SWAG; CO_2; matured oil fields; EOR

ÖZET

Geliştirilmişmiş petrol üretimi (EOR), son petrol damlasını çıkarmaya çalışan en önemli petrol üretim yöntemlerinin genel adıdır. Geliştirilmişmiş petrol üretimi için birkaç teknik vardır; bunların belirlenmesi rezervuar kayaç ve sıvılarının özelliklerine dayanır. Sadece su veya gaz enjeksiyonu ile viskoz olgun petrol sahalarında ideal üretim yeterliliği, sorunun yerine geçme ve sürme olgusu düzleminde gerçekleştirilemez. Bu şekilde incelemede, piston benzeri bir kök sökme gerçekleştirmek ve üretim verimliliğini artırmak amacıyla Su dönüşümlü gaz (WAG) tarafından iyileştirilmiş petrol geri kazanımının uygulanabilirliği araştırılacaktır.

Su dönüşümlü gaz (WAG), geçen yüzyılın ortalarından beri petrol endüstrisinde kullanılan EOR stratejilerinden biridir. Bu strateji, üstün iyileşme etkinliği kadar ekonomik açıdan da karlılık sağladığı olduğu kadar gerçeği ışığında farklı EOR tekniklerine karşı tercih edilmektedir (Afzali, vd., 2018). Son zamanlarda, hacimsel yer değiştirme verimliliğini artırmaya ve daha fazla petrolün geri kazanılmasına yardımcı olan hem karışabilir hem de karışmaz yer değiştirme yoluyla olgunlaşmış petrol sahalarında bir EOR stratejisi olarak WAG ölçümü üzerine birçok deneme ve çalışma yapılmıştır. Bu teknik, verilen gaz ve suyun rezervuara geri enjekte edilerek yeniden kullanılabileceği gerçeği ışığında, farklı stratejilere göre olağanüstü tercih edilen bir konumdur.

Bu çalışma, olgunlaşmış petrol sahasında WAG enjeksiyonunun etkisini incelemeyi amaçlamaktadır. Enjeksiyon döngüsü ve enjeksiyon sıvısı dahil olmak üzere belirli WAG enjeksiyon değişkenlerinin duyarlılık analizi yapılmıştır ve bunların etkileri kümülatif petrol ve su üretimi, su kesme ve gaz-yağ oranına göre analiz edilmiştir. Çalışma, 180 günlük enjeksiyon süresi boyunca önce gaz, ardından su enjekte etmenin diğer vakalara kıyasla en yüksek miktarda petrol ürettiği sonucuna varmıştır.

Anahtar Kelimeler: Su-Alternatif-Gaz; TARZ; CO_2; olgunlaşmış petrol sahaları; EOR

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LIST OF SYMBOLS AND ABBREVIATIONS

Ø:	Porosity
Kx, Ky, Kz:	Permeability in x, y, and z direction
FOPT:	Field oil production total
FWPT:	Field water production total
FGOR	Field gas-oil ratio
FWCT	Field water-cut
WAG	Water-alternating gas

CHAPTER 1
INTRODUCTION

1.1 Background

Enhanced oil recovery is one of the methods used to extract residual oil in place and improve the oil recovery from the reservoir by using different techniques, including thermal methods, gas flooding or chemical flooding. Around 20 – 30% of oil can be extracted by primary recovery or reservoir mechanism itself. Nearly up to 40% by secondary recovery which includes water injection or artificial lift. The recovery rate can be increased to 60-65% by using the modern enhanced oil recovery (Tariq, 2001). The most effective and common methods of EOR is gas injection and thermal recovery techniques to produce the residual oil. The common gases which were used for injection are nitrogen (N_2), carbon dioxide (CO_2) and produced gas from the reservoir (Taber et al., 1997). Carbon dioxide is extensively used as the injection gas in the water alternating gas process due to its availability and miscibility with displaced phase oil (except heavy oil). During the water alternating gas injection, the gas tends to contact the oil and causes changes in the composition of reservoir fluid and its equilibrium.

Water Alternative Gas (WAG) is a combination of water flooding and gas injection enhanced oil recovery techniques that it can be defined as the process of injecting water first then gas, and the cycle repeats till pushing the residual oil in place in to the producing wells. The process water-alternate-gas is that the water and gas are injected successively in which causes a reduction in the mobility of the gas and effectively help to reduce residual oil saturation in the reservoir. Figure 1.1 represents how WAG technique works(Muhammad, 2015).

Sweep efficiency is a measurement of the effectiveness of enhanced oil recovery (EOR) techniques that relies on the injection fluids contacted with the volume of the reservoir. The sweep efficiency depends on several parameters, including injection locations, fractures in the reservoir, reservoir thickness, permeability, positions of reservoir fluids contacts, flow rate, heterogeneity, reservoir rock wettability, mobility and density differences.

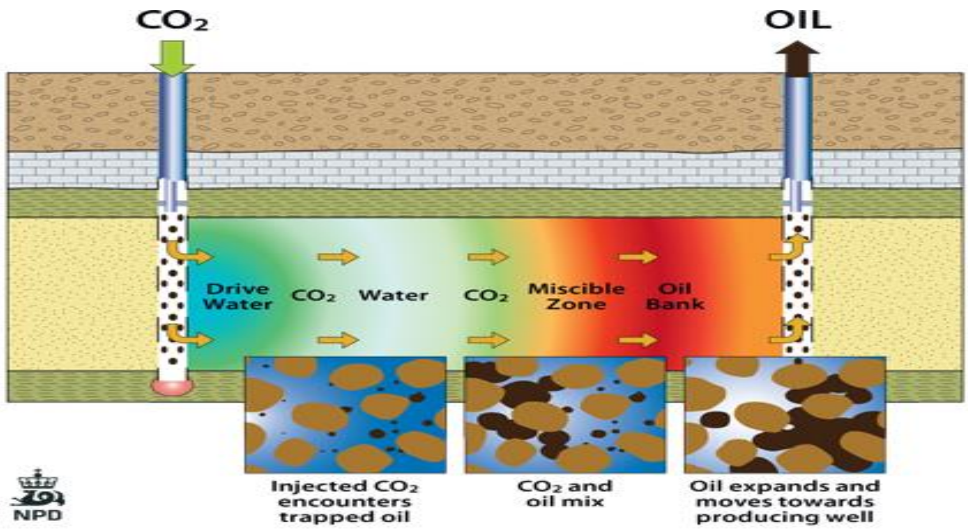

Figure 1.1: Water alternating gas process to recover oil (Muhammad, 2015)

Fluid properties, rock-fluid interaction, gas availability and composition, WAG ratio, permeability heterogeneity, injection pattern, cycling time, number of cycles, injection/production pressure and rate, three-phase relative permeability effects and flow dispersion, and finally time to initiate the WAG are all factors affecting WAG (Zahoor et al., 2011; Christensen et al., 2001; Heeremans, 2006).

WAG is the most common process and it's been carried out in different oil fields worldwide. There are many examples and case studies that describe the evaluation and effectiveness of WAG in the oil and gas fields. This technique has been used in an example of a field in an Iranian oil reservoir and its results indicated that high recovery efficiency is achieved (Reza et al., 2016). Based on previous field trails this method of enhanced oil recovery can be used in different reservoir conditions and types, as it can be used in water-wet system as well as oil-wet system due to its nature as it is a combination of both water flooding and gas injection methods.

This study will help to recognize the importance of WAG to improve oil recovery by increasing the sweep efficiency and reduce oil viscosity as well as this study helps to understand the important rock and fluid parameters as well as other variables that influence the degree of oil recovery by WAG process through using a simulation study.

This study also provides an overview to WAG injection process, and aimed to understand the factors that affect WAG process in order to maximize oil recovery by WAG injection, as well as it shows through a simulation work that WAG injection is most effective EOR method for matured oil fields.

1.2 **Research Objective**

The following are the main objectives of this study:

1. Using reveal simulation software to investigate oil recovery in brown-matured oil field (in declining production plateau).
2. Sensitivity analysis for gas and water injection fluid phase and cycles, and injection pattern through using reveal reservoir simulation software.

1.3 **Problem Statement**

Upgrade oil recovery EOR comprise of a few techniques like (thermal recovery, gas infusion, and surfactant injection and blend EOR strategies). Every one of them has its own methodology and picking measures, the best strategies rely upon the accessibility of materials which will be utilized just as the cost partners with the EOR strategy. Thermal methods are utilized for substantial unrefined petroleum, by warming the steam and infuse it to the oil reservoir and it decrease the consistency of weighty raw petroleum additionally increment streaming of oil through the rock. Another kind of EOR is gas injection; its recovery component relies upon the miscibility of the infused gas with the dislodged stage. With this strategy the thickness of dislodged stage (oil) will be diminished and hence expanded portability of oil will be accomplished in the reservoir. The gases which utilized for gas infusion generally are petroleum gas, nitrogen, or carbon dioxide (CO_2).

Substance Improve Oil Recovery incorporate three compound flooding measure like polymer flooding, surfactant-polymer flooding and antacid surfactant-polymer flooding (EOR). Today the majority of Oil Companies are zeroing in on expanding oil production just as limiting the activity cost. So as to get more advantage through the EOR procedure, the (WAG) strategy is broadly applied which is the blend of both water flooding and gas flooding. There are a few sorts which are Miscible Water Alternating Gas (MWAG) Immiscible Water Alternating Gas (IWAG), Saline Water Alternating Gas (SWAG), Hybrid Water Alternating Gas (HWAG), Foam Assistant Water Alternating Gas (FWAG) yet typically isolated into MWAG or IWAG, and generally IWAG is a viable cycle for weighty unrefined petroleum repository since it very well may be utilized in sandstone and chalk stone. In addition, it is additionally viewed as more efficient whenever contrasted with warm and substance EOR measure in light of the fact that both warm and synthetic EOR require surface framework and greater operating expenses (OPEX).

The WAG cycle with CO_2, as infused gas stage, is generally utilized in various sort of supplies as a result of both monetary and specialized inclinations. The IWAG indicated high recuperation productivity whenever contrasted and other WAG strategies, since these techniques decline water relative permeability in three immersion locales and improve volumetric compass proficiency. Besides, when the miscibility pressure is reached in the supply the consistency of oil diminishes and, in this way, expanded recovery factor. Anyway, MWAG measure is a powerful strategy for light raw petroleum as the miscibility weight can be effortlessly reached however the cost partners with this cycle can obstruct its application.

1.4 **Scope of Study**

Enhanced oil recovery (EOR) is the last method to recoup the rest of the oil in the reservoir which it comprises of many techniques, WAG is one of them. This investigation can be directed in zones where the primary and secondary oil recoveries have been utilized and oil remaining should be reduced.

EOR recoups the greater part of the rest of the oil higher than primary and secondary recovery methods, and it is applied when the reservoir pressure is low. The WAG cycle can be utilized and the achievement of the cycle relies upon liquid properties, rock-liquid interaction, accessibility of gas, WAG proportion, porosity heterogeneity, infusion design, cycling time, number of cycles, WAG proportion, infusion/production pressure and rate, three-stage relative permeability impacts and stream scattering lastly an ideal opportunity to start the WAG.

This project will predict the performance of water alternating gas (WAG) in matured oil field, which different scenarios will be examined, including injection cycle and pressure. The best scenario will be selected based on the simulation result, which the outcomes will be based on cumulative field oil production, oil recovery, GOR, and water-cut.

1.5 Structure of the Thesis

The first chapter of this thesis provides an introduction to the thesis topic and the second chapter contains an extensive review of past literature. The third chapter describes the methodology used in this thesis while the fourth chapter discusses the results gotten. Finally, the fifth chapter gives the conclusions and recommendations of this research.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

In the United States, EOR technology produced around 707,000 barrels of oil per day in 1998, accounting for about 12% of total crude oil output (Advanced Resources Internationa, 1999). Roughly 393,000 BOPD, or about 7% of total US output, comes from thermal EOR (mainly steam, hot water drive, and huff-and-puff activities). EOR using carbon dioxide (CO_2) recovers around 196,000 barrels of oil per day (BOPD), or about 3% of US output. Hydrocarbon miscible EOR (mainly natural gas injection) recovers around 86,000 BOPD, or about 1.5 percent of US output, whereas nitrogen miscible/immiscible EOR recovers approximately 32,000 BOPD, or about 0.5 percent of US output. Chemical EOR and microbiological EOR, both still in the research stage, account for less than 1% of total EOR generation in the US (Advanced Resources International, 1999). Enhanced oil recovery methods are being used to recover around a third of Alberta's conventional recoverable oil reserves. As exploration prospects dwindle, the capacity to extract more oil from existing reserves has grown in importance as a source of new oil supply (Watkins and Chant, 1985). Since it is believed to be the future fuel source, EOR is gaining prominence. Every couple of years, the Oil & Gas Journal publishes a thorough research, and the data shows that oil output utilizing EOR techniques in Canada and the United States of America is increasing by approximately 25% and 10% of total oil production, respectively, and it is expanding. With increased oil costs and worries about future oil supply, Enhanced Oil Recovery is receiving renewed interest. By pumping specific fluids into the reservoir and sweeping the leftover oil, EOR techniques may substantially improve the recovery factor from reservoirs. Some of these EOR techniques are currently being used to generate a considerable amount of extra oil. Other methods, such as the microbiological technique, have yet to be commercially successful (Roger et al., 2004).

Because of the combination of solution gas drive, oil swelling, viscosity decrease, and miscible effects produced by hydrocarbon extraction from the oil, carbon dioxide is used in EOR methods. Light oil swells because carbon dioxide is highly soluble in hydrocarbons;

however, in methane reservoirs, less carbon dioxide dissolves in the crude oil, resulting in less oil swelling. In heavy oil, CO_2 solubility decreases, and EOR transitions to immiscible CO_2 flooding.

The viscosity of reservoir oil drops dramatically when it is saturated with carbon dioxide at high pressures (over the miscibility pressure). Carbon dioxide has an effect on the water in the formation; it expands, causing the density to drop, which implies that after injecting carbon dioxide, both the oil and water densities decline. CO_2 and water can be combined to produce a water alternating gas (WAG), as seen in Figure 2.1. This approach can be utilized to generate more favourable mobility ratios, and it will be employed later in this project.

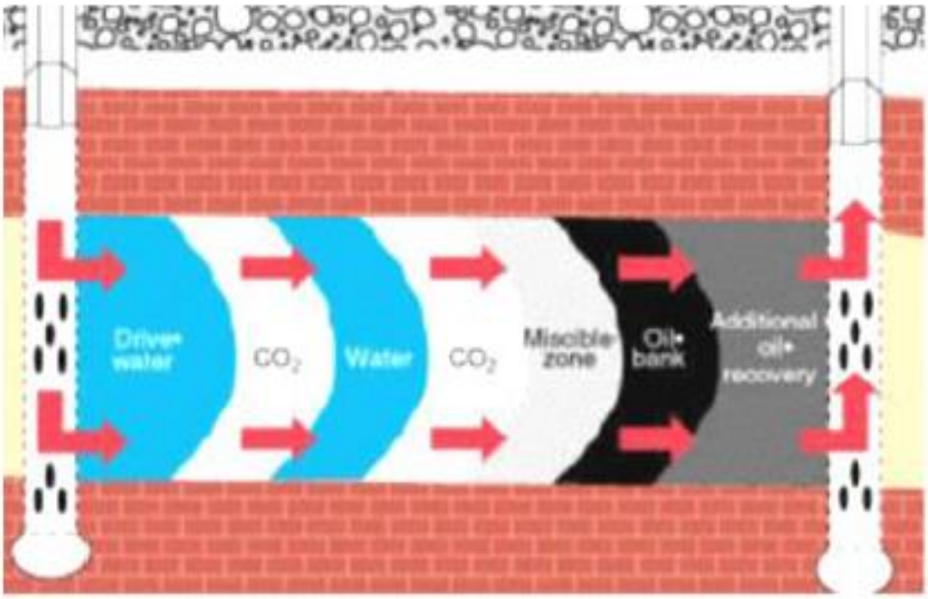

Figure 2.1: Combination of CO_2 and Water inject (WAG) (Qadir et al., 2021)

Additionally, WAG injection is used to touch attic oil that is not reached by water injection alone. Gravity segregation is frequent in highly porous sandstone reservoirs; as a result, gas tends to migrate to the reservoir's top, whereas dense water migrates to the reservoir's bottom. Thus, by injecting WAG, the injected gas may come into touch with attic oil in the top portion of the reservoir, and the resulting water flood will push the miscible slug. This increases microscopic efficiency by reducing the unswept reservoir area. Reduced residual oil in the reservoir results in increased oil recovery. As shown in Figure 2.2, the gravitational effect occurs during gas, water, and WAG injection (2018).

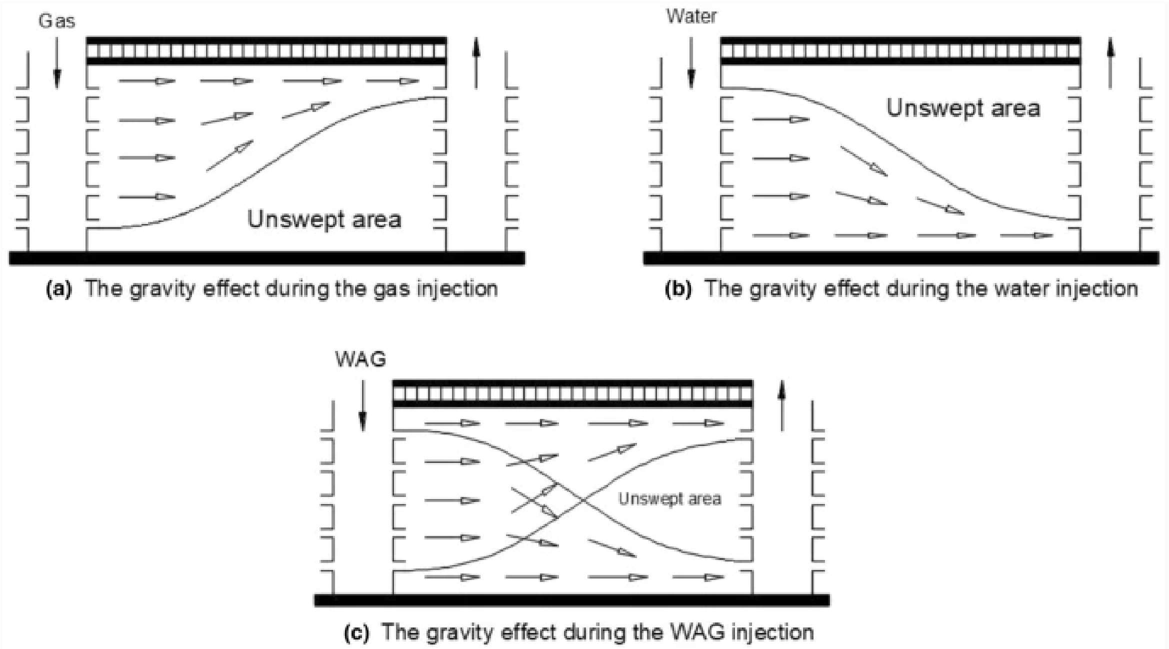

Figure 2.2: The gravity effect during gas, water and WAG injection (Mohammad and Mahmoud, 2018)

2.2 Water-Alternating-Gas

Water-alternating-gas is one of the most efficient oil recovery technologies, and it usually improves the range's efficiency while injecting gas. Water alternating gas (WAG) uses water and gas pumping cycles to enhance large oil recovery while just maintaining pressure in the supply. In wells where the wetting phase of the reservoir rock is water, water flooding is often used to increase oil recovery, but in wells where the wetting phase is oil, gas infusion is favored. Water alternating gas (WAG) has a better oil recovery rate than gas pumps and water floods alone, and it's widely used in both the oil and water wet phases to boost recovery and production (Freistuhler et al., 2000; Soares, 2008). When contrasted with gas or water infusion methods, the WAG cycle has two kinds of dislodging efficiencies: more noteworthy infinitesimal gas uprooting productivity and predominant plainly visible water clear proficiency, the two of which can prompt improved oil removal and recuperation (Christensen et al., 1998, 2001; Dehghan et al., 2009; Rouzbeh and Larry, 2010; Sohrabi et al., 2004).

Basically all undertakings in the WAG association incorporate gas mixture using the WAG strategy; it is represented that the United States has the most raised part of WAG application, followed by Canada, and it very well may be used to different kinds of vaults like sandstone and chalk. In the WAG measures, CO_2 gas is utilized 47% of the time, followed by hydrocarbon 42% of the time. Exxon made the essential WAG field application in 1959 in Alberta, with the recovery got by imbuing miscible gas following flooding. In diverged from either water or gas mixture, the results exhibited additionally created recovery. The dissolvability of the mixed gas in the overabundance oil grows the measure of oil that may be recovered in this strategy.

Lately, created hydrocarbon gas has been re-injected in water imbuement wells to additionally foster oil recovery and pressure insurance. Oil recovery by WAG imbuement has been ascribed to contact with upswept zones, particularly recovery of extra space or storm cellar oil by using gas partition to the top or water accumulation toward the base. Since extra oil after gas flooding is routinely lower than waiting oil after water flooding, three-stage zones may find lower remaining oil submersion. Influence imbuement can work on the efficiency of little moves. Thusly, WAG imbuement can construct oil recovery by solidifying additionally created versatility control and coming to upswept zones, similarly as by dealing with minute removing. Figure 2.3 depicts the recovery instrument in the WAG connection.

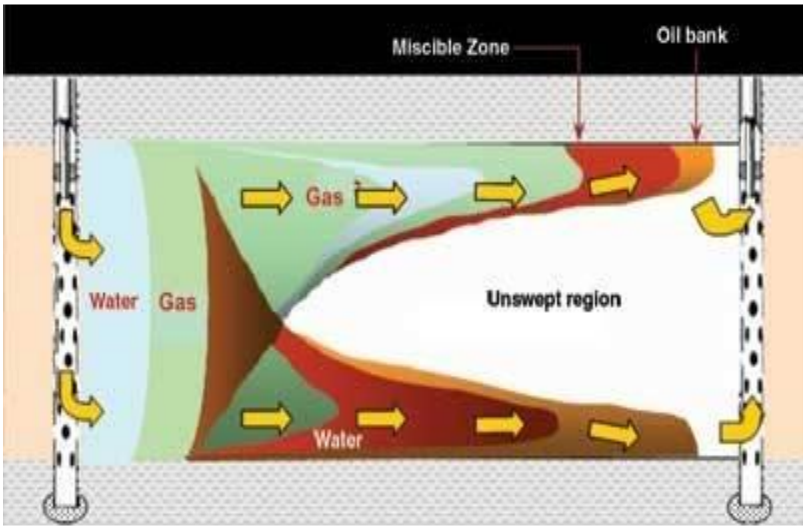

Figure 2.3: WAG injection technique (Paschoa, 2014)

WAG injection displacement tests were performed in the laboratory to assess its use in GS-5C sand from a developed light oil field (Srivastava and Mahli, 2012). The number of cycles in the WAG injection procedure has an effect on the recovery of oil from the circular sample. The five-cycle WAG injection method has an incremental displacement efficiency of 19.3 percent of Hydrocarbon Pore Volume (HCPV), compared to roughly 12.75 percent of HCPV in the single cycle WAG injection process. The WAG injection technique has also been validated for raising and lowering the WAG ratio (tapering). It was discovered that tapering in the WAG injection procedure restored displacement efficiency. Gas tapering with rising and decreasing WAG ratios results in incremental displacement efficiency of 20.73 and 23.84 percent of HCPV in the core pack, respectively.

The gas effect observations indicated that the CO_2 gas with five cycle WAG process provides an incremental displacement efficiency of 40.18 percent of HCPV, which is significantly greater than the displacement efficiency of 19.3 percent of HCPV in the five cycle WAG process utilizing hydrocarbon gas (Foraie et al., 2005; Henderson et al., 2000).

2.3 WAG Process Classification

There are numerous types of water-alternating-gas processes, but the most common are miscible and immiscible displacement processes (Christensen et al., 1998, 2001; Ho and Webb, 2006; Jensen et al., 2000). There are two types of gas utilized in the WAG process:

non-hydrocarbon and hydrocarbon. Non-hydrocarbon gases have a greater molecular weight, such as nitrogen and carbon dioxide, whereas hydrocarbon gases have a lower molecular weight, such as methane, ethane, and propane.

The gas is injected above the miscibility pressure and dissolves in the oil phase, resulting in decreased viscosity of the oil and increased flow of oil into the production well in the miscible WAG process. The gas does not dissolve in the oil in the immiscible water-alternating-gas process. Due to the three phase and hysteresis effect, the immiscible WAG process (IWAG) increases volumetric sweep efficiency and helps to lower interfacial tension (IFT). It also tends to minimize residual oil saturation. In light of various cycles, including worked on volumetric compass by water following gas, oil recuperation effectiveness in immiscible water substituting gas (IWAG) can be more noteworthy than that of water flood (Fernández Righietl., 2004). The presence of free gas in the permeable media decreases water relative penetrability in three-stage zones contrasted with pores involved only by water and oil, preferring water redirection to already un-cleared areas.

The reduction in oil consistency achieved by gas deterioration further fosters the adaptability extent of water-oil dislodging by virtue of (immediately) under doused oil. Since separated gas makes oil develop, extra oil contains less stock tank oil, growing recovery even without extra waiting oil inundation (Sor) cutting down part. Reduced interfacial strain (IFT) (gas-oil IFT is lower than water-oil IFT) awards gas to remove oil through little pore throats not accessible by water alone at the rhythmic movement pressure point. Getting of gas during imbibition cycles in water-wet stone can achieve oil actuation at low inundations and a fruitful reducing in the three-stage remaining oil submersion.

2.4 Factors Affecting WAG Design

The stone liquid association, gas accessibility and piece, WAG proportion, penetrability heterogeneity, infusion design, cycling time, number of cycles, WAG proportion, infusion creation strain and rate, three-stage relative porousness impacts, and stream scattering analogs are on the whole factors that impact the plan and execution of a water-rotating gas (WAG) measure. Increment the quantity of WAG infusion cycles to further develop clear proficiency.

2.4.1 Fluid properties and rock fluid interaction

The thickness of unrefined petroleum inside the repository is inseparably connected to liquid properties. These characteristics are surveyed utilizing standard testing methods. Sadly, on the grounds that the examples were gathered from different areas inside the repository, the test discoveries don't mirror an overall element of the supply. As the conditions inside the supply change because of tasks, unconstrained responses happen during infusion and handling exercises, making anticipating repository liquid properties essentially more troublesome (Zahoor, 2011).

Changes in rock-liquid communication as a result of changing repository conditions sway stream boundaries like fine strain and relative porousness (Josephina et al., 2006; Zahoor, 2011). In supply displaying, the stone liquid qualities of attachment, spreading, and wettability are frequently surveyed as a solitary amount, relative penetrability. Accordingly, when repository reproductions are utilized to acknowledge projections, this boundary is significant (Rogers and Grigg, 2000).

2.4.2 Reservoir heterogeneity and stratification

The level of network between the pores of an oil supply is commonly not equitably appropriated because of the non-consistency of pore size, bringing about confused and complex repository liquid stream direct. In geography, this is known as the hypothesis of heterogeneous porousness, and it can show up as unmistakable separate layers inside the oil repository, bringing about numerous homogenous layers with differing permeabilities:

Delineation and heterogeneity in various supplies might particularly affect a few boundaries like as slim tension, relative porousness, and versatility. The presence of various permeabilities and heterogeneity across a repository impacts the evacuation of local liquids by infusion liquid. As the uprooting dissolvable is coordinated into high porousness locales, its stockpiling and removal proficiency is decreased (Wu, 2004).

Notwithstanding, in light of the fact that this marvel administers the infusion and clear examples in the flood, it altogether affects the proficiency of the WAG cycle plan. This marvel will deliver critical changes in the supply's vertical and even porousness. Cross stream, thick, narrow, gravity, and dispersive powers all affect vertical porousness (Madhav, 2003). In any case, since gravity isolation doesn't rule liquid stream conduct, a low vertical to even penetrability proportion is invaluable for high recuperations (Zahoor, 2011; John and Reid, 2000).

2.4.3 Availability and composition of injection gas

The cost-effectiveness of a WAG method is heavily influenced by the availability of gas. During the WAG process, gas generated with oil from a reservoir is frequently removed and re-injected, resulting in lower expenses. Despite the fact that CO_2 WAG provided higher incremental output in the lab, Jensen believes hydrocarbon gas is more suited for the Ekofisk field (Jensen, 2000).

Mustafa (2001) led a mathematical examination at Turkey's B.Kozluca Field to assess the utilization of an EOR framework in the extension of oil creation. Under supply conditions, the field's oil gravity was around 12.6 API, with a similarly high consistency of 500 cp. Since a CO_2 supply is simply around 10 kilometers from the B.Kozluca field, a CO_2 gas infusion strategy was picked over other warm ways to deal with upgrade oil recuperation. Therefore, the accessibility of gas infusion is basic for computing the ideal WAG proportion.

The gas creation is basic in the WAG cycle plan since it is a choice boundary that chooses whether the interaction is miscible or immiscible at the current tension and temperature conditions inside the oil supply (Zahoor, 2011). Another significant thought is that gas arrangement is basic in the WAG cycle plan since it is a choice boundary that chooses whether the interaction will be miscible or immiscible at the current strain and temperature conditions inside the oil supply (Zahoor, 2011).

2.4.4 WAG ratio

In the WAG stage, gas and water slugs are of course implanted in a predestined blend known as the WAG infusion. As demonstrated by Wu, the WAG extent may then again be portrayed as the extent of the volume of water imbued into the store to the volume of implanted gas (2004). The WAG extent is a basic estimation to improve during the WAG stage. The WAG extent is critical in perceiving the ideal recovery part regard that identifies with the best WAG extent. Since the adequacy of any WAG plot is unequivocally subject to permeability assignment similarly as parts that choose the effect of gravity segregation (fluid densities, viscosities, and supply stream rates), the ideal WAG extent is storehouse express (Wu, 2004). According to John and Reid (2000), the WAG extent is unequivocally subject to the stockpile's wettability and the accessibility of the gas to be siphoned.

At the point when the WAG proportion is high, it can bring about oil ensnarement because of water blockage, or in any event, it can obstruct legitimate dissolvable oil association, making yield flood. In the event that the WAG proportion is extremely low, then again, the gas might channel and the yield effectiveness will seem to work like a gas flood, with fast tension decreases and early gas leap forward, bringing about a quick creation rate fall (Wu, 2004).

2.4.5 Injection pattern

Since the distance between the injector and the creating admirably impacts the oil clear execution, the situation of the wells is basic in the WAG interaction plan (Christensen et al., 1998, 2001; Mohammad et al., 2010).

A five-spot implantation setup is recommended in specific cases since it obliges more forward-looking migration control (Zahoor, 2011). In an Iranian broke stockpile, Mohammad et al. (2010) tracked down that a 4-spot plan (4 creators with 2 injectors) produces higher recovery than a 5-spot plan (6 producers with 2 injectors). Since it changes starting with one storehouse then onto the next, exhibiting studies ought to be used to choose the best implantation plans. Well course was assessed by Chase and Todd (1984), who arrived at the goal that coordinating with vertical creators with even injectors would extend recovery.

By making a scope of situations and assessing front engendering and recuperation improvement, reproduction studies have had the option to build up the ideal arrangement and course of wells, just as components, for example, WAG proportion, on account of advances in PC innovation and programming improvement (Farzaneh et al., 2009).

2.4.6 Injection/production pressure and rates

Maker base opening strain is perhaps the principal component influencing yield capability. Wu (2004) investigated the impact of Producer base opening strain on oil recovery using earlier exhibiting tests heterogeneous vaults, and tracked down that the creator base opening strain should be to some degree not exactly the air pocket point pressure, and that oil recovery is ideal at this pressure. If the producer base opening strain is basically lower than the air pocket point pressure, for example, gas headway happens fast, achieving a drop in oil yield. Relocation strain for dissolvable floods ought to be kept above MMP to deliver miscibility and uproot oil all the more proficiently. Lower infusion and creation pressures are set up therefore. The top furthest reaches of dislodging pressure is dictated by the development break pressure. The ideal plan objective at these strain limits is to infuse and convey at the most elevated potential rates. Water and gas injectivities in low and high porousness layers will be managed by the water-gas proportion and infusion speeds (Surguchev, 1992).

2.4.7 WAG cycle time

Another consideration while improving the WAG system is the timing of the shift from gas to water. Furthermore, over a large field, the timing of gas, water, and WAG inputs will give significant gas storage improvements (Wu, 2004). The use of a simulator enables a more in-depth examination of WAG cycle characteristics such as cycle length (Pritchard et al., 1992). To examine alternative cycle durations, Wu(2004) proposes replicating the WAG technique. This would allow us to figure out what cycle durations are best for our circumstance, as well as the effect of water and gas slug sizes on oil recovery.

2.5 Experimental Investigation of Miscible and Immiscible Water-Alternating-Gas Process

After thermal techniques utilized in substantial oil fields, gas infusion is the following most ideal choice. Madhav and Dandina (2005) researched the presentation of the WAG cycle as a component of gas–oil miscibility and brackish water organization in an exploratory review. To assess their exhibition, the oil recuperations from WAG infusion were contrasted with those from consistent gas infusion (CGI). The ideal technique for gas infusion, as per the finishes of this review, is a mix of CGI and WAG kinds of gas infusion (Madhav and Dandina, 2005).

A few creators did a review on tertiary immiscible WAG infusion with the Negara field in Argentina as the objective repository. As per their discoveries, oil recuperation effectiveness by means of WAG infusion was significant, bringing about lingering oil immersion as low as 13% (Femandez et al., 2004).

2.6 Types of WAG Injection

2.6.1 Simultaneous water-alternating-gas injection (SWAG)

Humble Oil and Refining Co. rushed to implant water and improved gas in Seeligson Field, Kleberg Country, Texas, in 1963 (simultaneous water pivot gas implantation). The mixture rate was missing, and the implantation pressure was superfluous. This part is routinely implied as a WAG variety recorded as a hard copy, regardless the way that it doesn't have a repetitive construction. In 1964, water was moreover used to override improved coal.

While the rate was higher in the primary cycle, gas was diminished at the creation wells, and water fixation at the wellbore worked on in later cycles. As per research, SWAG infusion has a higher versatility power than WAG infusion. The oil recuperation that follows is an all the more consistent gas uprooting. Joffre Viking Tertiary Oil Unit explored a few infusion strategies, including consistent CO_2 infusion, water rotating (CO_2-WAG) infusion, and equal CO_2 and water infusion, for pilot study (JVTU). In the pilot research, the SWAG administration was outfitted with twin tubing strings. The outcomes uncovered that synchronous water and CO_2 infusions at the 1:1 infusion stage expanded range productivity more than standard CO_2-WAG-and ceaseless CO_2 infusions. Tests further show that the SWAG has more prominent scope execution: in five-point floods, concurrent water and gas infusion brought about 90% clearing proficiency, contrasted with 60% for gas infusion alone (Caudle and Dyes, 1958). In specific cases, consolidated water and gas infusions incorporate techniques that incorporate infusing a water arrangement and broke up CO_2 into the tank, a method known as a carbonated water infusion or "bubble flood." When contrasted with WAG-EOR systems or full-scale miscible gas floods, carbonated water infusion didn't give massive money saving advantages. Carbonated water infusion has been fruitful in normally cracked supplies and repositories with low porousness (e.g., Austin chalks). In spite of the advantages of SWAG infusion, there are various downsides, including higher well-completing, gear, and working costs; complex plan; gravity isolation; and shakiness in the gas front (Rogers and Grigg, 2000).

2.6.2 Water alternating steam process (WASP)

The water alternating steam method (WASP) was created to beat issues with steam infusion like fume gravity, steam directing, and sporadic surface releases. This cycle might be viewed of as a change in WAG that works on the repository's upward conformance/removal. The fume stage (steam) in WASP can be consolidated, while the gas stage in the ordinary WAG measure is normally not condensable. The fume additionally gives nuclear power, which lessens oil consistency and lifts oil yield and clearing proficiency (by altering the portability proportion). The gravity overflow is reduced in size after the vapor condensation. Greater steam compliance, lower channeling capacity, less heat losses from spraying, faster production rate, and enhanced incremental oil recovery are just a few of the benefits of WASP over continuous steam inundations. The WASP was brought to the pilot stage at West Coalinga to address the issue of steam breakthrough (Hong and Stevens, 1990). The water alternating steam method (WASP) was created to beat issues with steam infusion like fume gravity, steam directing, and sporadic surface releases. This cycle might be viewed of as a change in WAG that works on the repository's upward conformance/removal. The fume stage (steam) in WASP can be consolidated, while the gas stage in the ordinary WAG measure is normally not condensable. The fume additionally gives nuclear power, which lessens oil consistency and lifts oil yield and clearing proficiency (by altering the portability proportion).

2.6.3 Foam assisted WAG injection (FAWAG)

The essential utilization of froth in EOR measures is to lessen the versatility of the gas stage, bringing about worked on clearing quality and more slow yield. Bond and Holbrook proposed the utilization of froth to control liquid front movement in 1958. To lessen execution, CO_2 froths containing surfactants were utilized broadly. Quite possibly the main variable affecting the effectiveness of the FAWAG interaction is the froth's solidness and qualities. The accomplishments of SWAG and FWAG were assessed in a progression of key flooding tests, with the SWAG strategy showing promising outcomes in lessening unfriendly versatility, force isolation, and thick fingering issues; nonetheless, in the FAWAG stage, a higher Recovery Factor (RF) happened, with RF initially expanding to 61 percent, and afterward ascending to 92 percent after FAWAG application as s Foam infusions have been used in a few EOR projects in the North Sea area for portability the board and well handling yield (to diminish produced GOR). Due to the low fluid flow resistance, foams can be formed in situ, most commonly in highly porous layers. The production of the in-person foam from a particular surfactant is a complicated event depending on oil saturation and capillary pressure. Figure 2.4 depicts the continuous gas (CO_2) injection displacement patterns, conventional WAG injections and FAWAG injections respectively (Afzali, 2018).

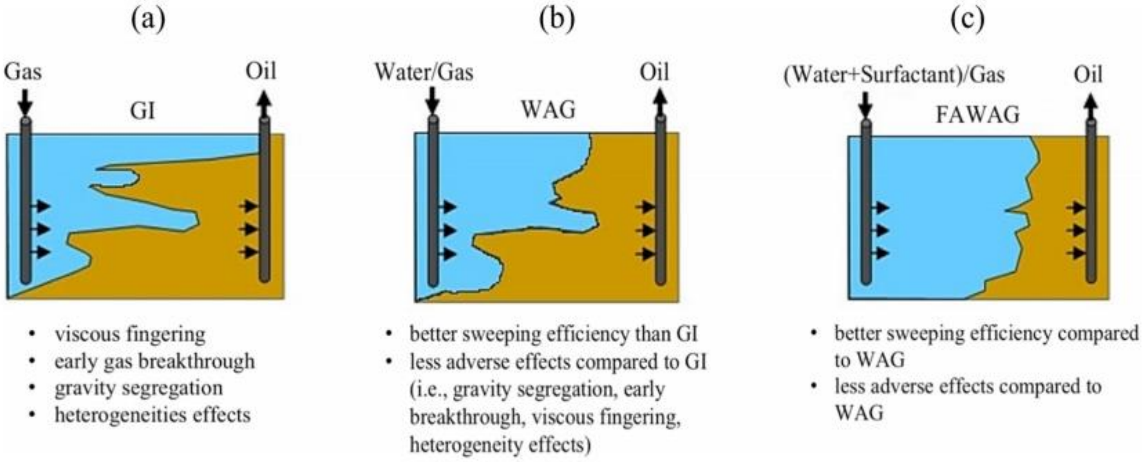

Figure 2.4: Schematic of challenges and benefits of continuous gas injection, conventional WAG injection and FAWAG injection in a reservoir modified after EOR respectively (Afzali et al, 2018)

2.7 Advantages and Disadvantages of the WAG Techniques

A few fields in the north have utilized this advanced infusion technique. Different fields in Canada have profited from these methodologies also. Contingent upon the properties of the supply and how the system is developed, the efficiencies might be significant. The adequacy is because of the advantages given by WAG system, which incorporate (Helena, 2012):

• Controls portability (lessens Gas preparing)

• Improves activity (less gas cycling)

• Improve leftover oil recuperation

The WAG approach, similar to some other strategy, has hindrances. The trouble of overseeing gas break as the flood continues is the essential impediment of this methodology. The subsequent impediment is slug size; the ideal slug size is frequently half HCPV inj. The shortfall of injectivity (water), which can be pretty much as high as 70%, is the last impediment. The accompanying ideal outcomes can be reached on a field-wide scale when the WAG interaction is successfully advanced: expanded in general recuperation (clear quality and oil recuperation), and improved monetary execution (Helena, 2012).

2.8 WAG Injection Technology Application

Sway infusion technique consolidates the upsides of two regular approaches to further developing oil recuperation proficiency: water and gas flooding. Sway establishment can improve both minute oil dislodging and clear proficiency (Surguchev et al., 1992). The concurrent infusion of water and gas from a similar infusion well is known as WAG infusion, and it further develops generally speaking breadth effectiveness by:

1. Because of oil enlarging, oil thickness is diminished and repository oil volume is expanded (Moffitt and Zornes, 1992).
2. Light oil part hydrocarbon stripping and vaporization (Jakobsson and Christian, 1994).
3. When contrasted with waterflooding, gas infusion diminished lingering oil immersion (Moreno et al., 2010).
4. Working on the consistence of waterfloods to build oil recuperation (Champion and Shelden, 1989).
5. Sway hysteresis, which is described by diminished water and gas mobilities just as decreased remaining oil immersion (Lazreg et al., 2017).
6. Gas infusion to build loft oil creation (Christensen et al., 2001). Maintaining reservoir pressure is number seven (Hermansen et al., 1997).

Different benefits of WAG infusion incorporate further developed gas the executives and in situ lifting.

The level of miscibility between infusion gas and in situ repository oil under supply conditions is utilized to characterize miscible and immiscible WAG infusion procedures. The WAG cooperation is miscible if the gas mixture pressure is more essential than the base miscibility pressure (MMP); regardless, the cycle isn't miscible. In field applications, the presentation and recovery factor of miscible WAG imbuement (MWAG) are generally higher than those of immiscible WAG mixture (IWAG) (Christensen et al., 2001).

During the WAG cooperation, hydrocarbon or non-hydrocarbon gases can be introduced. Non-hydrocarbon gases consolidate carbon dioxide (CO_2) and nitrogen. Hydrocarbon gases, similar to methane and ethane, are paraffins with a lower sub-nuclear weight (N_2).

The WAG imbuement contrives, similarly as the WAG extent, WAG cycle, WAG slug size, implantation rates, WAG term, and start-up time, are gigantically huge parts that influence the introduction of the WAG mixture (Yang et al., 2008).

Most of powerful WAG pilot projects have been represented from fields in the United States and Canada (Christensen et al., 2001). In the North Sea, China, Venezuela, North Africa, the Middle East, Malaysia, and Croatia, a couple of viable pitched exercises have been done.

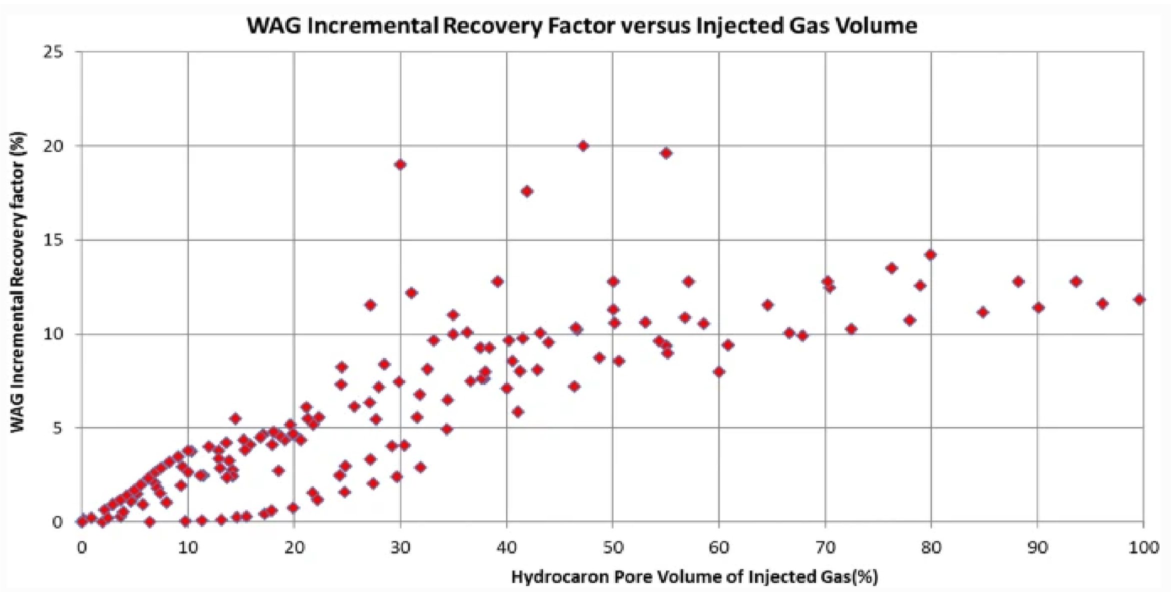

Figure 2.5: WAG incremental recovery factor vs injected HC pore volume

2.8.1 WAG success criteria

1. A higher rate of output and a lower rate of water production (Ma and Youngren, 1994).
2. Prompt and long haul expansions in oil creation and possible recuperation (Hinderaker et al., 1996).
3. The oil's thickness was brought down, while the oil's light parts were improved (Jingcun et al., 1997).
4. Coreflooding in the research facility uncovered that caught gas brings leftover oil down to waterflood, sorw. To decrease the leftover "stable" oil immersion, the oil's versatility must be expanded (Champion and Shelden, 1989).
5. Sway infusion has been found to increment waterflood proficiency and lower the water–oil proportion (WOR) (Champion and Shelden, 1989).
6. An increase in the well's GOR with time, as well as a flattening of the water cut and oil production rate (Choudhary et al., 2011).
7. The decline rate was over 55 percent prior to the introduction of WAG, but after a year, it had dropped to less than 25 percent (Choudhary et al., 2011).
8. A laboratory displacement study indicated a 14.5 percent improvement in displacement efficiency in the target sand as compared to a water flood (Ramachandran et al., 2010).
9. After the commencement of WAG, oil output from pilot wells rose, while water cut reduced (Ramachandran et al., 2010).

2.8.2 Mechanisms and advantages of WAG recovery

1. Oil expanding makes the consistency of the oil drop and the volume of the supply oil to develop (Moffitt and Zornes, 1992).
2. Strain support, gravity waste, and compositional impacts such vaporization and thick oil dislodging by gas (Hermansen et al., 1997).
3. Hydrocarbon stripping, oil enlarging and vaporization, and tension help (Jakobsson and Christian, 1994).
4. Sub-atomic dispersion, gravity waste, vaporization/depriving of oil beneath the air pocket point, enlarging of oil over the air pocket point, relocation of gooey fluids (Jakobsson and Christian, 1994).
5. Gas infusion versatility is controlled, diminishing gas dealing with needs (Champion and Shelden, 1989).

6. Higher oil recuperation factor because of improved waterflood consistence (Champion and Shelden, 1989).
7. Oil enlarging and thickness decrease help in preparing (Hsie and Moore, 1998).
8. Repository heterogeneity, scattering, and dissemination were considered to expand CO_2 spread and blending in with supply oil, accordingly expanding volumetric compass (Hsie and Moore, 1998).
9. More proficient repository the executives (further developed gas taking care of, in-situ lifts) (Ma and Youngren, 1994).

2.8.3 Pilot WAG difficulties and concerns

1. The creation of in situ carbonic corrosive is relied upon to prompt the breakdown of carbonate establishing components inside the repository (Hsie and Moore, 1998).
2. Because of sand creation, disintegration upgraded downhole consumption (Hsie and Moore, 1998).
3. Likewise with gas infusion, gas isolation rules downdip infusion (Hinderaker et al., 1996).
4. Repository intricacy/thickness of arrangement, connect between principal field and east side, creation well inclusion, distance between WAG injector and creation wells, impressive gas relocation vertical in the development, WAG execution was thought little of in reproduction (Crogh et al., 2002).
5. A full field reproduction model doesn't as expected repeat the WAG cycle in light of the fact that to network size and vertical repository penetrability (Crogh et al., 2002).
6. During the WAG interaction, there is a gas sidestep (Pritchard et al., 1990).
7. CO_2 was infused generally through a porous pathway (Jingcun et al., 1997).
8. The infusion strain of the water injector was expanded (Jingcun et al., 1997).
9. The resultant fluid was fairly acidic after calcium, magnesium, chloride, and saltiness were added (Jingcun et al., 1997).
10. The strain at the wellhead expanded as the gas–oil proportion expanded (Jingcun et al., 1997).
11. As repository versatility lessened, well temperatures dropped and makers' fluid creation declined (Jingcun et al., 1997).

12. The improvement's prosperity relied on the capacity to control mixture between the upper and lower zones (Al Shamsi et al., 2012).

CHAPTER 3
METHODOLOGY

The entire process used in this project is discussed and outlined in this chapter. The knowledge learned from simulation experiments has been analyzed and briefly discussed here.

3.1 Scenario 1

Reveal reservoir simulation used in this project. An imaginary reservoir model has been created. In this simulation run, WAG injection has been investigated. The simulation runs for 1720 days of production. Different injection cycles and injection fluid has been examined. The results are analyzed and compared through water-cut, gas-oil ratio, total pol production and cumulative water produced.

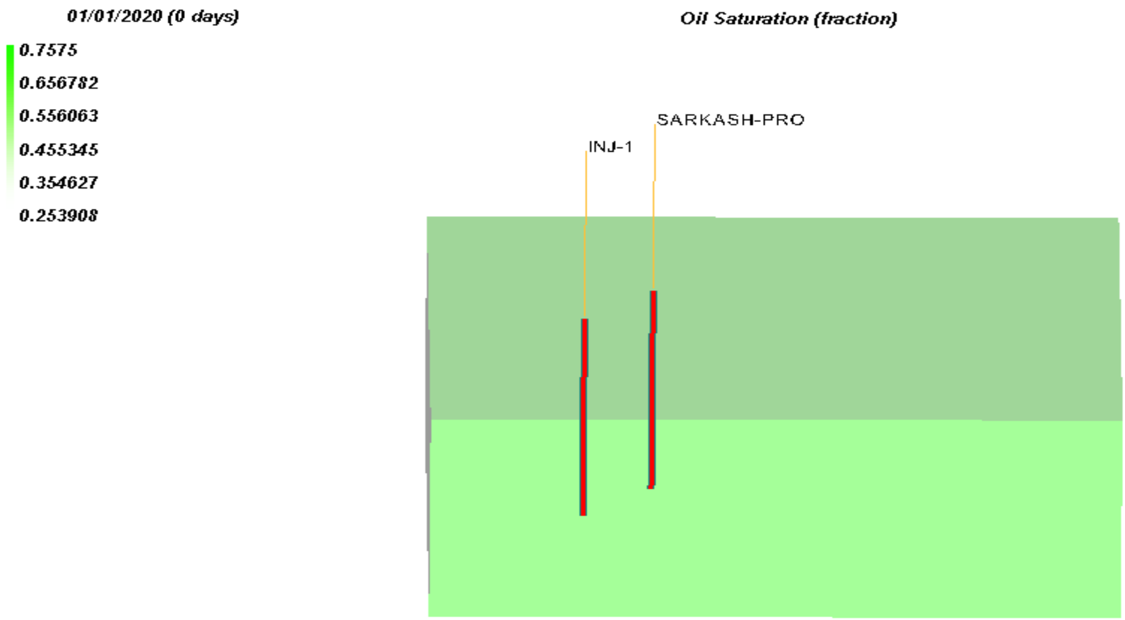

Figure 3.1: 3D reservoir model

The reservoir dimensions are 20x15x2, include a production well located in cell (7, 6) and completed in the layers 1-2 and an injection well located in (5,8) and completed in both layers. The reservoir model used in the simulation analysis is depicted in Figure 3.1. the created reservoir model is an imaginary one for the purpose of investigating WAG injection parameters and their effect on production performance.

Relative permeability data of oil-water and gas-oil are shown in Tables 3.1, 3.2 and 3.3.

Table 3.1: Water-oil relative permeability data

Sw	Krw	So	Krow
0.25	0	0.25	0
0.269861	1.20E-06	0.29206	0.0021
0.290722	2.20E-05	0.33378	0.0115
0.311583	0.00012	0.3755	0.0316
0.332444	0.00037	0.41722	0.0647
0.353306	0.0009	0.45894	0.1129
0.374167	0.0019	0.50067	0.178
0.395028	0.0035	0.52153	0.2173
0.415889	0.0061	0.54239	0.2615
0.43675	0.0097	0.56325	0.3107
0.457611	0.0149	0.58411	0.365
0.478472	0.0218	0.60497	0.4247
0.499333	0.0309	0.62583	0.4898
0.541056	0.0574	0.64669	0.5607
0.582778	0.0981	0.66756	0.6373
0.6245	0.1574	0.68842	0.7199
0.666222	0.2401	0.70928	0.8087
0.707944	0.3518	0.73014	0.9036
0.75	0.5	0.75	1
1	1		

Table 3.2: Oil-Gas relative permeability data

So	Krog	Sg	Krg
0.25	0	0.05	0
0.29206	0.000595	0.073	0.003
0.33378	0.0047	0.104	0.0072
0.3755	0.0158	0.136	0.014
0.41722	0.0374	0.167	0.0234
0.45894	0.073	0.199	0.0363
0.50067	0.126	0.229	0.0515
0.52153	0.1602	0.292	0.0946
0.54239	0.2	0.324	0.1227
0.56325	0.2459	0.386	0.19
0.58411	0.2984	0.417	0.2305
0.60497	0.3578	0.512	0.3851
0.62583	0.4247	0.574	0.5124
0.64669	0.4994	0.637	0.6648
0.66756	0.5824	0.668	0.7487
0.68842	0.6742	0.684	0.7943
0.70928	0.775	0.701	0.8446
0.73014	0.8855	0.718	0.8967
0.75	1	0.734	0.9475
		0.75	1

Figure 3.2 shows the oil FVF versus pressure for different temperature conditions. Based on the plot, the greater the temperature, the higher the FVF of the oil.

Figure 3.3 shows the reservoir oil pressure before injecting EOR. It’s clear that the pressure is reducing over time. Figure 3.4 shows the oil viscosity vs. pressure for different temperature conditions. Based on the plot, the greater the temperature, the lower the viscosity of the fluid.

Figure 3.5 shows the bubble pointvs. pressure for different temperature conditions. Based on the plot, the greater the temperature, the greater the bubble point of the fluid.

Table 3.3: The main reservoir data

Parameter	Value	Unit
Reference Depth	4921	ft
Pressure	2148	psi
Reservoir Temperature	170	^oF
Production Rate	3000	bpd
Reservoir Dimension	20x15x2	(dx,dy,dz)
Pore volume compressibility	4.00E-06	1/psi
dx size	100	ft
dy size	100	ft
dz size	100	ft
Porosity	30%	Percent
Permeability	170	md
GOR	100	SCF/STB
Oil Gravity	30	API
Gas Gravity	0.78	Sp.gravity
Water Gravity	1.08	Sp.gravity
Mole Percent H_2S	0	%
Mole Percent CO_2	0	%
Mole Percent N_2	0	%

3.2 Simulation Procedure

The following steps represent the simulation procedure:

1. Prepare the simulation data
2. Examine the original case and estimate the time at which EOR is needed
3. Apply WAG injection method to the original case

4. Examine different injection cycles of 90 days, 180 days, and 360 days of injecting gas then water
5. Examine different injection fluid cycles, using water then gas
6. Compare the results
7. Select the optimum scenario

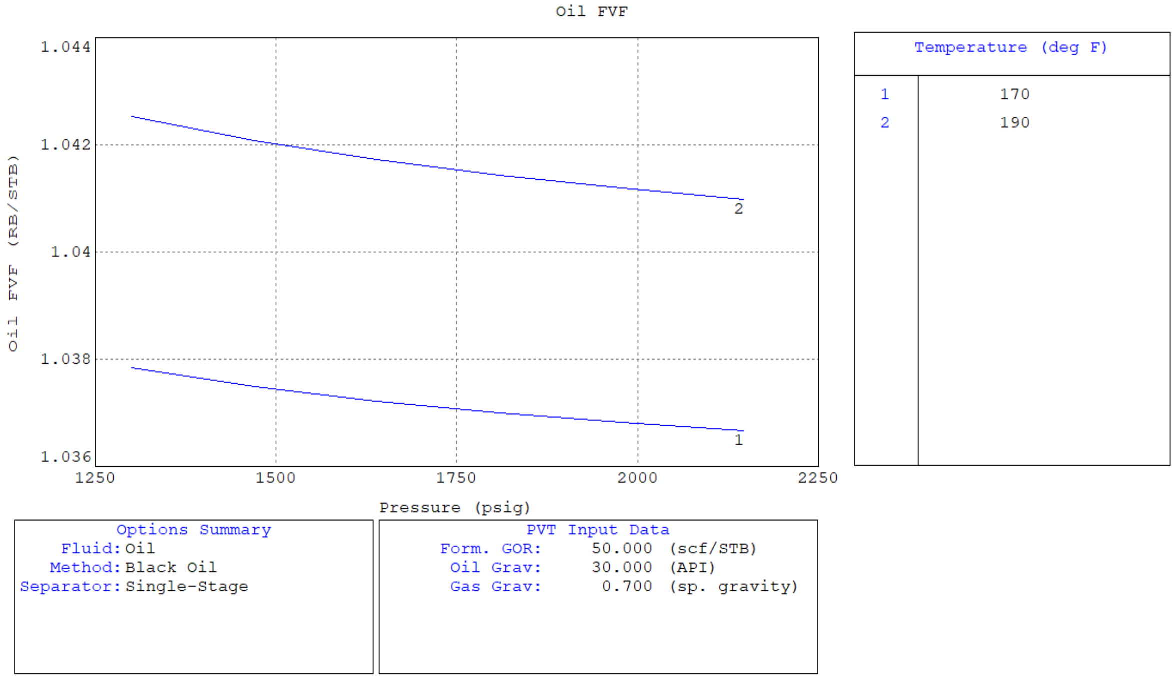

Figure 3.2: Oil FVF versus pressure for different temperature conditions

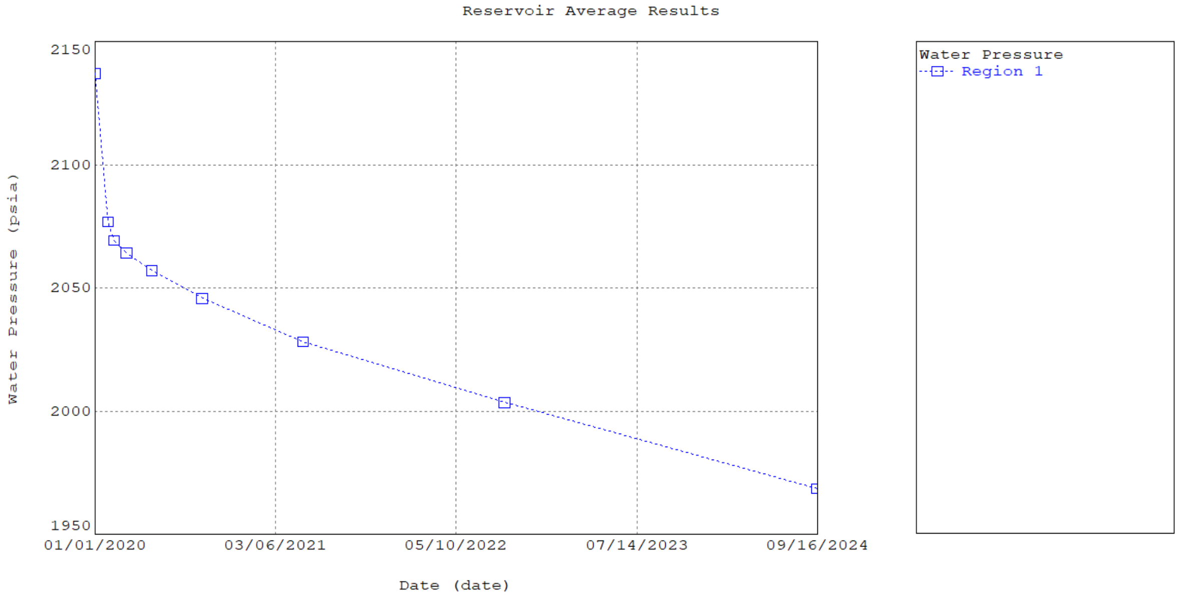

Figure 3.3: Reservoir pressure

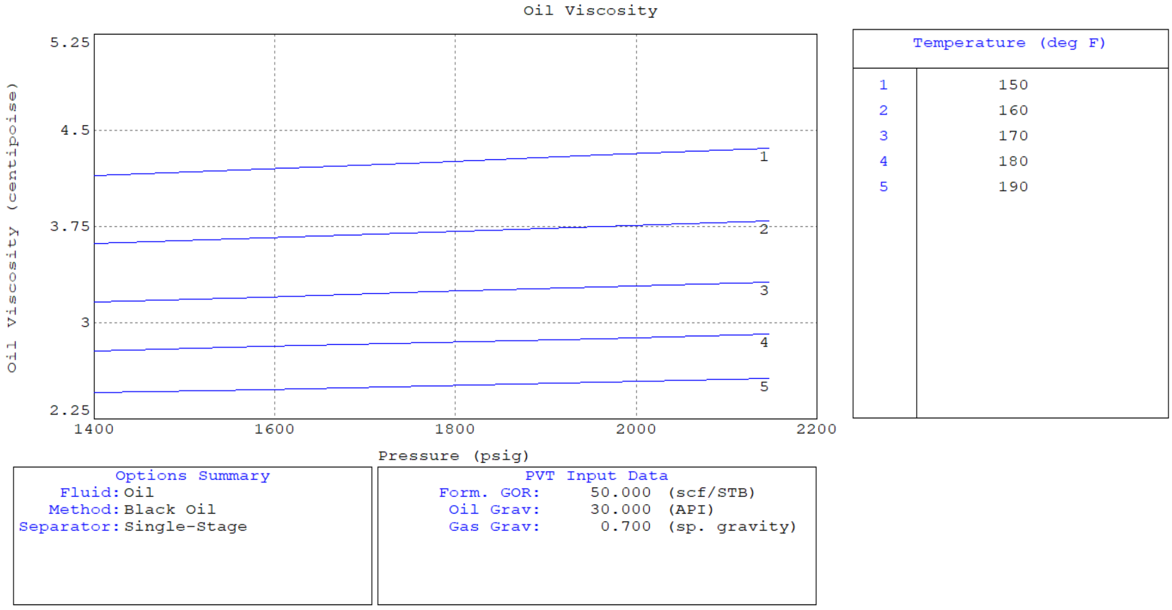

Figure 3.4: Oil viscosity vs. pressure for different temperature conditions

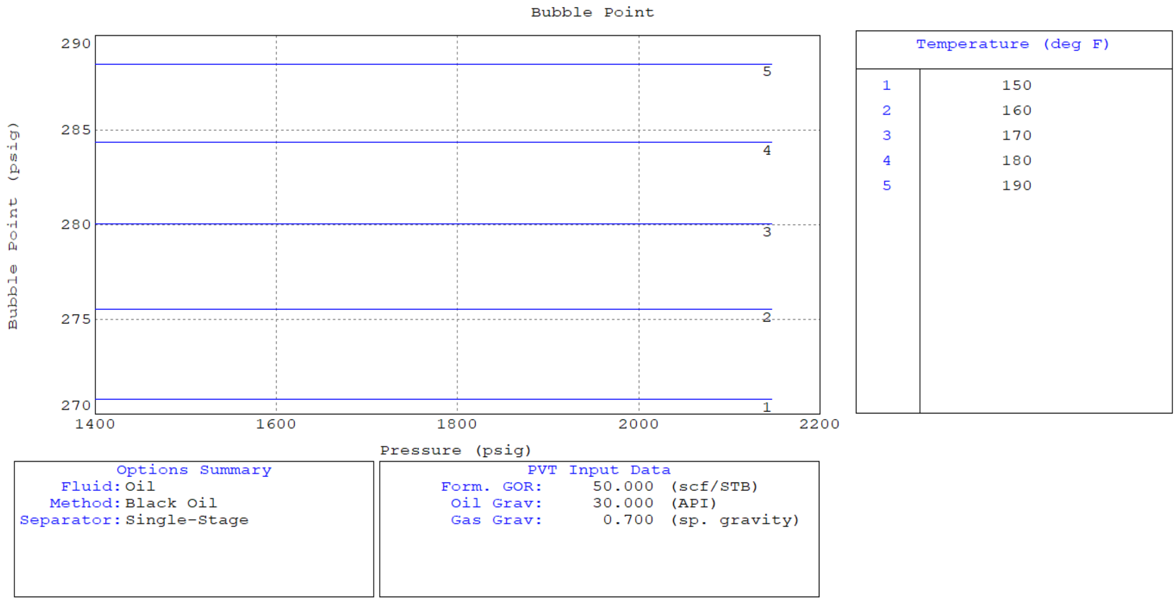

Figure 3.5: Bubble point vs. pressure for different temperature conditions

CHAPTER 4
RESULTS AND DISCUSSIONS

The findings of the investigation into the effects of WAG injection on matured oil fields using the Reveal compositional reservoir simulator are discussed and analyzed in this section. The impact of the WAG injection cycle on injection time and injection fluid is studied. The simulation was conducted for 1720 days and included a single production well as well as an injection well.

4.1 Effect of WAG Injection Cycle (Gas – Water)

4.1.1 Effect of 90 days WAG injection cycle on production performance

90 days WAG injection cycle has been investigated to see its impact on production performance in terms of cumulative oil production, cumulative water production, water-cut and GOR. Figure 4.1 shows the cumulative oil production and water cumulative production versus time for 90 days' injection cycle. Based on the result, a total of 3.22 million barrels of oil is produced and 3.82 million barrels of water also been produced.

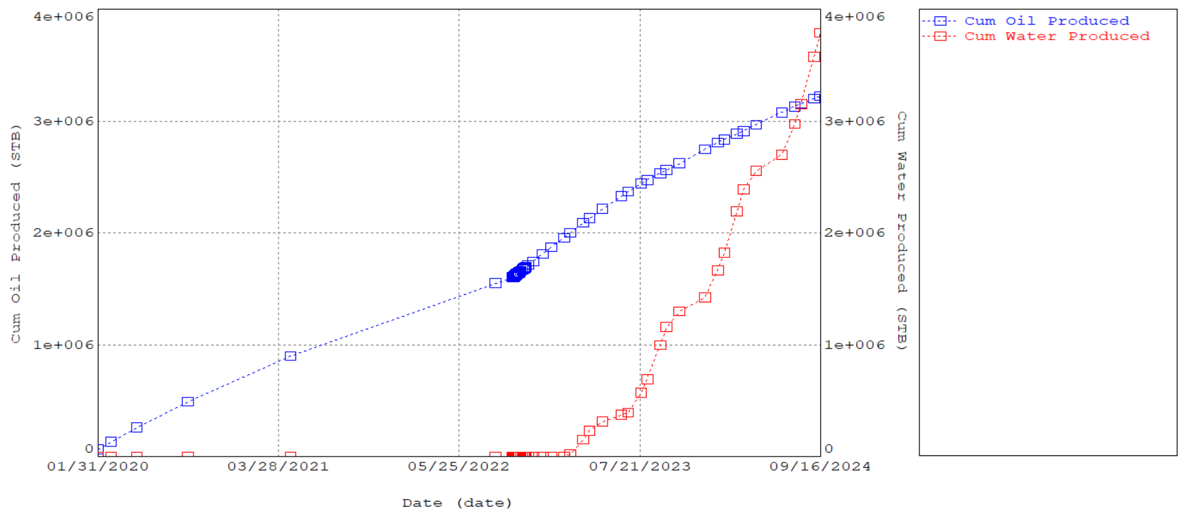

Figure 4.1: Cumulative oil production and water cumulative production versus time for 90 days' injection cycle (Gas-Water)

Additionally, the impact of 90 days' injection cycle on water-cut and GOR also has been investigated and Figure 4.2 shows the effect of 90 days' injection cycle on GOR and water-cut. Based on the obtained result, it is clear from Figure 4.2 that 90 days' injection cycle results in increasing GOR to 49247 scf/stb. The water-cut is increased to 88 % due to water injection applied after injecting the gas.

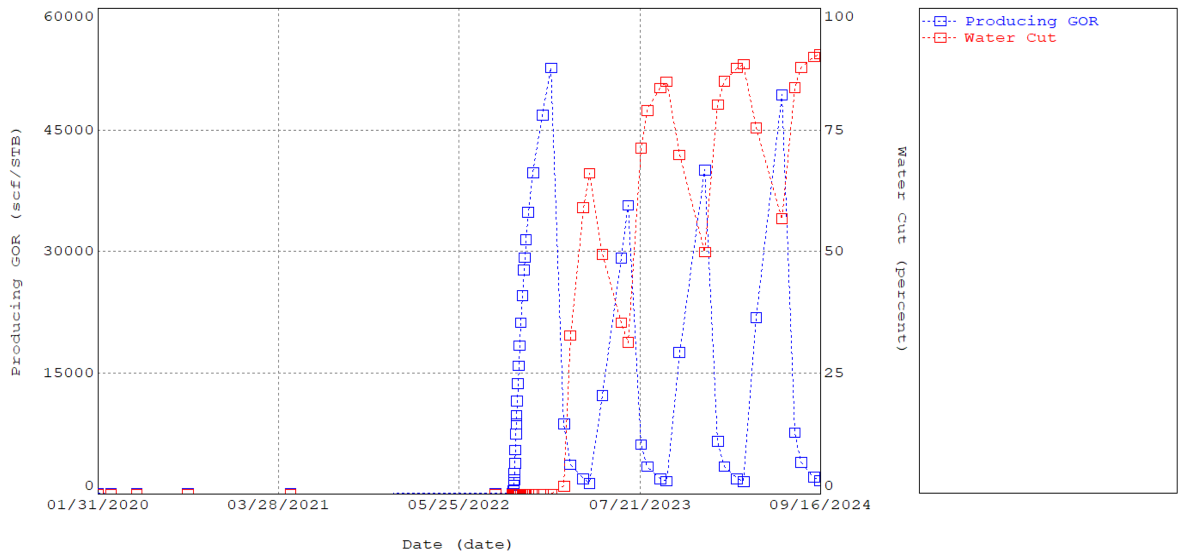

Figure 4.2: GOR and WCT versus time for 90 days' injection cycle (Gas-Water)

4.1.2 Effect of 180 days WAG injection cycle on production performance

The effect of a 180-day WAG injection period on production efficiency in terms of cumulative oil production, cumulative water production, water-cut, and GOR has been studied. Figure 4.3 depicts the combined oil and water production over time for a 180-day injection period. As a result, a total of 3.28 million barrels of oil were made, as well as 3.97 million barrels of water been produced.

The effect of a 180-day injection period on water-cut and GOR has been investigated, as seen in Figure 4.4, which indicates the effect of a 180-day injection cycle on GOR and water-cut. Figure 4.4 shows that a 180-day injection period results in an increase in GOR to 62370 scf/stb based on the collected results. The water-cut has been raised to 88 percent as a result of water injection after injecting the gas, as shown by the red colour.

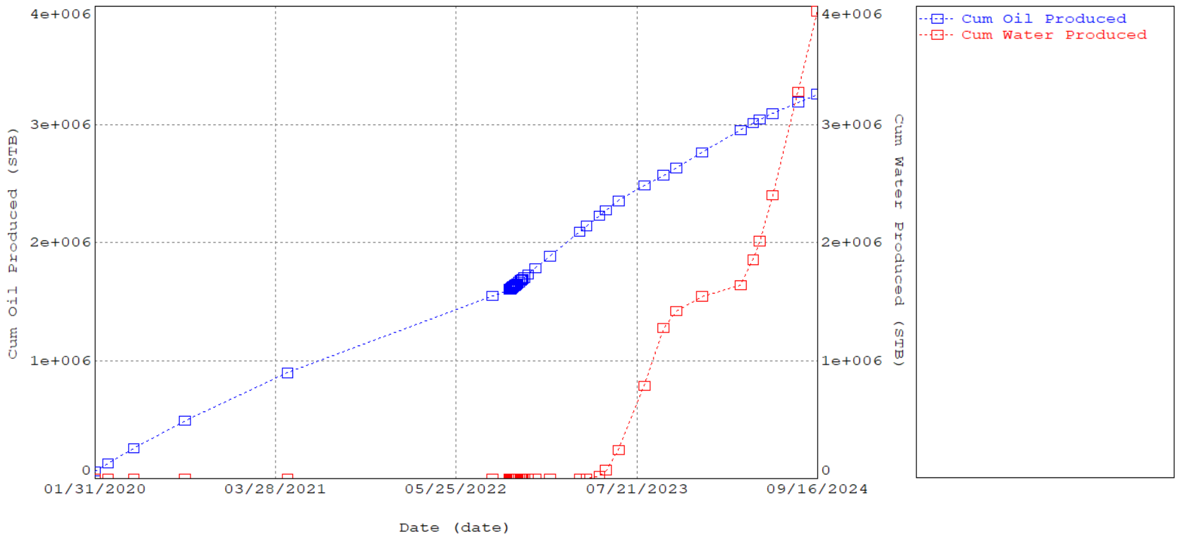

Figure 4.3: Cumulative oil production and water cumulative production for 180 days' injection cycle Gas-Water)

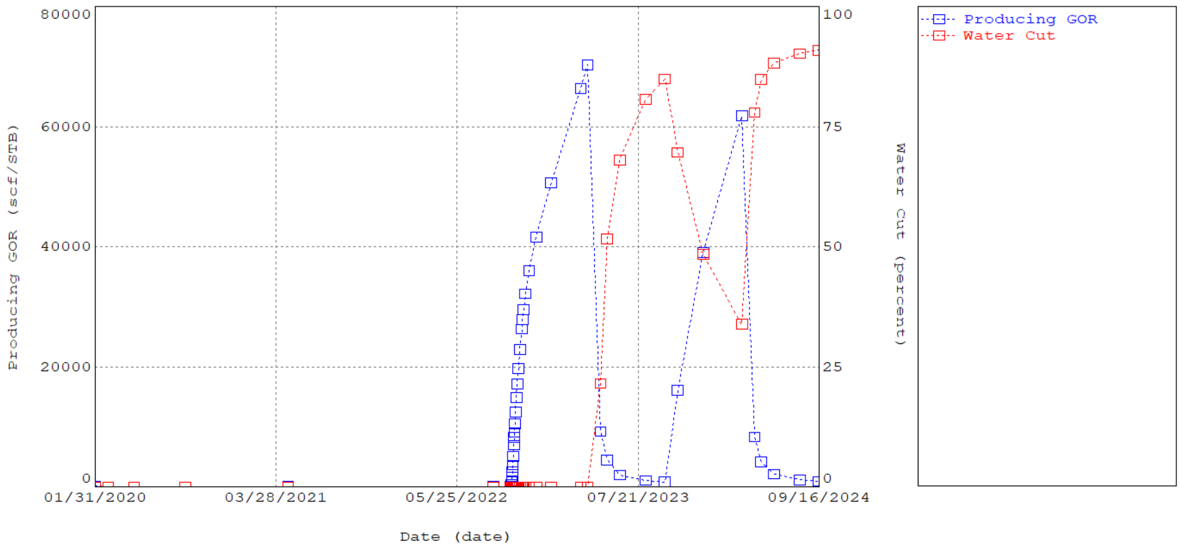

Figure 4.4: GOR and WCT versus time for 180 days' injection cycle Gas-Water)

4.1.3 Effect of 360 days WAG injection cycle on production performance

One-year cycle of gas-water WAG injection method has been used in this section. The result of the simulation run is shown in Figure 4.5 and 4.6. Figure 4.5 shows the effect of 360 days' injection cycle on total oil and water production. Based on the simulation result, this scenario has produced a cumulative oil of 3.19 million barrels while a total of 4 million barrels of water has been produced.

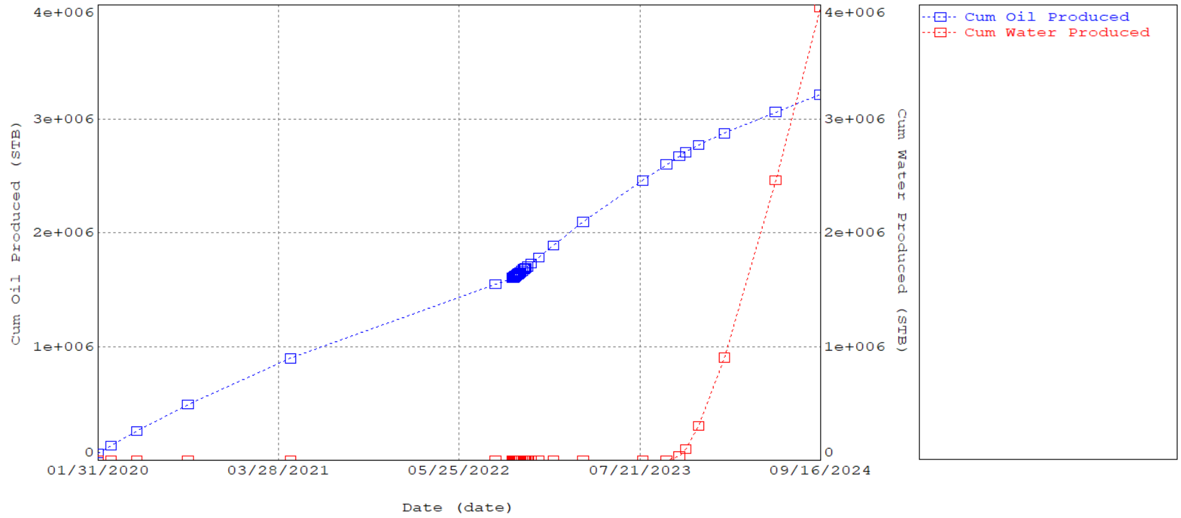

Figure 4.5: Cumulative oil production and water cumulative production versus time for 360 days' injection cycle (Gas-Water)

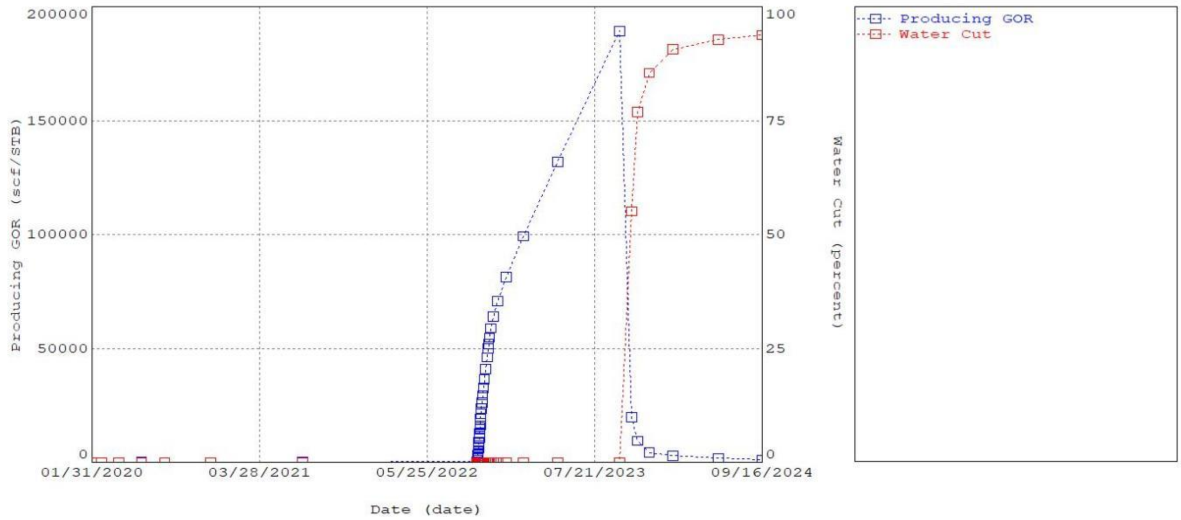

Figure 4.6: GOR and WCT versus time for 360 days' injection cycle (Gas-Water)

The effect of a 360-day injection period on water-cut and GOR has been studied, as seen in Figure 4.6, which demonstrates the effect of a 360-day injection cycle on water-cut and GOR. Based on the collected data, Figure 4.4 indicates that a 180-day injection cycle results in a rise in GOR to 112575 scf/stb. As shown by the red colour, the water-cut has increased to 91.3% as a result of water injection after injecting the gas.

4.2 Effect of WAG Injection Cycle (Water – Gas)

4.2.1 Effect of 90 days WAG injection cycle on production performance

The effect of a 90-day WAG injection period on production performance in terms of cumulative oil production, cumulative water production, water-cut, and gas-oil ratio has been studied. Figure 4.7 depicts the combined oil and water production versus time over a 90-day injection period. According to the results, a total of 2.83 million barrels of oil and 4.87 million barrels of water were made.

Furthermore, the effect of a 90-day injection period on water-cut and GOR has been studied, and Figure 4.8 describes the effect of a 90-day injection cycle on water-cut and GOR. Figure 4.8 shows that a 90-day injection period increases GOR to 48125 scf/stb based on the obtained data. The water-cut is raised to 90% as a result of the water injection.

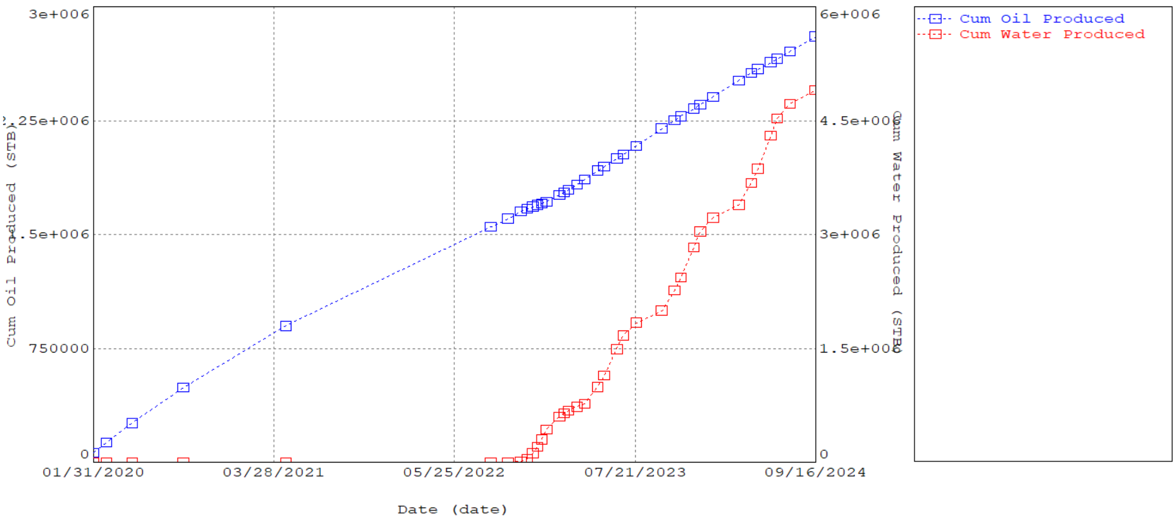

Figure 4.7: Cumulative oil production and water cumulative production versus time for 90 days' injection cycle (Water-Gas)

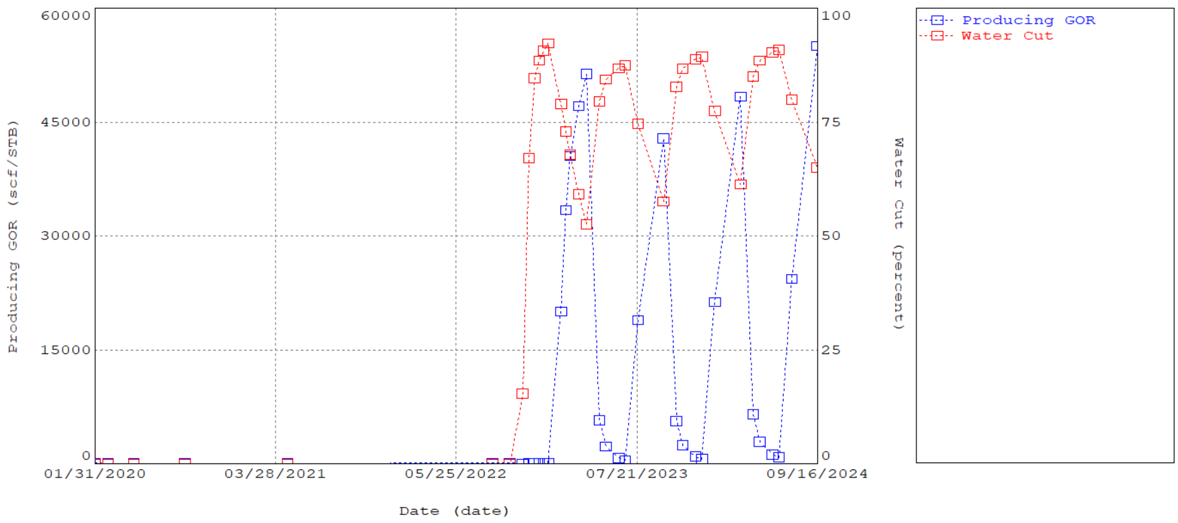

Figure 4.8: GOR and WCT versus time for 90 days' injection cycle (Water-Gas)

4.2.2 Effect of 180 days WAG injection cycle on production performance

This scenario involves using WAG injection method for an injection cycle of 180 days in which water is injected first then gas. Figure 4.9 shows the cumulative oil and water output over a 180-day injection duration. As a result, a total of 2.84 million barrels of oil and 5.53 million barrels of water were produced.

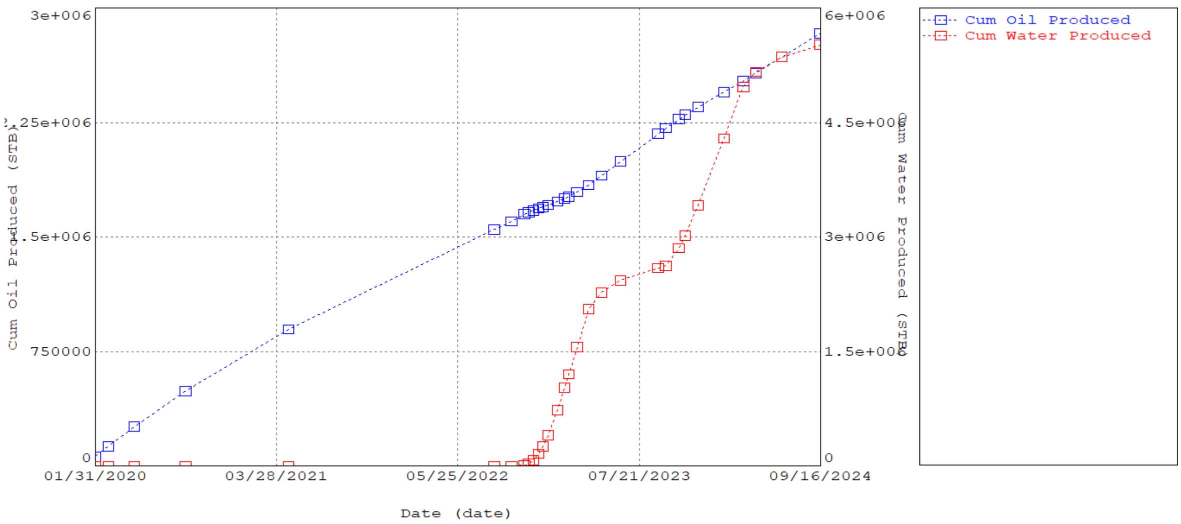

Figure 4.9: Cumulative oil production and water cumulative production versus time for 180 days' injection cycle (Water-Gas)

Based on the collected data, Figure 4.10 reveals that a 180-day injection cycle results in a rise in GOR to 58300 scf/stb. As shown by the red colour, the water-cut has increased to 89.2 percent as a result of water injection. The high GOR is due to the injected gas, in which its been produced with oil.

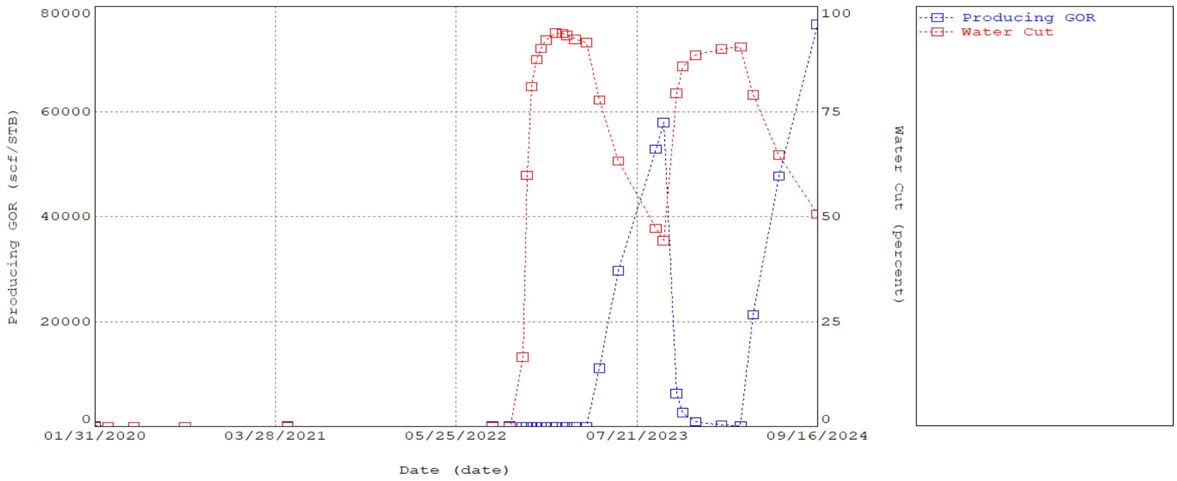

Figure 4.10: GOR and WCT versus time for 180 days' injection cycle (Water-Gas)

4.2.3 Effect of 360 days WAG injection cycle on production performance

The effect of a 360-day injection period on overall oil and water production is represented in Figure 4.11. According to the simulation results, this scenario provided a total of 2.84 million barrels of oil and 6.13 million barrels of water.

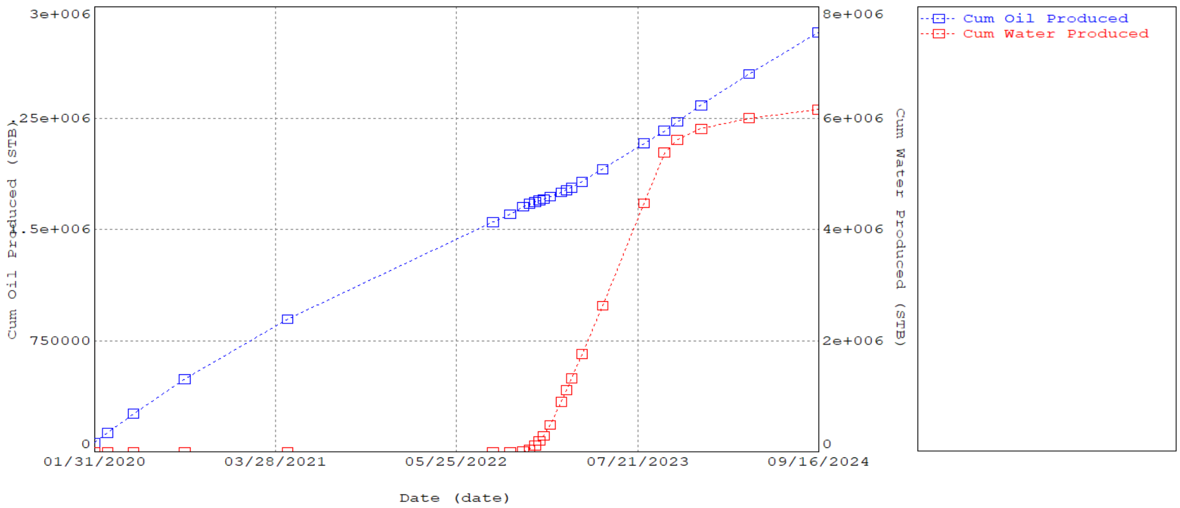

Figure 4.11: Cumulative oil production and water cumulative production Versus time for 360 days' injection cycle (Water-Gas)

Figure 4.12 shows the effect of a 360-day injection cycle on water-cut and GOR. Figure 4.12 shows that a 360-day injection period increases GOR to 95325 scf/stb based on the data obtained. As shown by the red colour, the water-cut rate has risen from zero at the beginning and began to rise when water was injected on January 2023 to 92 percent as a result of water injection, then decreased when gas was injected.

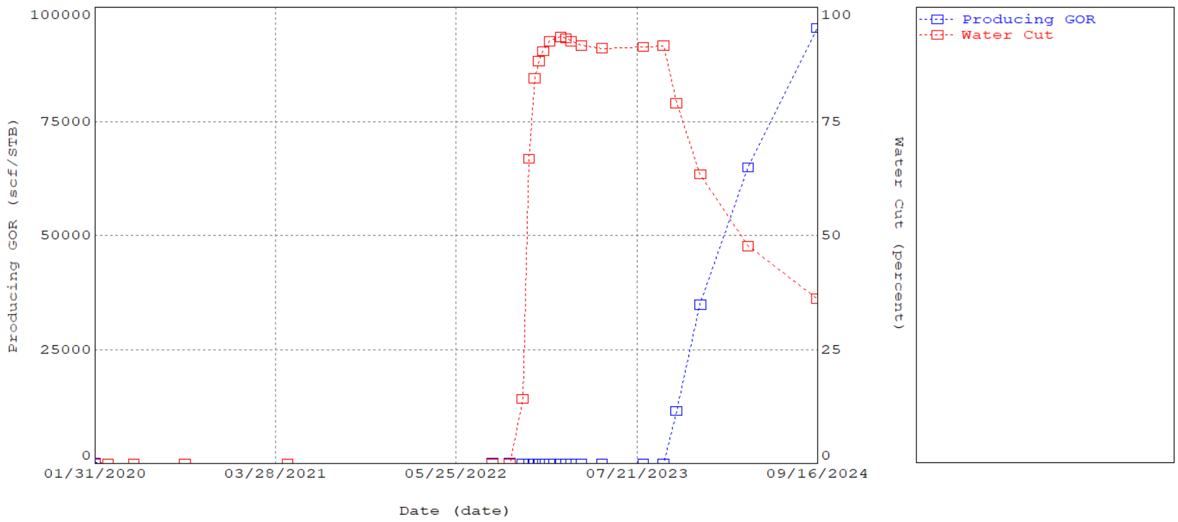

Figure 4.12: GOR and WCT versus time for 360 days' injection cycle

4.3 WAG Injection Pattern

4.3.1 90 days injection cycle (Gas – Water)

a. Well injection pattern (10-3)

In this study, injection pattern also been studied to investigate its impact on production performance. The best scenario (Gas-Water) among injection cycles is selected to be investigated in this section. The injection well position has changed to see its influence on cumulative oil production. Three different well injection positions have been selected, including cells (10-3, 10-10, and 18-6).

Figure 4.13 shows the cumulative oil production and cumulative water production versus time for WAG injection (Gas then Water) for 90 days' injection cycle after changing the injection pattern to cells (10-3). Based on the simulation result, a total of 3.7 million barrels of oil has been produced and a total of 2.45 million barrel of water has been produced.

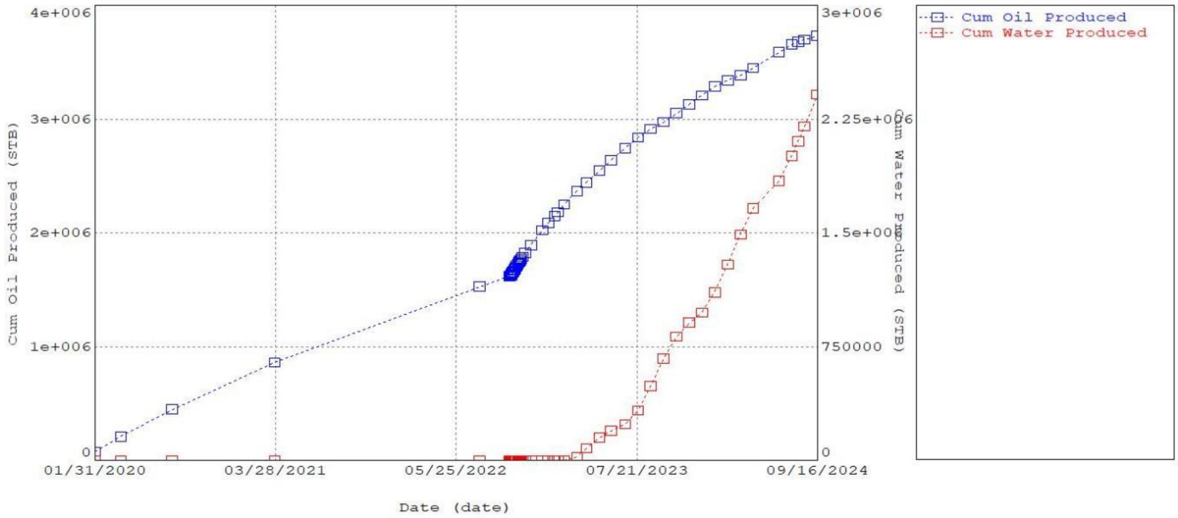

Figure 4.13: Cumulative oil production and water cumulative production versus time for injection pattern (10-3)

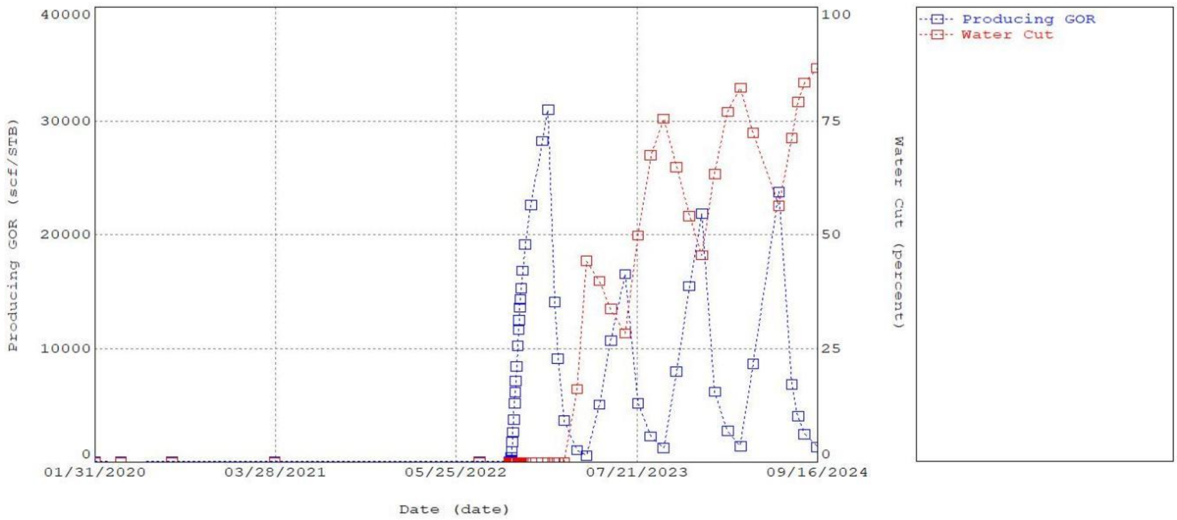

Figure 4.14: FGOR and WCT versus time for injection pattern (10-3)

Figure 4.14 shows the effect of a 90-day injection cycle (Gas-Water) with an injection pattern of 10-3 on water-cut and GOR. Figure 4.14 shows that GOR increases in mid of 2022 as gas been injected and the GOR increases to 32,000 scf/stb and reduced as water is injected based on the data obtained. As shown by the red colour, the water-cut has risen from zero at the beginning and began to rise when water was injected on January 2023 to 72 percent as a result of water injection, then decreased when gas was injected.

b. Well injection pattern (10-10)

The cumulative oil and water output versus time for WAG injection (Gas then Water) during a 90-day injection cycle after switching to a cell injection pattern of (10-10) is shown in Figure 4.15. A total of 4.35 million barrels of oil and 2 million barrels of water were produced as a consequence of the simulation.

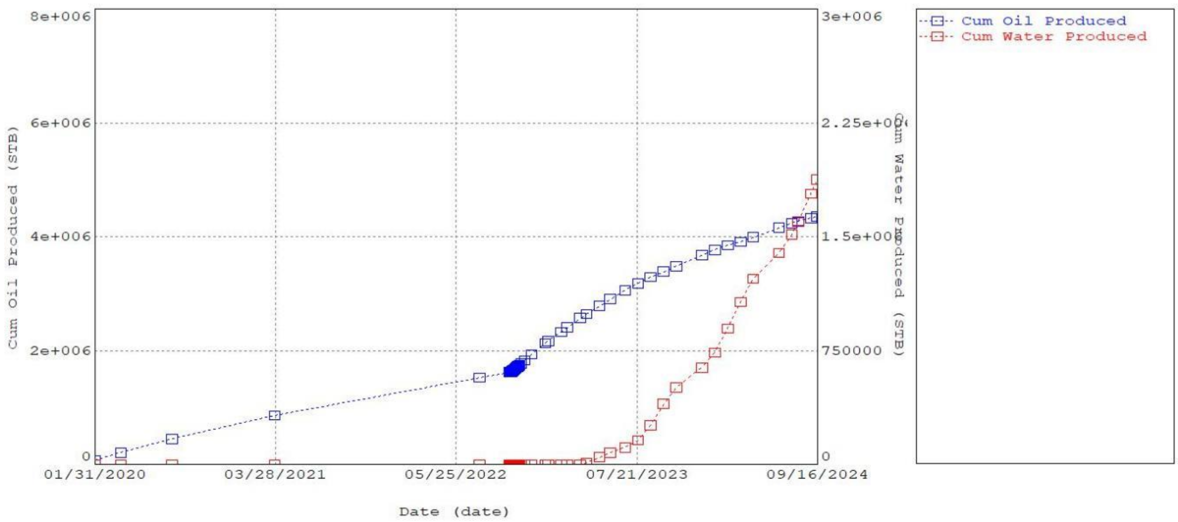

Figure 4.15: Cumulative oil production and water cumulative production versus time for injection pattern (10-10)

The impact of a 90-day injection cycle (Gas-Water) with a 10-3 injection pattern on water-cut and GOR is shown in Figure 4.16. According to the data collected, GOR rises to 20,000 scf/stb in mid-2022 when gas is injected and decreases as water is injected. As shown by the red color, the water-cut has grown from zero at the start to 58 percent as a consequence of water injection in January 2023, then dropped when gas was injected and rose over time as water is injected.

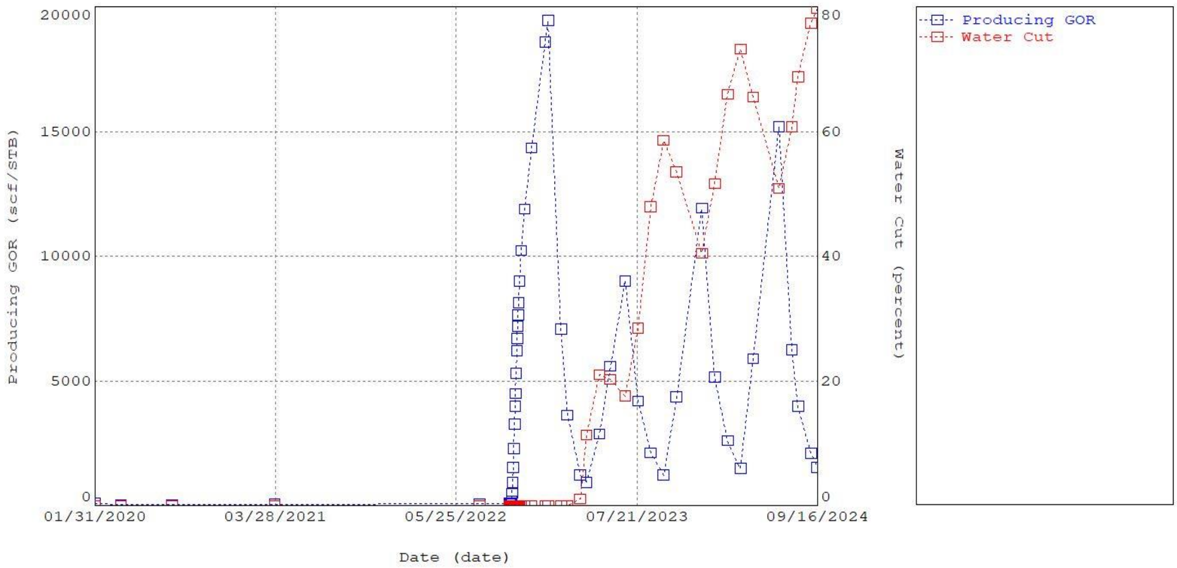

Figure 4.16: FGOR and WCT versus time for injection pattern (10-10)

c. Well injection pattern (18-6)

Figure 4.17 illustrates the cumulative oil and water production against time for WAG injection (Gas then Water) over a 90-day injection cycle after a transition to a cell injection pattern of (18-6). The simulation resulted in the production of 6 million barrels of oil and 120,000 barrels of water.

Figure 4.18 illustrates the effect of a 90-day injection cycle (Gas-Water) with an 18-3 injection pattern on water-cut and GOR. GOR increases to 4500 scf/stb in mid-2022 when gas is injected and declines when water is pumped, according to the data gathered. As shown by the red colour, the water cut has increased from zero to 25% as a result of water injection in 2024.

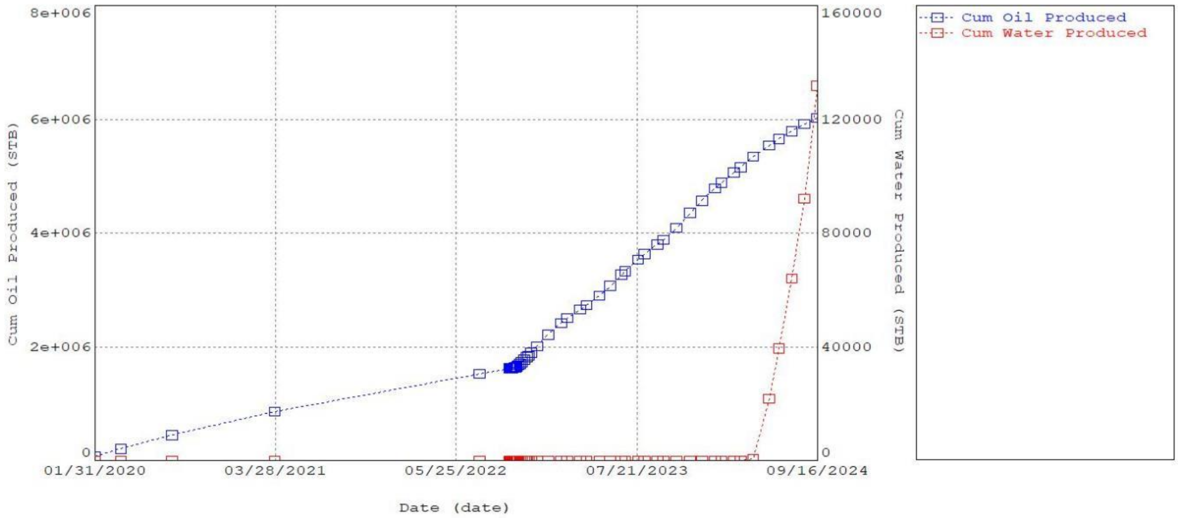

Figure 4.17: Cumulative oil production and water cumulative production versus time for injection pattern (18-6)

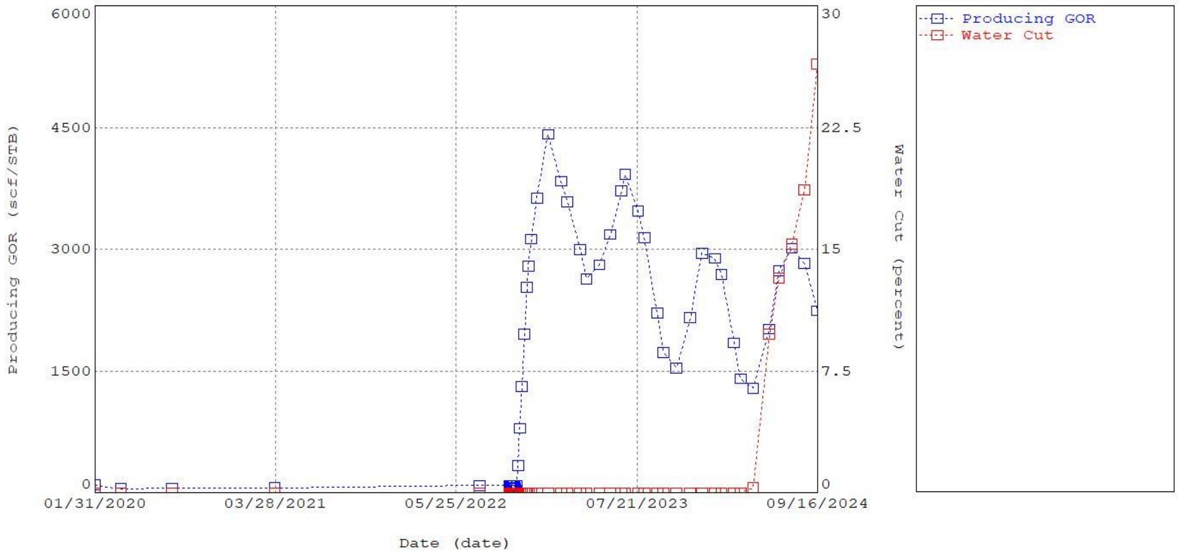

Figure 4.18: FGOR and WCT versus time for injection pattern (18-6)

4.3.2 180 days injection cycle (Gas – Water)

a. Well injection pattern (10-3)

Different well injection pattern for Gas-Water WAG injection cycle 180 days also been investigated and the result are analyzed based on water-cut and GOR.

Figure 4.19 shows the cumulative oil production and cumulative water production versus time for WAG injection (Gas then Water) for 180 days' injection cycle after changing the injection pattern to cells (10-3). Based on the simulation result, a total of 3.8 million barrels of oil has been produced and a total of 2.3 million barrel of water has been produced.

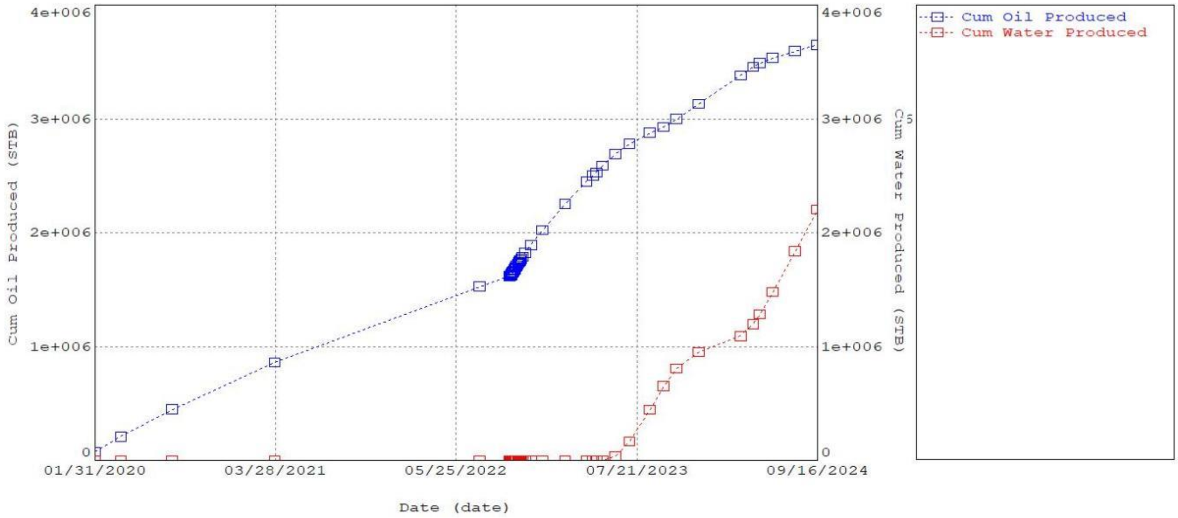

Figure 4.19: Cumulative oil production and water cumulative production versus time for injection pattern (10-3)

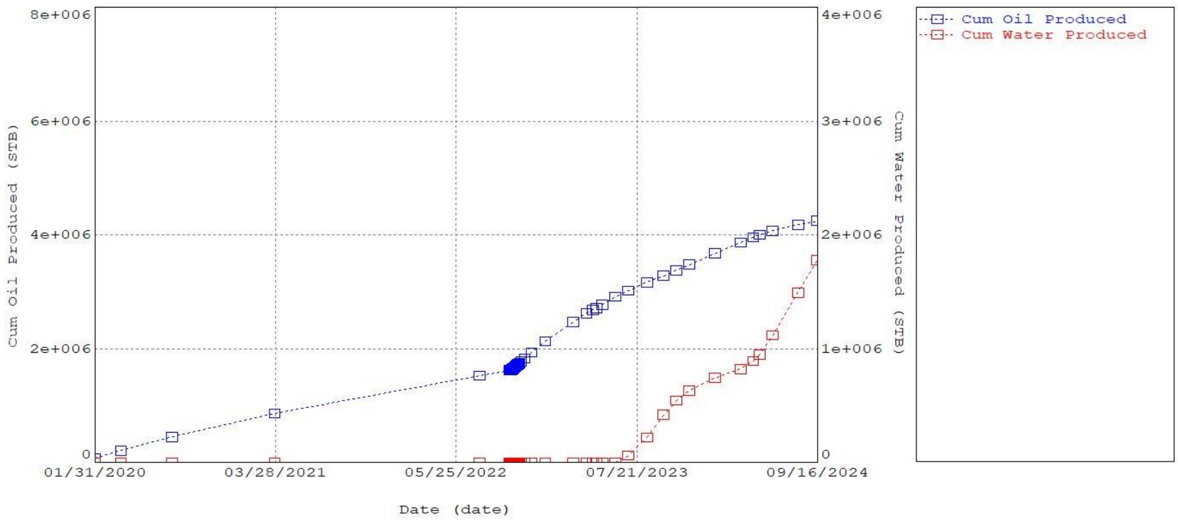

Figure 4.20: FGOR and WCT versus time for injection pattern (10-3)

The impact of a 180-day injection cycle (Gas-Water) with a 10-3 injection pattern on water-cut and GOR is shown in Figure 4.20. According to the research conducted, GOR rises to 47,000 scf/stb in mid-2022 when gas is injected and decreases as water is injected. As shown by the red color, the water-cut has increased from zero at the start to 83 percent as a consequence of water injection in July 2023, then dropped when gas was injected.

b. Well injection pattern (10-10)

Figure 4.21 shows the cumulative oil and water production, as well as time, throughout the 180-day injection cycle that is used for WAG injection (Gas then Water) after making the transition to a cell injection pattern (10-10). As a result of the simulation, a total of 4.2 million barrels of oil and 1.8 million barrels of water were produced.

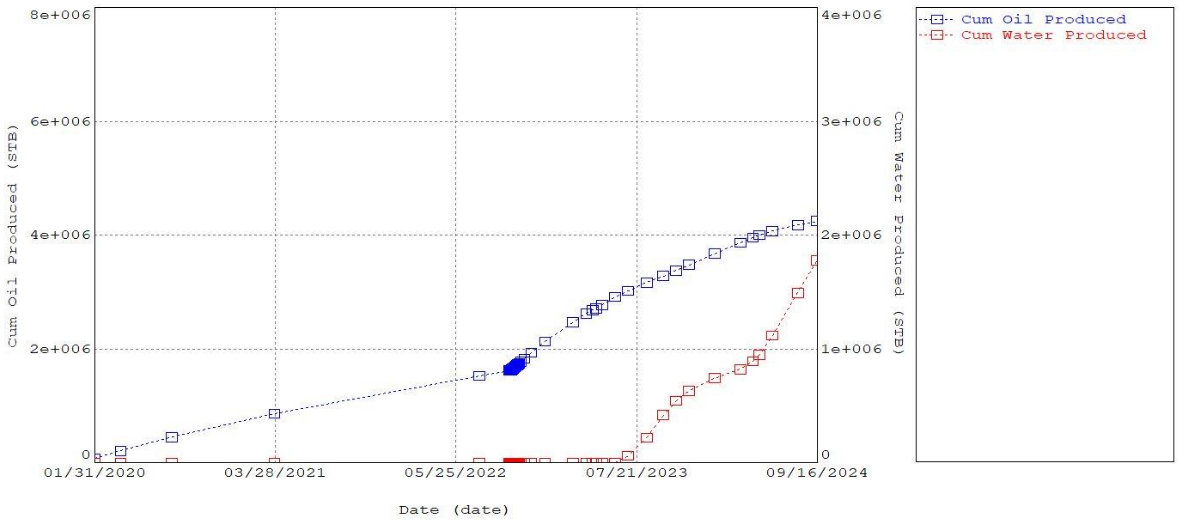

Figure 4.21: Cumulative oil production and water cumulative production versus time for injection pattern (10-10)

In Figure 4.22, the Gas-Water (180-day injection cycle with a 10-10 injection pattern) and GOR effects are illustrated. According to the findings, the level of GOR has increased to 31,000 scf/stb in 2022. We can see that the water-cut has increased from zero to 61% over time because of water injection in July 2023, after which it fell as gas injection was made and climbed again when water injection was restarted.

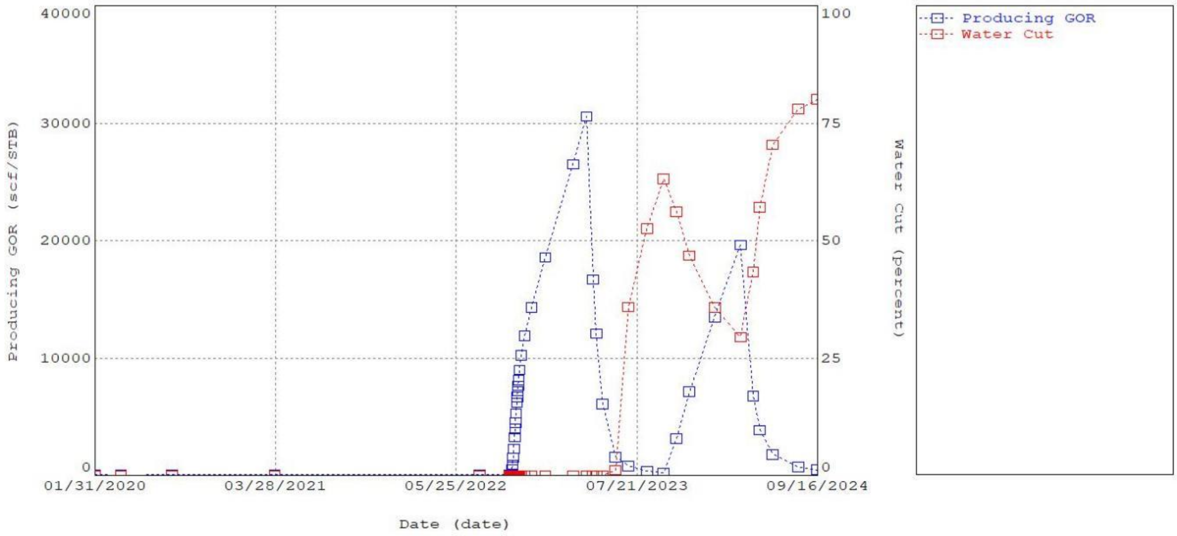

Figure 4.22: FGOR and WCT versus time for injection pattern (10-10)

c. Well injection pattern (18-6)

A demonstration of cumulative oil and water output over a 180-day injection cycle (gas then water) following a change to a cell injection location can be shown in Figure 4.23. Simulation results were achieved when 5.88 million barrels of oil and 130,000 barrels of water were produced.

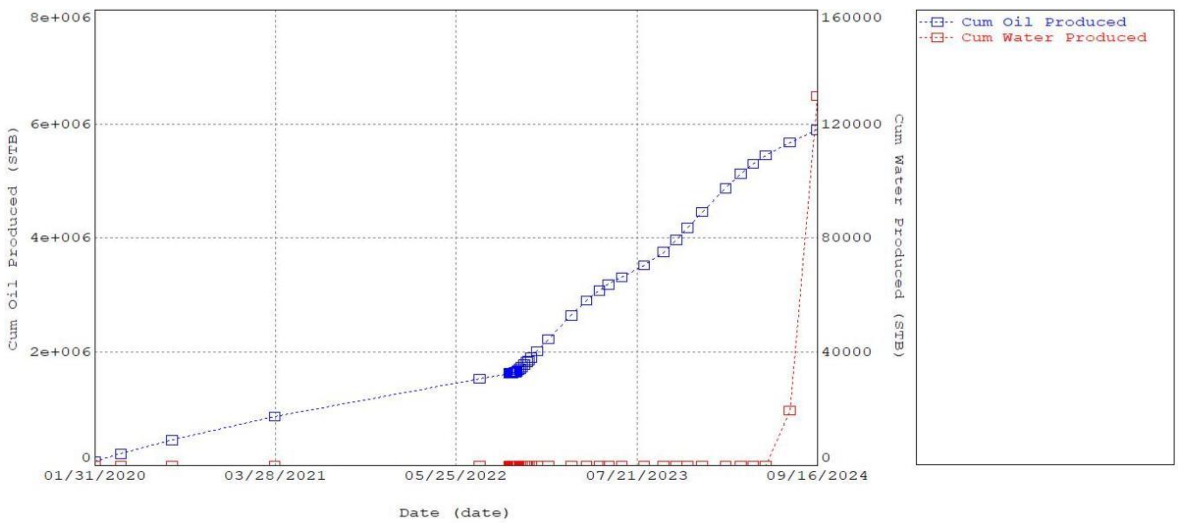

Figure 4.23: Cumulative oil production and water cumulative production versus time for injection pattern (18-6)

Figure 4.24 illustrates the effect of a 180-day injection cycle (Gas-Water) with an 18-6 injection pattern on water-cut and GOR. GOR increases to 7800 scf/stb in mid-2022 when gas is injected and declines when water is pumped, according to the data gathered. As shown by the red colour, the water cut has increased from zero to 35% as a result of water injection in 2024 and the amount is low due to the injection well location which it contributed to push the oil without resulting in excessive oil production.

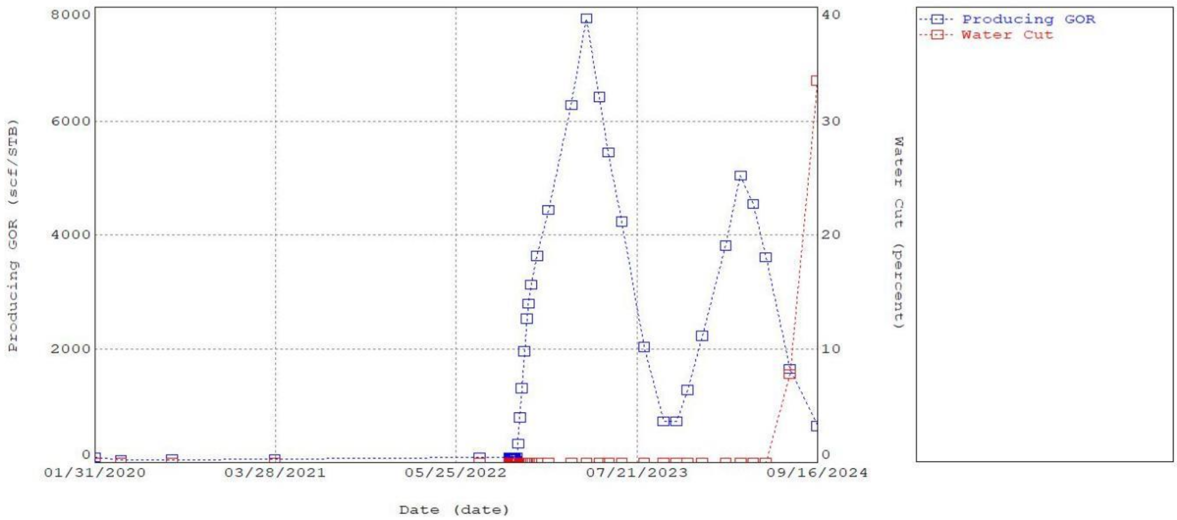

Figure 4.24: FGOR and WCT versus time for injection pattern (18-6)

4.3.3 360 days injection cycle (Gas – Water)

a. Well injection pattern (10-3)

To aid in the calculation of water cuts and GOR, the well injection pattern used in the Gas-Water WAG injection cycle has been studied. For the full 360 days of injection, cumulative oil production and cumulative water production as a function of time for WAG injection (Gas then Water) are shown in Figure 4.25. A total of 3.6 million barrels of oil have been produced as indicated by the simulation result, whereas a total of 2 million barrels of water have been generated.

In Figure 4.26, we see how an injection cycle of Gas-Water with a 10-3 injection pattern has an effect on water-cut and GOR. The study found that gas injection causes the GOR to increase to 77,000 scf/stb in 2022, and when water injection occurs, the GOR goes down. In July of 2023, water injection was started, resulting in an 86% increase in the water-cut.

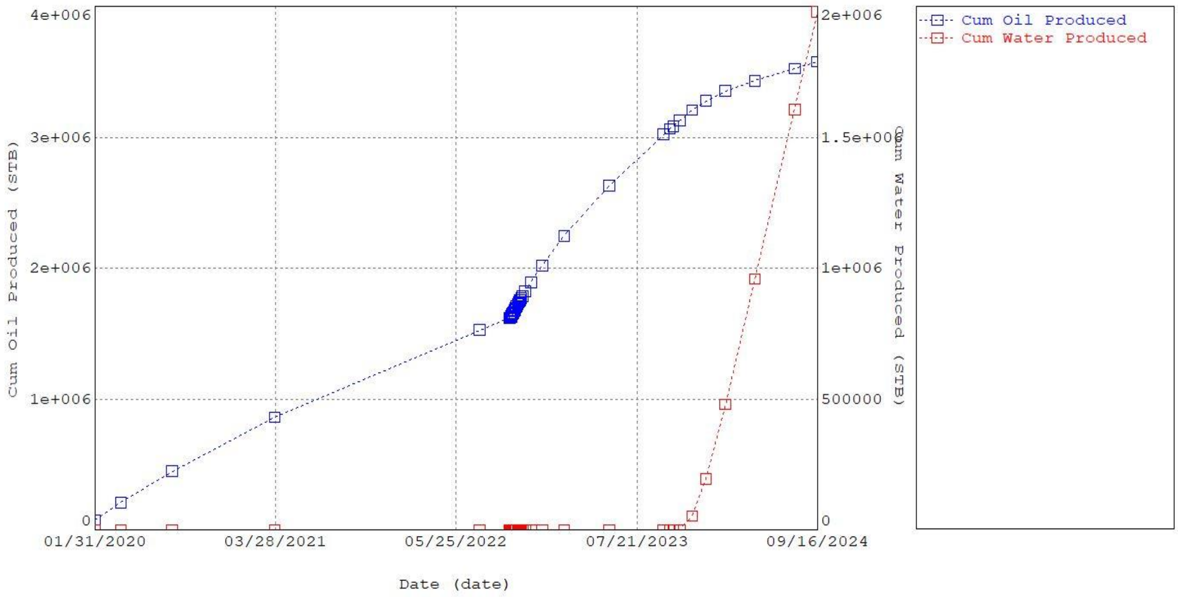

Figure 4.25: Cumulative oil production and water cumulative production versus time for injection pattern (10-3)

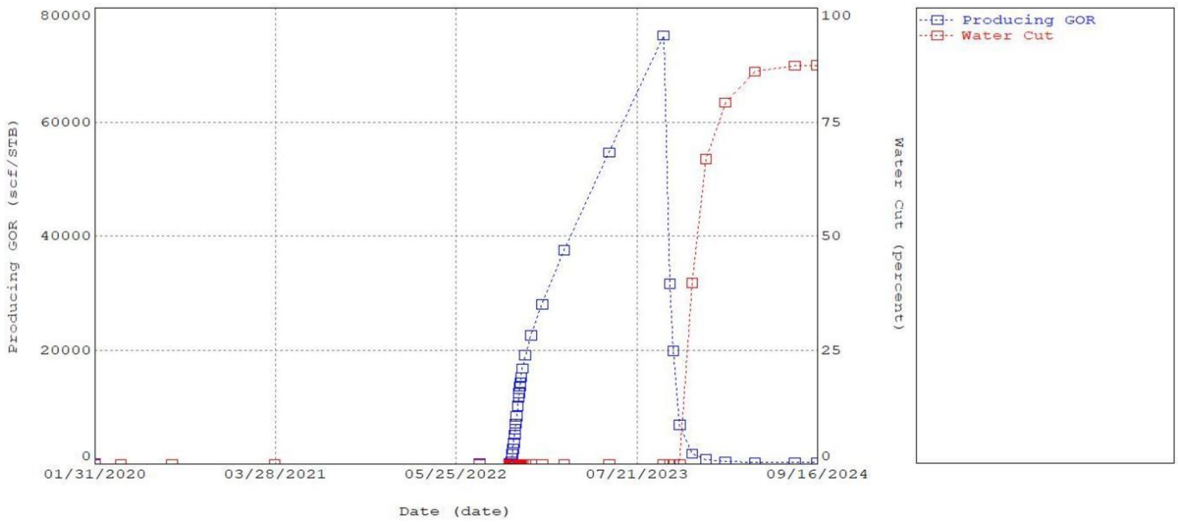

Figure 4.26: FGOR and WCT versus time for injection pattern (10-3)

b. Well injection pattern (10-10)

In Figure 4.27, we see the total oil and water output, as well as time, accrued during the 360-day injection cycle for use in well injection patterns after the cycle has switched to the new injection pattern, which is shown in Figure 4.27. 4.1 million barrels of oil and 1.65 million barrels of water were produced as a result of the simulation.

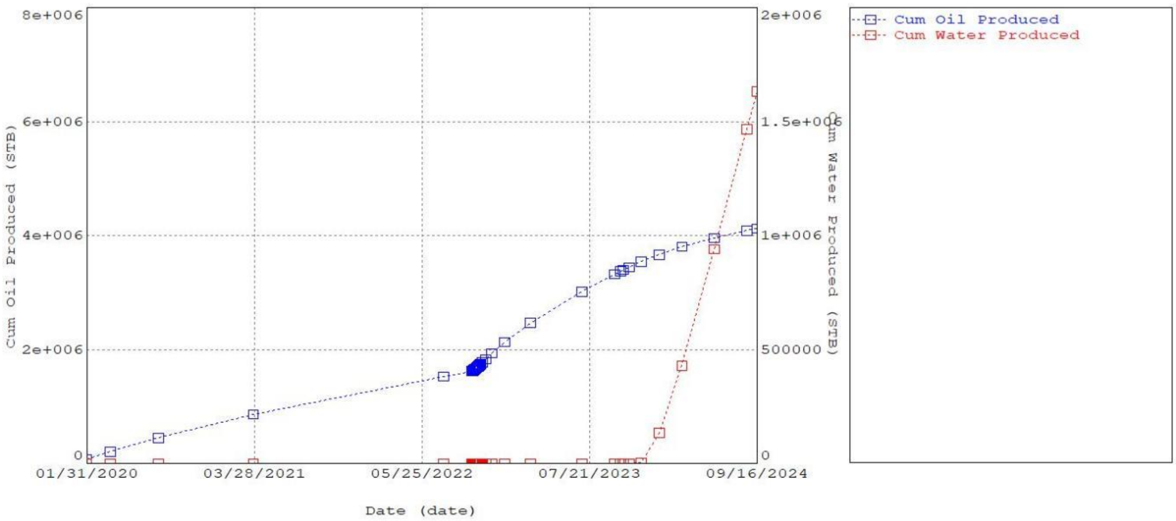

Figure 4.27: Cumulative oil production and water cumulative production versus time for injection pattern (10-10)

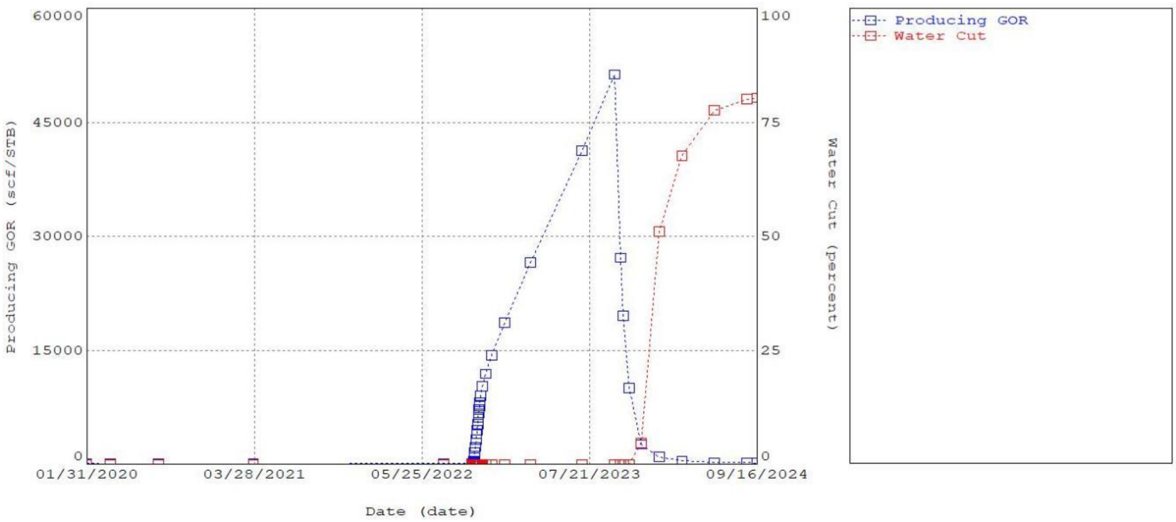

Figure 4.28: FGOR and WCT versus time for injection pattern (10-10)

The Gas-Water (360-day injection cycle with a 10-10 injection pattern) and GOR effects are shown in Figure 4.28. According to the results, GOR will reach 55,000 scf/stb in 2022. We can observe that the water-cut has risen from zero to eighty percent over time as a result of water injection in July 2023.

c. Well injection pattern (18-6)

Figure 4.29 illustrates the cumulative oil and water production during a 360-day injection cycle (Gas first, then Water) after a change in cell injection site. The simulation results were obtained by producing 5.6 million barrels of oil and 100,000 barrels of water.

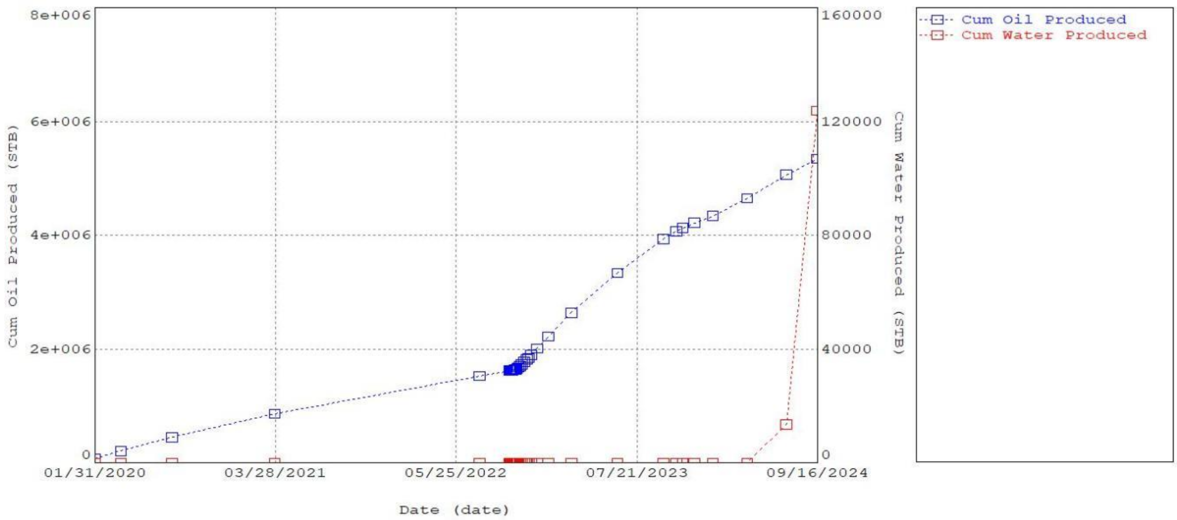

Figure 4.29: Cumulative oil production and water cumulative production versus time for injection pattern (18-6)

The impact of a 360-day injection cycle (Gas-Water) with an 18-6 injection pattern on water-cut and GOR is shown in Figure 4.30. According to the data collected, GOR rises to 16000 scf/stb in mid-2022 when gas is injected and decreases when water is pumped. As shown by the red color, the water cut rose from zero to 28 percent in 2024 as a consequence of water injection, and the quantity is modest owing to the injection well position, which assisted in pushing the oil without resulting in excessive oil output.

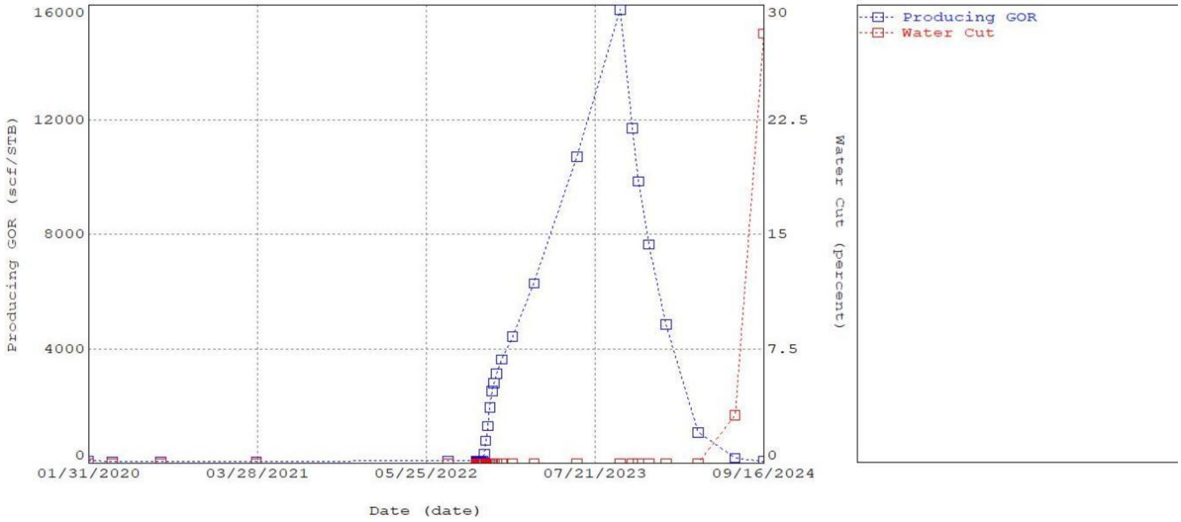

Figure 4.30: FGOR and WCT versus time for injection pattern (18-6)

4.4 Discussion

In this study, three main cases were discussed, including injection cycle, injection fluid phase cycle, and injection pattern. Injecting gas then water in three different cycles, including 90 days, 180 days, and 360 days, and another case involve injecting water then gas with the same three different cycles have been investigated. Injection pattern also been investigated in which three different injection locations including (10-3), (10-10), and (18-6). Table 4.1 shows the comparison between all the scenarios that have been studied in this study. Based on the result, injecting gas then water for 360 days with an injection pattern of (18-6) produces the largest amount of oil of 6 million barrels compared to all the other injection cycle cases. However, its indeed important to consider the economics of the process, in which produced water and gas needs to be considered. According to the result, the produced water and gas is close to each other among the cases, and due to the fact that the produced gas and water will be eventually used for the WAG injection process, then WAG injection with injecting gas then water for a period of 360 days with a well injection location of (18-6) have been selected as the best scenario for this study due to the fact that it only results in GOR of 16,000 scf/stb and water cut of 28% in addition to the production of the highest amount of oil of about 6 million barrels of oil.

Table 4.1: Simulation result comparison

Case	Scenario/Parameter	FOPT (Million Barrels)	FWPT (Million Barrels)	FGOR scf/stb	FWCT
Gas/Water	90-days	3.22	3.82	49247	88%
	180-days	328	3.97	62370	92.47%
	360-days	3.19	4	112575	91.30%
Water/Gas	90-days	2.83	4.87	48125	90%
	180-days	2.84	5.53	58300	89.20%
	360-days	2.84	6.13	95325	92%
90 Days injection cycle	Well injection pattern (10-3)	3.7	2.45	32000	72%
	Well injection pattern (10-10)	4.35	2	20,000	58%
	Well injection pattern (18-6)	6	120,000	4500	25%
180 Days injection cycle (Gas-Water)	Well injection pattern (10-3)	3.8	2.3	47,000	83%

	Well injection pattern (10-10)	4.2	1.8	31,000	61%
	Well injection pattern (18-6)	5.88	130,000	7800	35%
360 Days injection cycle (Gas-Water)	Well injection pattern (10-3)	3.6	2	77,000	86%
	Well injection pattern (10-10)	4.1	1.65	55,000	80%
	Well injection pattern (18-6)	6	100,000	16,000	28%

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results, the following points are the main conclusive remarks of this study:

1. The WAG injection technique is a good way to boost oil recovery in matured oil wells.
2. Injection cycle is a critical parameter that provide a significant effect on oil recovery.
3. When compared to injecting water then gas, injecting gas then water should be considered in the WAG injection procedure because it gives better oil recovery and reduced WCT and gas-oil ratio.
4. The well injection pattern is an important element that should be thoroughly investigated, as our study found that different injection patterns result in varied outcomes.
5. Injection scenario of 360 days of WAG injection (gas then water) has provided the most of oil with a cumulative oil production of 6 million barrels and only 100,000 barrels of water compared to all the other scenarios, so it has been selected as the best case of this study.

5.2 Recommendations

I recommend the parties related to petroleum industry in Iraq to use water-alternating-gas injection method instead of other EOR method, as the counter is going through an economic crisis, the WAG process is less expensive and recover oil effectively. Additionally, I want to recommend further study on the topic in terms of other parameters, including injection temperature, type of gas, etc.

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APPENDICES

APPENDIX 1

RESERVOIR SIMULATION RESULT

Date (date)	GOR (scf/STB)	WaterCut (percent)	CumWaterProduced (STB)	CumOilProduced (STB)
1/31/2020	149.674	1.89E-05	0.011645	61620
3/1/2020	52.8956	1.69E-05	0.02319	129835
4/30/2020	52.2552	1.79E-05	0.046111	257915
8/28/2020	54.3785	1.94E-05	0.091375	490989
4/25/2021	66.2254	2.18E-05	0.17959	896265
8/18/2022	89.9379	2.56E-05	0.346909	1.55E+06
9/27/2022	92.8301	2.60E-05	0.360777	1.60E+06
9/27/2022	86.7037	2.48E-05	0.361108	1.60E+06
9/28/2022	81.8973	2.31E-05	0.361278	1.61E+06
9/29/2022	112.799	1.28E-05	0.361613	1.61E+06
9/30/2022	480.61	0	0.361613	1.61E+06
10/2/2022	1379.21	5.73E-08	0.361616	1.62E+06
10/4/2022	2502.59	1.29E-09	0.361616	1.62E+06
10/7/2022	4060.66	0	0.361616	1.63E+06
10/10/2022	5939.03	0	0.361616	1.64E+06
10/12/2022	7223.99	0	0.361616	1.65E+06
10/15/2022	8921.44	0	0.361616	1.65E+06
10/20/2022	11507.4	0	0.361616	1.67E+06
10/27/2022	14713	0	0.361616	1.69E+06
11/6/2022	18615.3	0	0.361616	1.72E+06
11/13/2022	21158.1	4.41E-08	0.361626	1.74E+06
11/21/2022	23353.8	0	0.361626	1.77E+06
12/6/2022	26661	5.42E-08	0.361651	1.81E+06
1/7/2023	31873.3	0	0.361651	1.89E+06

3/10/2023	42017	9.72E-09	0.361666	2.05E+06
3/26/2023	44342.9	0	0.361666	2.09E+06
4/25/2023	6507.76	4.8519	3951.9	2.17E+06
5/25/2023	2105.07	51.0422	70309.3	2.23E+06
7/24/2023	1299.78	69.989	319475	2.34E+06
9/22/2023	648.689	79.5942	675315	2.43E+06
10/22/2023	7494.95	67.0261	770561	2.48E+06
12/21/2023	21341	49.3584	864419	2.57E+06
3/20/2024	34442.7	33.9701	938733	2.72E+06
4/19/2024	5816.43	70.7548	1.05E+06	2.76E+06
5/19/2024	2431.85	81.904	1.25E+06	2.81E+06
7/18/2024	1153.44	86.2513	1.73E+06	2.88E+06
9/16/2024	752.894	88.012	2.27E+06	2.96E+06

APPENDIX 2

SIMULATION DATA

```
*/
!------------------------------------------
!
! control section
!
!------------------------------------------

section control

  import_case_type none
  phases 3
  components total 3
  startdate 01/01/2020
  comp_model simple
  ! components 1-3 are hydrocarbon
  fracture off
  aquifer off
  well_microwave_heating off
  well_heater off
  ref_temperature 170    ! deg F
  ref_depth 4921    ! feet
  min_porosity 1e-005    ! fraction
  min_gridvol 1e-006    ! ft3
  wettability off
  miscibility off
  solve full_implicit
  solve implicit_temperature on
  solve rs_solve on
  solve dead_oil off
```

```
! solver options
implicit maxdp_iter 500    ! psi
implicit maxds_iter 0.5    ! fraction
implicit maxdt_iter 100    ! deg F
implicit maxdp_conv 10    ! psi
implicit maxdsw_conv 0.1    ! fraction
implicit maxdso_conv 0.1    ! fraction
implicit maxdsg_conv 0.1    ! fraction
implicit maxdt_conv 10    ! deg F
implicit maxdqq_conv 0.1    ! fraction
implicit rowcol_order automatic colour 0
implicit point_scheme 9
implicit newt_miniter 1
implicit newt_maxiter 10
implicit newt_redoiter 8
implicit newt_holditer 6
implicit diverge_crit 1000    !
implicit max_newt_step 1    !
implicit min_dp 0.01    ! psi
implicit preconditioner ILUTP
implicit prec_fill -33
implicit prec_level 3
implicit prec_droptol 0.001 auto_tune    !
implicit prec_permtol 0.0001    !
implicit gmres_subs 0
implicit sol_residreduc 0.001    !
implicit sol_residmax 0    !
implicit scale_matrix 0
implicit min_matrix 0    !
implicit adaptive_parameter 0.01    !

end
```

```
!-------------------------------------------
!
! reservoir section
!
!-------------------------------------------

section reservoir

  grid coordinates cartesian
  grid blocks 20 15 2
  grid dx range 1 20   100    ! feet
  grid dy range 1 15   100    ! feet
  grid dz range 1 2   100    ! feet
  grid mapaxis origin 0 0    ! feet feet
  grid mapaxis xax 1 0    ! feet feet
  grid mapaxis yax 0 1    ! feet feet
  porosity range x 1 20 y 1 15 z 1 2   0.3    ! fraction
  x_permeability range x 1 20 y 1 15 z 1 2   170    ! md
  y_permeability multiple_of_x_perm 1
  z_permeability multiple_of_x_perm 0.1
  depth range x 1 20 y 1 15   0    ! feet
  extern transmissibility off
  rock_types total 1
  rock_types range x 1 20 y 1 15 z 1 2  1
  pvt_regions total 1
  pvt_regions range x 1 20 y 1 15 z 1 2  1
  eql_regions total 1
  eql_regions range x 1 20 y 1 15 z 1 2  1
  fip_regions total 1
  fip_regions range x 1 20 y 1 15 z 1 2  1
  nonneighbour_connections pinch 0.001    ! feet
  nonneighbour_connections minpv on
  nonneighbour_connections mintz off
```

```
end

!-------------------------------------------
!
! physical section
!
!-------------------------------------------

section physical

  heat_capacity component 1 1    ! BTU/lb/F
  JT_coef component 1 0    ! degrees F/psi
  heat_capacity component 2 0.5    ! BTU/lb/F
  JT_coef component 2 0    ! degrees F/psi
  heat_capacity component 3 0.2    ! BTU/lb/F
  JT_coef component 3 0    ! degrees F/psi
  diffusivity off
  density rock_type 1 160    ! lb/ft3
  porethroat_mult rock_type 1 1    !
  porethroat_dev rock_type 1 2    !
  heat_capacity rock_type 1 0.8    ! BTU/lb/F
  compressibility rock_type 1 value 5.7e-006 pressure 2148 pore_volume    ! 1/psi psia
  density overburden 160    ! lb/ft3
  density underburden 160    ! lb/ft3
  heat_capacity underburden 0.8    ! BTU/lb/F
  heat_capacity overburden 0.8    ! BTU/lb/F
  conductivity off
  dispersivity off
  IFT_calculation off
  water_viscosity default
  petex_pvt file SARKASH-BO

end
```

```
!-------------------------------------------
!
! relperm section
!
!-------------------------------------------

section relperm

  model stone1
  desaturation off
  endpoint_scaling off
  hysteresis off
  data for rock_types all
  critical saturation HT water 0.25    ! fraction
  critical saturation HT oil_water 0.25    ! fraction
  critical saturation HT oil_gas 0.25    ! fraction
  critical saturation HT gas 0.05    ! fraction
  capillary_pressure gas/oil table 1
!    Sg      Pcg
     0       0    ! fraction psi

  capillary_pressure table 1
!    Sw      Pc
     0.25       0    ! fraction psi

  relperm HT water table 20
!    Sw      krw
     0.25       0    ! fraction
     0.269861       1.2e-006    ! fraction
     0.290722       2.2e-005    ! fraction
     0.311583       0.00012    ! fraction
     0.332444       0.00037    ! fraction
```

```
    0.353306      0.0009    ! fraction
    0.374167      0.0019    ! fraction
    0.395028      0.0035    ! fraction
    0.415889      0.0061    ! fraction
    0.43675      0.0097    ! fraction
    0.457611      0.0149    ! fraction
    0.478472      0.0218    ! fraction
    0.499333      0.0309    ! fraction
    0.541056      0.0574    ! fraction
    0.582778      0.0981    ! fraction
    0.6245      0.1574    ! fraction
    0.666222      0.2401    ! fraction
    0.707944      0.3518    ! fraction
    0.75      0.5    ! fraction
    1      1    ! fraction
  relperm HT oil_water table 19
!    So      krow
    0.25      0    ! fraction
    0.29206      0.0021    ! fraction
    0.33378      0.0115    ! fraction
    0.3755      0.0316    ! fraction
    0.41722      0.0647    ! fraction
    0.45894      0.1129    ! fraction
    0.50067      0.178    ! fraction
    0.52153      0.2173    ! fraction
    0.54239      0.2615    ! fraction
    0.56325      0.3107    ! fraction
    0.58411      0.365    ! fraction
    0.60497      0.4247    ! fraction
    0.62583      0.4898    ! fraction
    0.64669      0.5607    ! fraction
    0.66756      0.6373    ! fraction
    0.68842      0.7199    ! fraction
    0.70928      0.8087    ! fraction
```

0.73014 0.9036 ! fraction

0.75 1 ! fraction

relperm HT oil_gas table 19

! So krog

0.25 0 ! fraction

0.29206 0.000595248 ! fraction

0.33378 0.0047 ! fraction

0.3755 0.0158 ! fraction

0.41722 0.0374 ! fraction

0.45894 0.073 ! fraction

0.50067 0.126 ! fraction

0.52153 0.1602 ! fraction

0.54239 0.2 ! fraction

0.56325 0.2459 ! fraction

0.58411 0.2984 ! fraction

0.60497 0.3578 ! fraction

0.62583 0.4247 ! fraction

0.64669 0.4994 ! fraction

0.66756 0.5824 ! fraction

0.68842 0.6742 ! fraction

0.70928 0.775 ! fraction

0.73014 0.8855 ! fraction

0.75 1 ! fraction

relperm HT gas table 26

! Sg krg

0.05 0 ! fraction

0.073 0.003 ! fraction

0.104 0.0072 ! fraction

0.136 0.014 ! fraction

0.167 0.0234 ! fraction

0.199 0.0363 ! fraction

0.229 0.0515 ! fraction

0.261 0.0714 ! fraction

0.292 0.0946 ! fraction

```
    0.324      0.1227    ! fraction
    0.355      0.1541    ! fraction
    0.386      0.19    ! fraction
    0.417      0.2305    ! fraction
    0.449      0.2773    ! fraction
    0.48      0.3277    ! fraction
    0.512      0.3851    ! fraction
    0.542      0.444    ! fraction
    0.574      0.5124    ! fraction
    0.605      0.5844    ! fraction
    0.637      0.6648    ! fraction
    0.668      0.7487    ! fraction
    0.684      0.7943    ! fraction
    0.701      0.8446    ! fraction
    0.718      0.8967    ! fraction
    0.734      0.9475    ! fraction
    0.75      1    ! fraction

end


!-------------------------------------------
!
! aquifer section
!
!-------------------------------------------

section aquifer


end


!-------------------------------------------
```

```
!
! mobility section
!
!-------------------------------------------

section mobility


end


!-------------------------------------------
!
! phase section
!
!-------------------------------------------

section phase


end


!-------------------------------------------
!
! adsorption section
!
!-------------------------------------------

section adsorption


end
```

```
!------------------------------------------
!
! water chemistry section
!
!------------------------------------------

section wchemistry


end


!------------------------------------------
!
! solids section
!
!------------------------------------------

section solids


end


!------------------------------------------
!
! well section
!
!------------------------------------------

section well

  well model block shear off
```

```
  well INJ-1 at 18 6
  well INJ-1 layer range 1 2 perforated
  well INJ-1 layer range 1 2 radius 4.2    ! inches
  well INJ-1 layer range 1 2 skin_factor 0    !
  well INJ-1 layer range 1 2 theta 1    !
  well INJ-1 drainage_model diffusivity 1    ! days
  well INJ-1 allow_unstable_flow on
  well INJ-1 crossflow on
  well INJ-1 bhpmode top
  well INJ-1 pseudo_pressure off

  well SARKASH-PRO at 7 6
  well SARKASH-PRO layer range 1 2 perforated
  well SARKASH-PRO layer range 1 2 radius 4.2    ! inches
  well SARKASH-PRO layer range 1 2 skin_factor 0    !
  well SARKASH-PRO layer range 1 2 theta 1    !
  well SARKASH-PRO drainage_model diffusivity 1    ! days
  well SARKASH-PRO allow_unstable_flow on
  well SARKASH-PRO crossflow on
  well SARKASH-PRO bhpmode top
  well SARKASH-PRO pseudo_pressure off


end


!------------------------------------------
!
! wellbore_heating section
!
!------------------------------------------

section wellbore_heating
```

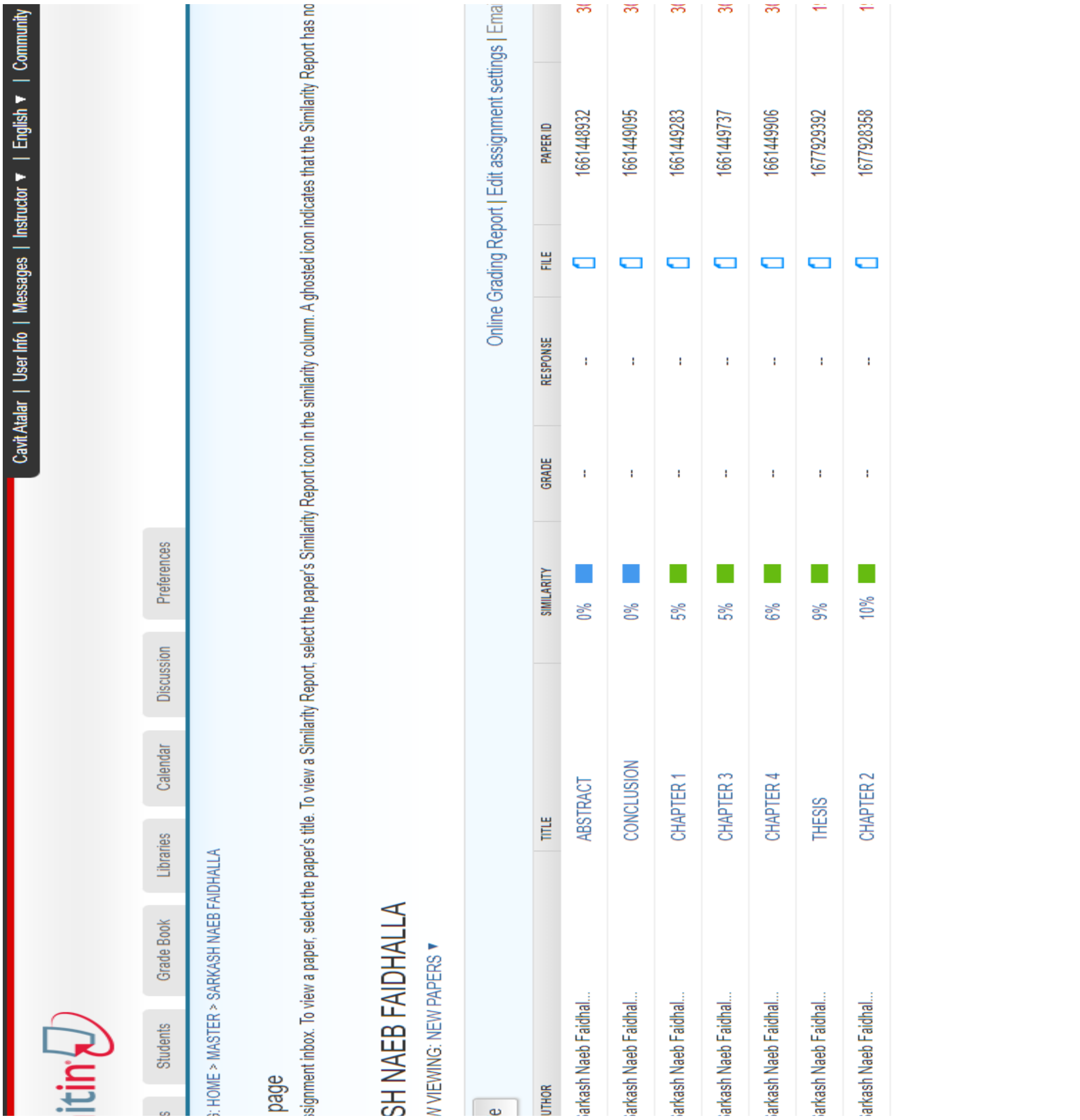
```
end



!-------------------------------------------
!
! initialisation section
!
!-------------------------------------------

section initialisation

  data_for pvt_region 1
  petex_pvt file SARKASH-BO
  data_for eql_region 1
  initial_pressure 2148 at depth 4921    ! psia feet
  initial_temperature reference 170 gradient 0 depth 4921    ! deg F deg F/ft feet

  equilibration



end



!-------------------------------------------
!
! schedule section
!
!-------------------------------------------

section schedule

  timestep initial 30    ! days
```

```
  restart_file off

  closed well INJ-1
  produce well SARKASH-PRO rate 8000     ! STB/day

  for time 1000    ! days

then

  timestep initial 30    ! days

  restart_file off

  inject well INJ-1 type gas
  inject well INJ-1 pressure 3000 temperature 180     ! psia deg F
  inject well INJ-1 rperm standard
  produce well SARKASH-PRO rate 8000     ! STB/day

  for time 180    ! days

then

  timestep initial 30    ! days

  restart_file off

  inject well INJ-1 type water
  inject well INJ-1 pressure 3000 temperature 180     ! psia deg F
  inject well INJ-1 rperm standard
  produce well SARKASH-PRO rate 8000     ! STB/day

  for time 180    ! days
```

```
then

  timestep initial 30    ! days

  restart_file off

  inject well INJ-1 type gas
  inject well INJ-1 pressure 3000 temperature 180     ! psia deg F
  inject well INJ-1 rperm standard
  produce well SARKASH-PRO rate 8000     ! STB/day

  for time 180    ! days

then

  timestep initial 30    ! days
  restart_file off

  inject well INJ-1 type water
  inject well INJ-1 pressure 3000 temperature 180     ! psia deg F
  inject well INJ-1 rperm standard
  produce well SARKASH-PRO rate 8000     ! STB/day

  for time 180    ! days
end
```

APPENDIX 3

SIMILARITY REPORT



APPENDIX 4

ETHICAL APPROVAL LETTER

YAKIN DOĞU ÜNİVERSİTESİ

ETHICAL APROVAL DOCUMENT

Date: 20/06/2021

To the **Institute of Graduate Studies**

The research project titled "**ENHANCED OIL RECOVERY BY WAG PROCESS IN A MATURE OIL FIELD**'' has been evaluated. Since the researcher will not collect primary data from humans, animals, plants or earth, this project does not need through the ethics committee.

Title: Prof. Dr.

Name Surname: Cavit ATALAR

Signature:

Role in the Research Project: Supervisor

Title: Assist.Prof. Dr.

Name Surname: Ersen ALP

Signature:

Role in the Research Project: Co-Supervisor