MOHAMMED FATEEH GHAFOUR

DETERMINATION AND REDUCTION OF CONING EFFECT

NEU 2021

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

By
MOHAMMED FATEEH GHAFOUR

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

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Mohammed Fateeh GHAFOUR: DETERMINATION AND REDUCTION OF CONING EFFECT

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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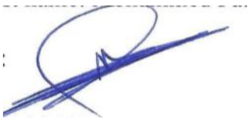
Signature: 

Date: 22/06/2021

ACKNOWLEDGEMENTS

Firstly, I offer my sincerest gratitude to my supervisor Prof. Dr. Cavit Atalar, for his brilliant guidance and support in this work. His ideas, his time, and reinforcement, made it possible for me to complete this work.

It is a great pleasure to thank everyone who supported me during my project. And I am truly indebted and thankful to my Co-Supervisor Dr. Ersen Alp for his continuous support and encouragement.

Finally, I am most grateful to my wife and my family and friends who supported me and motivated me from the start of the project up to the end.

To my Family…

ABSTRACT

Most workover operations could be considered as a proper approach toward solving well problems especially water and gas coning problems. As it's well-known, both coning problems will lead to become a barrier and reduce production of hydrocarbon in the life of the wells due to rising oil-water contact level or dropping gas-oil contact level to the perforation interval of the well. In this situation water or gas production increase and on the other hand, oil production dramatically reduces. This project selected three different wells in Khurmala dome oil field in North-West Kerkuk field including (Well-A, Well-B and Well-C) which faced water and gas coning problems. It can be said that, through collecting workover operation data of mentioned wells, production, design and total drilling interval will be shown before and after work over operation by comparing the production result of each well. As a result of the study, Work over operations proved to be very effective in solving water and gas coning problems after noticing the increase in production rate and reduction in water-cut and GOR, more clearly, gas production rate has decreased after implementing workover operation. Also, related to water-cut, Figure 4.7 shows that, water-cut significantly reduced from 15-20% to a water-cut of 1.5%. It means, after implementing workover operation, the water-cut and gas production reduces.

Keywords: Water coning; gas coning; perforation zone; Khurmala dome oil field; well workover

ÖZET

Work over işlemlerinin çoğu, kuyu sorunlarının, özellikle de su ve gaz konileşmesi sorununun çözümüne yönelik uygun bir yaklaşım olarak düşünülebilir. Bilindiği gibi, her iki konileşme sorunu da petrol-su ara yüzeyinin yükselmesi veya kuyu perforasyon aralığına gaz- petrol temasının azalması nedeniyle kuyuların ömrü boyunca bir engel oluşturacak ve hidrokarbon üretimini azaltacaktır. Bu durumda su veya gaz üretimi artar ve diğer yandan petrol üretimi önemli ölçüde azalır. Bu projede, Kuzeybatı Irak'taki Khurmala antiklinali petrol sahasında, su ve gaz iletim problemi ile karşı karşıya olan Kuyu-A, Kuyu-B ve Kuyu-C dahil olmak üzere üç farklı kuyu seçilmiştir. Söz konusu kuyuların workover işlem verilerinin toplanmasıyla, üretim, tasarım ve toplam sondaj aralığının çalışma öncesi ve sonrasında her bir kuyuya ait üretim sonucunun karşılaştırılmasıyla gösterileceği söylenebilir. Çalışma sonucunda, Workover operasyonu uygulandıktan sonra üretim hızındaki artış ve su kesintisinde azalma ve GOR, daha net bir şekilde gaz üretim hızının azaldığını fark ettikten sonra, Work over operasyonlarının su ve gaz koni problemlerinin çözümünde çok etkili olduğu kanıtlanmıştır. . Ayrıca, su kesimi ile ilgili olarak, Şekil 4.7, su kesiminin %15-20'den %1.5'lik bir su kesimine önemli ölçüde düştüğünü göstermektedir. Bu, workover operasyonu uygulandıktan sonra su kesintisi ve gaz üretiminin azaldığı anlamına gelir.

Anahtar Kelimeler: Su konisi; gaz konisi; perforasyon bölgesi; Khurmala kubbe petrol sahası; iyi çalışma

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LIST OF SYMBOLS AND ABBREVIATIONS

Q_c:	Critical production rate, STB/D
k_h:	Horizontal permeability, md
h:	Oil column thickness, m
μ_o:	Oil Viscosity, cp
Bo:	Oil formation volume factor
H.D:	Heterogeneity degree
ρ_w:	Water density, gm/cc
ρ_o:	Oil density, gm/cc
re:	Radius of drainage area, in
rw:	Radius of well, in
Ko:	Oil permeability, md
q_{CD}:	Dimensionless critical rate
tBT:	Time break through

CHAPTER 1
INTRODUCTION

1.1. Background

A workover can be defined as a movable self-propelled rig used to conduct one or more remedial operations, that consists of deepening, pulling, resetting liners and plugging back, on a gas well or producing oil to have a try for restoring or increasing the well's production. One of the most common critical operations in the oil and gas field development projects is the work over operation as it's the main part of production, optimization, management, and maintenance of oil and gas wells. Workover operations are very important to ensure business stability and maintaining oil production, in which there are various complexities within the oil and gas production operations, therefore workover can help to solve such issues. In extreme permeable reservoirs where natural fractures exist that are connected to an underground water source, excessive water production issues can be found such as in Daqing's eastern oil fields, which resulted in extreme water-cut and reduction in oil recovery. Water coning is a real issue in matured oil fields due to pressure depletion or increase in water oil contact (WOC), which results in killing the well through producing more water and reduction in oil rates as seen in Figure 1.1, to reduce the level of water production during work over operation (Taha & Amani, 2019).

In many oil field applications, gas or water cone is a serious problem. It is essential to minimize or delay coning because it affects the production rate of oil significantly. Minimizes or delay of water coning can be done by many ways, one of them is if assumed that there is no bottom water in reservoirs with a gas cap, normally vertical wells are perforated as low as possible. If the reservoir has a bottom water but there is no gas cap. The water coning is minimized or delay by completing the vertical wells to the top section of the pay zone. Normally the vertical wells are perforated below the centre of the oil zone or near to the centre if the oil reservoir has the bottom water table and a gas cap. That is because in the fluids the viscosity and density difference are proportional inversely to the coning tendencies. Water has more tendency to cone than gas, that is happing because the difference in density between water and oil is smaller than the difference in density between gas and oil. On the other hand, in a given reservoir for the same pressure drawdown the water flow rate will be lower than the gas flow rate because the water viscosity is much higher than the gas viscosity. Viscosity and density differences between gas and water try to balance each other. Thus, to minimize gas as well as water coning a preferred perforated interval is at the centre of the oil pay zone. The perforation of most of the wells is done closer to water-oil contact than to the gas-oil contact from the practical standpoint.

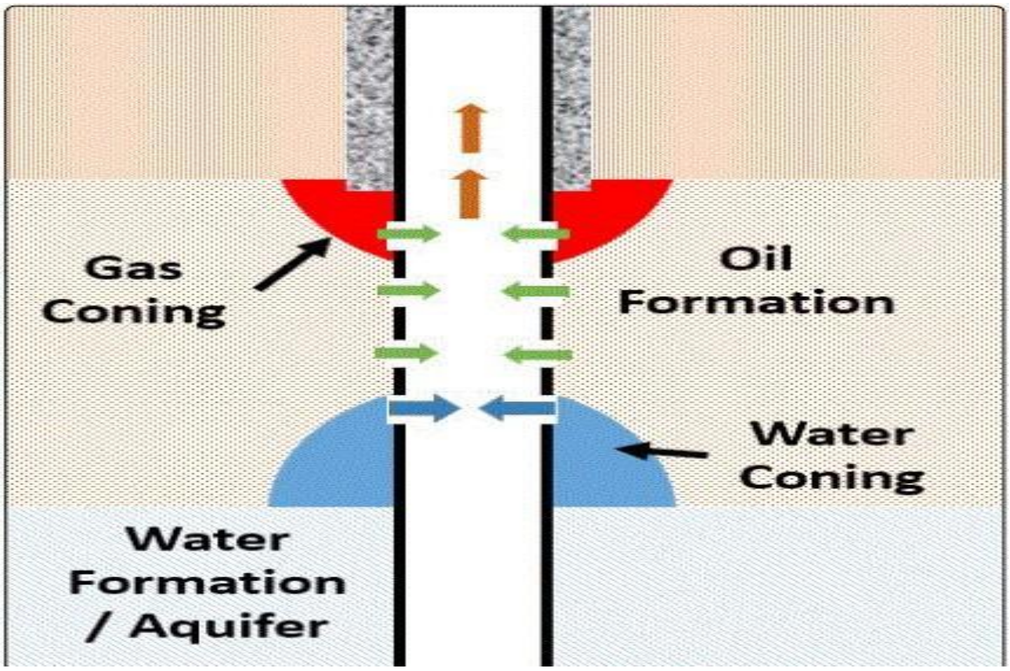

Figure 1.1: Water coning and gas coning in the wellbore (Taha & Amani, 2019)

Oftentimes, the borehole is completely squeezed off and the well is recompleted above the WOC. Goodwin (1984) stated that water production can only be altered by cement squeezing if the water is flowing through natural or formed cracks or channels in the primary cement casing. Work over operation such as water shut off (WSO) chemical methods or squeezing cements can help to minimize or eliminate the issue and increase oil recovery. Also, workover operations involve operations to treat scale formation, corrosion, casing failure, coning, and many other issues (Zhao et al., 2007). With increasing demands for oil and gas as energy sources, it’s vital to ensure adequate stable oil production, so workover is used to ensure production stability due to the fact that it deals with various operations within the oil and gas fields, and the following are the main scope of work of workover operations (Lei & Li, 2019; Wu et al., 2014; Zhang, 2005):

- Complete operations such as well cleaning, pressure testing, fluid displacement, perforation, and production sequence operation.
- Operation of the tube matrix with isolators to implement regional production and injection.
- Pump inspections, such as start-up and recovery of production pipelines, pump rods and pumps.
- Support pickling and crushing operations, including drilling and tool thread changing.
- Treatment of down hole faults, such as sand plug removal, dewaxing, sticking release, and catching.
- Confirmation, orientation and identification of leakage operations such as confirming stacker setup and checking for structural damage.
- Production testing procedures to determine the production capacity of oil and gas wells.
- Casing damage repair operations, such as casing damage sealing, smaller casing operation, casing remodelling, casing correction and casing replacement.
- Possible tapping operations in old wells such as monitoring window milling.
- Clogging and abandonment of oil, gas and water wells, such as drainage operations.

This study aims to design an effective plan for workover operation for a studied oil well. Additionally, investigating the GOR and water-cut before and after the workover operation is another goal of this study, which simulation study and mathematical correlations have been used to provide solutions to the coning issue. Also, specifically the coning problem discussed briefly in order to provide proper information about it and then, depending on the data that has been collected in Khurmala Field in north of Iraq workover plan and coning reduction shown clearly.

1.2. Objective of the Research

The aim of this research is the following:

1. Identification and determination of the design plan for workover operation in mentioned wells.
2. Evaluation the rate of Gas Oil Ratio (GOR) before and after work over operation.
3. Selecting the area of water coning and gas coning with showing re-perforation interval.
4. Providing literature about the topic with clarifying the main aspects.
5. Calculating the optimum production rate with different correlations.

1.3. Well Location Information

Kirkuk field is a super-giant field comprising three Domes that extend from southeast to the northwest by about 100 Km long and 4 Km wide. The two main domes (Baba and Avanah) are located in Kirkuk city, while the third one (Khurmala) is located in Erbil city. It has been decided that Erbil city will take the lead in managing and developing the Khurmala Dome.

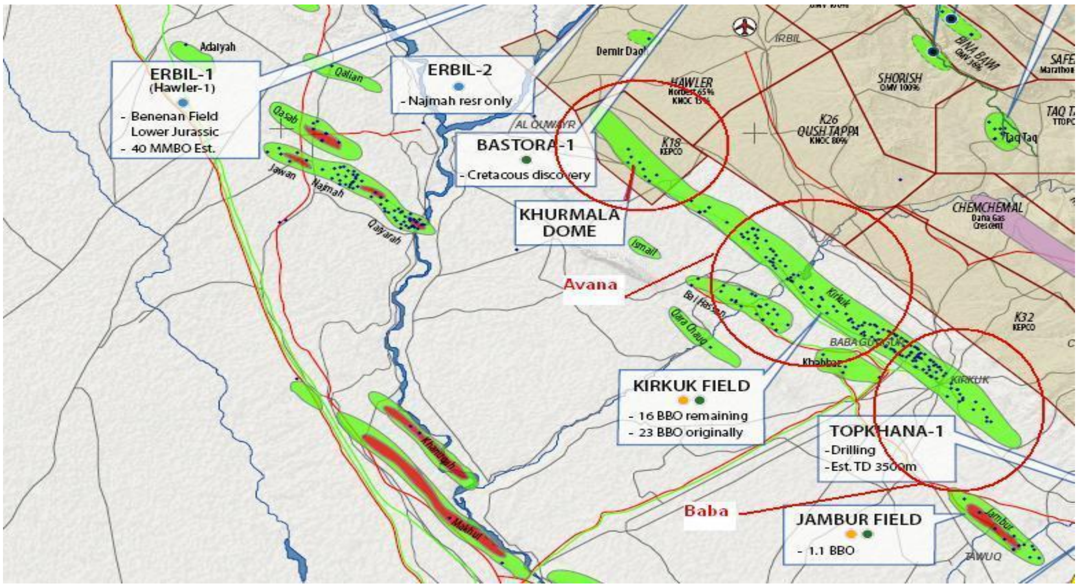

Figure 1.2: Khurmala dome location (A. Abdulla, 2012)

The Khurmala Dome is located about 80 km to the North West of Kirkuk city and 35 km West of Erbil city, lies fully on the territory of Erbil Governorate. The length of Khurmala dome extend about 22 kilometres with 3 kilometre wide which is divided into three stations which are South station, Middle station and North station. In this region, hydrocarbon extract in mainly limestone reservoir which is known as Tertiary reservoir. Mentioned reservoir has several reservoir characteristics, it is mostly characterized by natural fracture with having proper or good permeability and porosity. Moreover, based on the data, the thickness of its oil column is expected to be around 60 meter and it is located between aquifer and large gas cap. Oil and gas contact located at 590 m (MSL) as well as Oil water contact located between 660-670 m (MSL) and mentioned depths vary from one location to another.

1.4. Description of the Problem

Coning could be defined as a serious problem that appear while oil production process, either water coning in the bottom of the perforation zone or gas coning in the upper part of the perforation zone, and both of them lead to reduce oil production. There are some conditions which may be similar to gas coning problems, such as producing free gas from reservoir and it should not be confused with gas coning problem, because free gas is a natural expansion of gas in the reservoir due to reducing reservoir pressure. On the other hand, water coning should not be disorganized with producing water while climbing WOC from water influx.

Water coning and gas coning are the main factors that lead to reduced oil production in the life of the wells. Solving both water coning and gas coning problems require a number of strategies toward eliminating the problem as well as re-design of the well. Such as drilling a new section to reach oil-water contact and re-perforate the oil zone.

Gas coning can be defined as increasing or decreasing that happens due to the pressure drawdown during production. Coning occurs in vertical or slightly deviated wells and is affected by the characteristics of the fluids involved and the ratio of horizontal to vertical permeability.

There are many problems that come from the water coning, which is one of the biggest issues and challenges that most petroleum engineers face during the life of oil fields due to the huge consequences and the need for extra cost to manage it. These consequences of water coning can result in very negative impact on the oil production and gas fields, such as:

- Corrosion due to producing water and gas.
- Reduction in oil production rate as water and/or gas production after the cone breakthrough.
- Additional costs for gas and/or water handling facilities due to a high production of water and gas which requires separation to avoid consequent other problems.
- The well may be abandoned in early stages as the water cut increases to a limit that is economically unacceptable.
- Reduction of overall oil recovery.

These huge consequences are tough, because it reduces the quality of oil and reduces the profits.

It is very important to notice that water coning is not a simple water problem in oil and gas fields, as water coning is a very complex problem that cannot be eliminated easily without proper preparation and extra costs for facilities or technologies to handle the problem. Hassi R'mel field in Algeria is one of the largest gas fields in the world that made a study on the impact of water coning on performance of the wells by a simulation study of the field to predict the parameters such as critical rate and time to the cone to breakthrough in order to reduce the consequences of extra operation costs and maximize oil HC recovery (Recham et al., 2013). Asmary reservoir-fauqi field is another oil field in south Eastern of Iraq that concerns with coning issue and made a case study on water coning and proposed an empirical equation to calculate the critical production rate (Talib and Shaker, 2009).

1.5. Scope of Research Study

This thesis will discuss and focus on the water coning and gas coning problem in Khurmala dome of Kirkuk oil field located in North of Iraq. Through collecting available data about selected wells production including (water, gas and oil) before and after work over operation, it will be very significant in order to understand the workover operation and its effect based on the selected well design and the re-drilling interval.

This study is limited to strategic management of water coning problems in oil reservoirs. Calculations of critical rate, and comparison between their correlations is done, in addition to analysing the data based on real practical field data.

Thesis Structure

The thesis is divided into five chapters. The first chapter introduces the thesis topic, thesis problem and defines the objective of the thesis. The second chapter is a review of the previous literature related to coning and solutions to coning. The third chapter describes the thesis methodology while the fourth chapter describes the results of the thesis. Finally, the fifth chapter presents the conclusions of the study as well as recommendations.

CHAPTER 2
LITERATURE REVIEW

2.1. Overview

Drilling and completion are the major operations which perform to access hydrocarbon reserves; besides, production wells are to be optimized in terms of pressure drop in the reservoir to achieve maximum cumulative hydrocarbon production from the reservoir. During the course of production, optimized production rate can reduce due to fluid mechanical reasons such as water coning and gas coning. To eliminate these problems requires workover operations in order to bring back the reservoir pressure and increase daily production rate of oil. Mechanical and chemical processes of the oil and gas reservoir affect the wellbore, on the other hand most of the time reservoir pressure and its production seem to be good but due to changing oil water contact or gas water contact in the perforation interval cause reducing oil and gas production (CAPPA, 2013). Moreover, both types of coning are a very problematic situation in several oil and gas fields, also its not economic condition due to reducing oil production. More clearly, in any well after completion and under production for a period of time, any kind of mentioned problem may occur and it requires some operations to eliminate the problem and change the flow characteristics of the reservoir including, re-perforation workover, different zone completion operation, acidizing, fracturing, cement job, tube or casing leakage workover etc. (Recham et al., 2013). Coning issue that could be considered a problematic situation for a well production issue has been discussed below.

2.2. Water Coning

Producing oil in the reservoir when it is in between gas and water zones may face many challenges and problems such as producing high amounts of water and gas within oil production due to coning problems. In addition, coning problem is defined as a terminology to explain the movement of water upward and movement of gas downward to the perforation zone and decrease oil production. In other meaning, when coning occurs due to gas, Gas Oil Ratio (GOR) increases while when coning occurs due to water, water cut (WCT) in the reservoir happens and both situations lead to decrease oil production.

Figure 2.1 represents the water coning problem due to both water and gas movements toward the oil production zone (Mogbo, 2010).

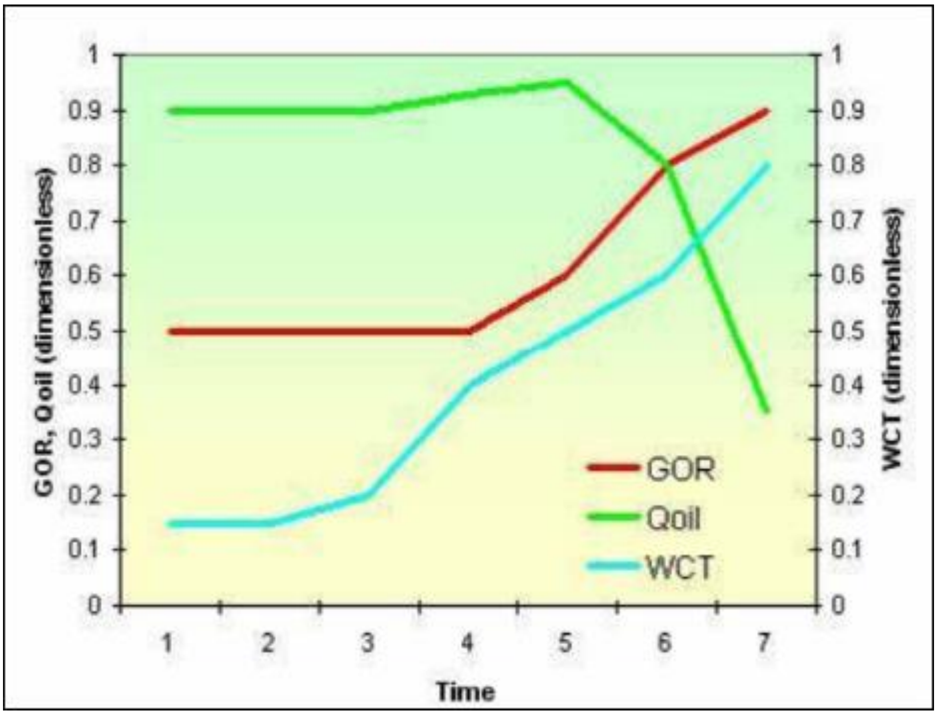

Figure 2.1: Typical effect of coning (Mogbo, 2010)

In addition, the pressure between well and gravitational force leads to an occurrence of coning problem in which the pressure that is created by the well is more that the gravitational pressure for both water and gas, and this leads to change the direction of gas and water toward the production zone called drawn of gas and water. So, coning issues are influenced by several characteristics in the reservoir such as viscosity, density of the fluid in the reservoir, permeability, well location, geometry of the reservoir. So, extreme water and gas production by reservoirs is the result of a coning problem (Onwukwe, 2015).

Moreover, the water coning problem is considered as a very big problem during the life of the well due to producing hydrocarbons for a long time with high rate of production. In this situation, water will move to the perforation zone which is called water breakthrough. Figure 2.2 represents the water and gas coning problems in the wells (Petrowiki, 2019).

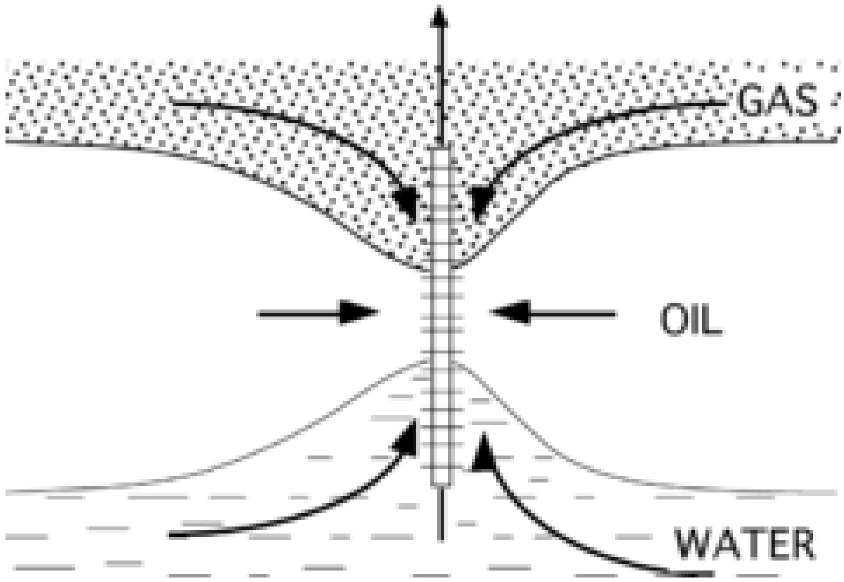

Figure 2.2: Water and gas coning problem (Petrowiki, 2019)

In addition, in some situations due to decreasing the level of hydrocarbon in the reservoir there is possibility to produce water and it’s not considered a water coning problem due to increasing water oil contact to the perforation zone. This means water production due to the hydrocarbon reduction and water production due to high rate of production is not the same. Also factors that are mentioned like different viscosity, permeability, pressure reduction and etc. have influence in the water coning occurrence in the well. So, based on some data, the water coning problem is the big well problem in the wells around the world (Hayward, 2015). Water and additionally gas coning is a significant issue in numerous supplies with wells creating from a zone hidden a gas top, overlying a water or both. Coning happens in a well when the water or gas zone climbs towards the wellbore as a cone. Also, there is a proportional relation between fluid densities and its tendency for coning, which means the possibility of coning occurrence increases by decreasing fluid density (Hatzignatiou & Mohamed, 1994).

There are several methods that used to decrease water coning problem such as:

- Reducing rate of production
- Increasing the efficiency of the well

- Drilling horizontally in order to produce hydrocarbons within the formation.
- Re-perforating of the well at the top of the pay zone in case of water coning and re-perforating well at the bottom in case of gas coning problem
- Increasing distance between GOC and OWC through proper well completion design
- Infill drilling (Hatzignatiou & Mohamed, 1994).

The factors that water coning depends on are properties of porous medium, density differences, viscosity of water and oil, relative permeability, pressure drawdown and the distance to the perforation (Saleh and Khalaf, 2009). In terms of oil recovery, water coning is highly unwanted, and that is because of minimizing oil production when the water reaches the well at high production rate. When the well is producing at low production rates, the water-oil interface assumes a stable shape, and at the same time the well performance will not be impaired. So, optimal production rate to ensure a stable well performance is of highly concerns in water coning problems. Basically, oil wells are perforated at the pay zone far from oil-water contact, to lower the risks of water coning. Pressure drawdown is the main factor that controls the water coning, in which the pressure drawdown increases at higher production rate, thus, pressure drawdown can be minimized by reducing production rate and this is not practically acceptable. Figure 2.3 shows the original condition of a reservoir before coning incident (Ahmed, 2010).

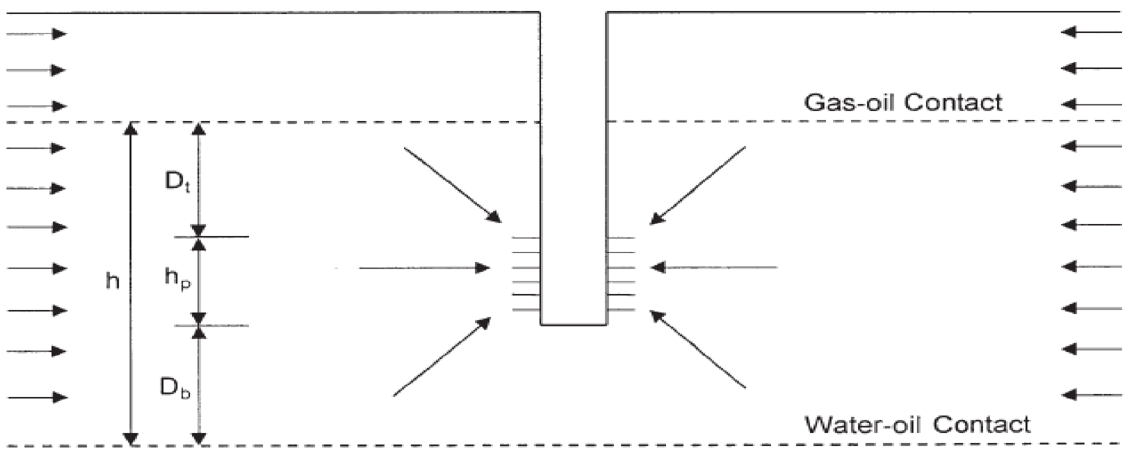

Figure 2.3: Oil reservoir at static condition (Ahmed, 2010)

In Figure 2.3, the symbols D_t represent distance from GOC to perforation, D_b refers to distance from OWC to perforation, h refers to total oil column and h_p refers to perforation interval. After producing oil at a high rate, the water-oil contact and gas-oil contact changed to a level that caused water or gas production. Figure 2.4 shows the oil reservoir after a long time of production.

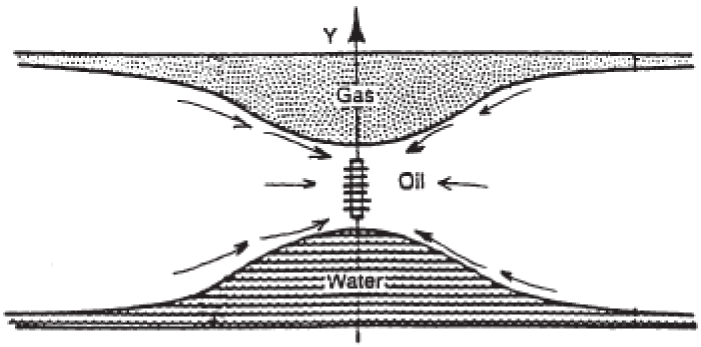

Figure 2.4: Water and gas coning (Ahmed, 2010)

There are essentially three main forces that contribute and affect coning phenomena, including gravity forces, viscous forces and capillary forces. When the well is producing for a period of time, and the gravity force is in balance with the viscous forces, then a stable cone may form without reaching the well. In contrast, when the viscous forces exceed the gravitational forces, then an unstable cone forms and breakthrough the well.

Treating coning is not an easy task like other types of water problems. Coning phenomena had been studied by many authors throughout the years. Different models and empirical correlations used in order to manage the coning problem and predict the optimal production rate and breakthrough time of the cone.

2.3. Critical Production Rate

Throughout the year's different practical experiments and theoretical analysis conducted in order to understand the coning phenomena and eliminate it. Critical production rate is the basic and most common method that has been used to predict and manage the water coning. This critical production rate analysis is based on the fact that when oil production rate is appropriately low or if the pressure drop is minimized, then the water coning phenomena can be avoided. So, critical production rate can be defined as the maximum oil production rate at which the well produces oil without water or gas. Critical rate is the maximum production rate which does not allow water to breakthrough into the production well. (Aliev et al., 2015).

Several empirical correlations are available by many authors to calculate the critical production rate in which it is valid for oil wells with the presence of water drive and a continuous oil-water contact. The critical production rate correlations depend on several parameters, including oil viscosity, density differences between reservoir fluids, vertical permeability, and well penetration ratio. The authors who developed empirical correlations to calculate critical production rate in vertical wells are Craft and Hawkins (1959), Mayer and Gardner (1963), Schols (1972), Chaperon (1986), Giger (1989), Hoyland et al. (1989), Guo and Lee (1992), and Saleh and Khalaf (2009).

Several of the equations presented below by some authors who have been mentioned above.

2.3.1. Hoyland Papatzacos and Skjaeveland's Method

Two different methods have been proposed by Hoyland, Papatzacos and Skjaeveland to predict critical production rate for a reservoir with a lowest water-coning, and similar formations layer with finalized well from the upper part of the formation. The first mode or system is a methodical method, as well as other one is numerical. The investigative solution or key method is provided depending on the theory of Muskat-Wyckoff (1935), this way undertakes in a steady-state form, in which analytical solution takes a modest system when it is joined with the technique of descriptions to give the border circumstances as it has been shown in Figure 2.5, which it shows the reservoir boundaries and the cone height (Hoyland et al., 1989).

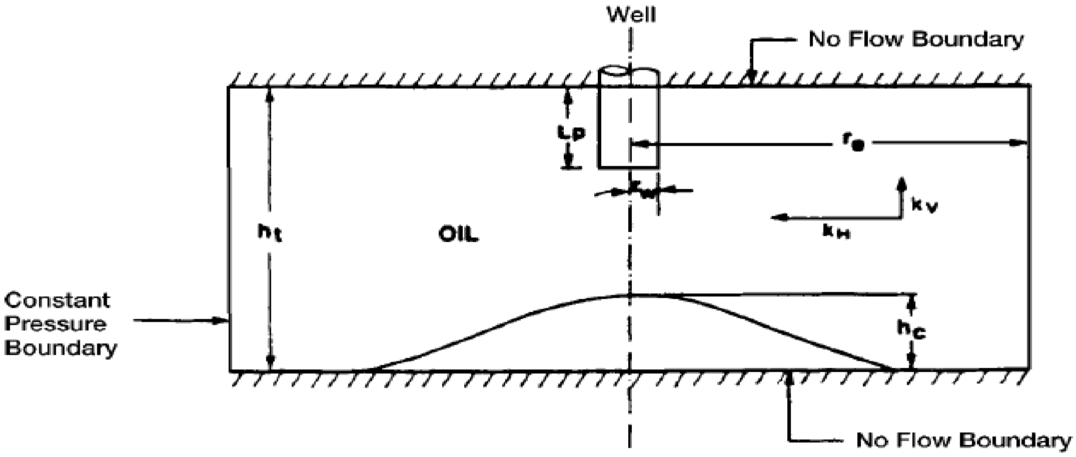

Figure 2.5: Boundary condition for analytical solution (Hoyland et al., 1989)

Hoyland, Papatzacos, and Skjaeveland proposed the analytical solution to predict the critical production rate in the following form:

$$Q_{oc} = 0.246 * 10^{-4}\left[\, h^2(\rho_W - \rho_O)Kh/\mu o\ Bo\right] q_{CD} \qquad (2.1)$$

Where

Q_{oc} = Critical production rate, STB/D

q_{CD} = dimensionless critical rate

k_h = horizontal permeability, md

h= oil column height, m

μ_o= oil viscosity, cp

Bo= oil formation volume factor

ρ_w= water density, gm/cc

ρ_o= oil density, gm/cc

The authors connected dimensionless parameters, including; dimensionless radius, dimensionless critical rate and fractional well penetration ratio as it is presented in Figure 2.6 (Hoyland et al., 1989).

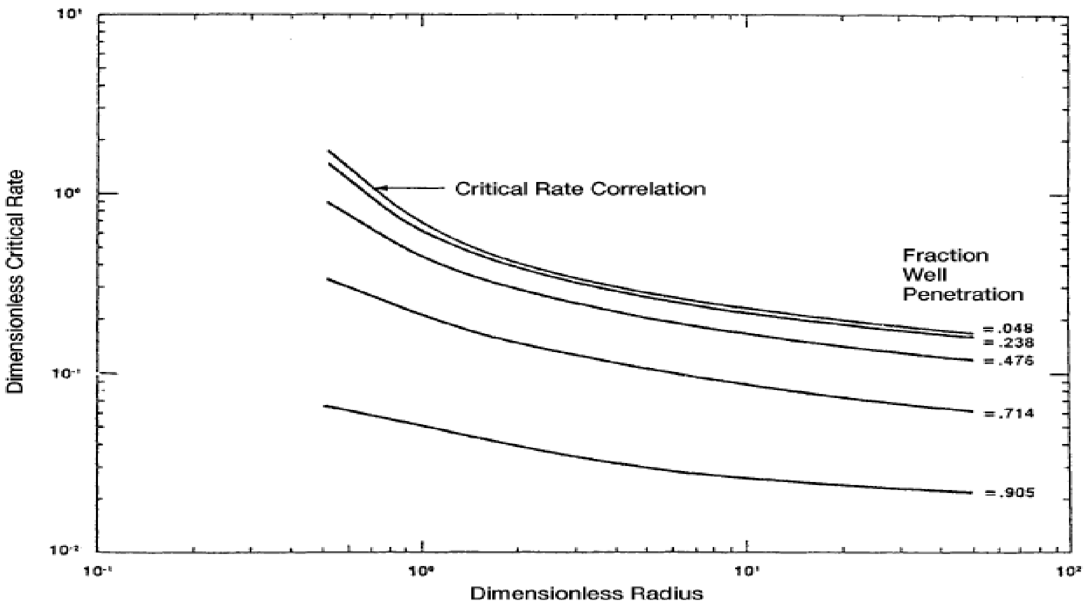

Figure 2.6: Critical rate correlation for different penetration ratios (Hoyland et al., 1989)

Where the dimensionless radius r_D can be computed by using the following equation:

$$r_D = r_e/h\sqrt{k_v/k_h} \qquad \textbf{(2.2)}$$

The numerical solution method is for an isotropic reservoir where Kh = Kv and correlate dimensionless variables and five different fractional well penetration in a graphical form as presented in Figure 2.7 (Hoyland et al., 1989).

$$\mathbf{Q_{oc} = 0.924 \times 10^{-4}\, K_O(\rho_w - \rho_o)/\mu_o B_o \left\{\left[1 - \left(h_p/h\right)^2\right]^{1.325} \times h^{2.238}[\ln(r_e)]^{-1.99}\right\}} \qquad \textbf{(2.3)}$$

Where:

Q_c= Critical production rate, STB/D

h= oil column thickness, m

h_p= perforation thickness, m

μ_o= oil viscosity, cp

Bo= oil formation volume factor

ρ_w= water density, gm/cc

ρ_o= oil density, gm/cc

re= radius of drainage area, in

Ko= oil permeability, md

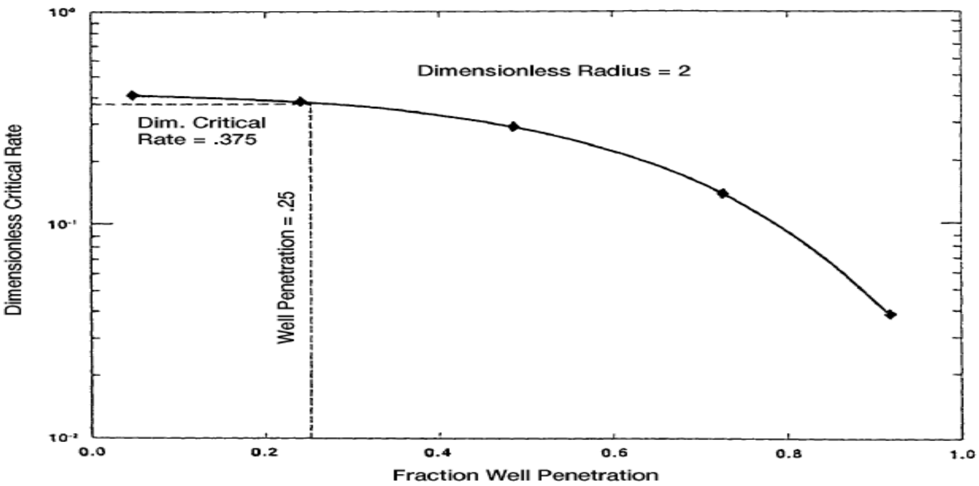

Figure 2.7: Critical rate correlation (Hoyland et al., 1989)

2.3.2. Chaperon's method

Chaperon proposed a simple correlation to calculate the critical production rate in vertical wells in an anisotropic reservoir where Kv ≠ Kh (Chaperon, 1986).

Equation 2.4 refers to Chaperon's correlation to predict critical production rate.

$$Q_c = \mathbf{0.0783 * 10^{-4}} [\, kh(h - hp)2/\mu o\ Bo\,]\ \{\rho_W - \rho_O) qc^* \qquad \textbf{(2.4)}$$

Where:

Q_c= Critical production rate, STB/D

Qc*= dimensionless function

h= oil column thickness, m

μ_o= oil viscosity, cp

Bo= oil formation volume factor

k_h= horizontal permeability, md

ρ_W= water density, gm/cc

ρ_o= oil density, gm/cc

2.3.3. Schols's method

Schols (1972) developed a correlation to calculate the critical production rate based on results from simulation runs and laboratory experiments.

Equation 5 refers to Schols's correlation to predict critical production rate.

$$\mathbf{q_{oc} = 0.0783 * 10^{-4} [(\rho_W - \rho_O)\ Ko\ (h^2 - hp^2)/\mu o\ B] * \left[0.432 + \frac{3.142}{\ln(re/rw)}\right] (h/r_e)^{0.14}} \qquad \textbf{(2.5)}$$

2.3.4. Saleh and Khalaf's Method

Saleh and Khalaf (2009) developed and proposed an equation to predict the critical production rate in Asmari-Reservoir Al-Fauqi oil field taking into account the reservoir rock and fluid parameters and heterogeneity degree.

Equation 2.6 refers to the proposed equation.

$$q_{oc} = 0.00175 \left\{\rho_W - \rho_O / \ln \ln \left(\frac{re}{rw}\right)\right\}^{1.075} \{Ko/\mu o\ Bo\} \left(h^{2.15} - D^{1.995}\right)(H.D) + 87.8 \ln Pc \quad (2.6)$$

Where:

B_o= oil formation volume factor

Q_c = Critical production rate, STB/D

h= oil column thickness, m

H.D = heterogeneity degree

μ_o= oil viscosity, cp

ρ_W= water density, gm/cc

ρ_o= oil density, gm/cc

re= radius of drainage area, in

rw= radius of well, in

Ko= oil permeability, md

2.4. Water Breakthrough Time

Water breakthrough time is a period it takes for the principal drop of water slice to come to the wellbore under the predominant creation rate system. Basic stream rate estimations much of the time show low rates that, for monetary reasons, can't be forced on creation wells. Along these lines, if a well delivers over its basic rate, the cone will get through after a given time span. Two of the most broadly utilized connections are recorded beneath:

2.4.1. Sobocinski-Cornelius method

Sobocinski and Cornelius (1965) advanced a relationship for expecting breakthrough time depending on data and forming outcomes. The writers connected the breakthrough time with two different constraints, which include cone height and breakthrough time. Both of them could be defined by below expressions:

Dimensionless cone height Z:

$$\boldsymbol{Z = 0.492 \times 10^{-4} (\rho_W - \rho_O) k_h h (h - h_p) / \mu_O B_O Q_O} \qquad \textbf{(2.7)}$$

Where:

Qo= oil production rate, STB/day

hp= perforated interval, ft

ρo= oil density, lb/ft3

ρw= water density, lb/ft3

kh= horizontal permeability, md

h= oil column thickness, ft

Dimensionless breakthrough time $(t_D)BT$:

$$\mathbf{t_D = 4Z + 1.75Z^2 - 0.75Z^3/7 - 2Z} \qquad \textbf{(2.8)}$$

Both Sobocinski and Cornelius planned below expression for expecting time to breakthrough from the value that extracted from $(t_D)BT$:

$$\mathbf{t_{BT} = 20325.0 \mu_O h \phi t_D / (\rho_W - \rho_O) k_v (1 + M^{\alpha})} \qquad \textbf{(2.9)}$$

Where:

φ= porosity, fraction

kv= vertical permeability, and

tBT = time to breakthrough, days

M= water-oil mobility

2.4.2. The Bournazel-Jeanson method

Depending on data, both Bournazel and Jeanson (1971) planned a practice that utilize the same values and procedure suggested in the Sobocinski-Cornelius technique. The whole explanation of the technique given below.

Step 1. Calculate cone height Z

Step 2. Calculate breakthrough time through using below expression:

$$\mathbf{t_D = (Z/3) - 0.7Z} \qquad \textbf{(2.10)}$$

Step 3. Calculate t_{BT} by through replacing the above-calculated values into Equation, i.e.

$$\boldsymbol{t_{BT} = 20325.0\mu_O h\phi t_D/(\rho_W - \rho_O)k_v(1 + M^{\alpha})} \qquad \textbf{(2.11)}$$

CHAPTER 3
METHODOLOGY

This chapter starts with the introduction of the all required steps in this project. Later on, methodology to complete this project is discussed.

3.1. Data Collection

The first step toward finalizing this thesis is data procurement for three available wells in two groups: first group includes obtaining data of (chock size, well head pressure (WHP), oil rate, gas oil ratio (GOR), basic sediment and water (BS&W)) parameters before and after workover for optimizing the production rate. To determine time of water breakthrough efficiency the second group of data includes (radial extent, wellbore radius, permeability thickness, stock tank oil and water density, pay-zone thickness, horizontal and vertical permeability) has been used corresponding effects of the simulation, to conclude this analysis precisely.

3.2. Methodology Description

The main steps that have been used in this study are listed below:

Step 1: Literature review studies on water coning phenomena.

Step 2: Data gathering on the correlations available to solve the water coning phenomena.

Step 3: Analysing the data.

Step 4: Perform calculations by using the available correlations to calculate the critical production rate in oil wells.

Step 5: Analysing and comparing the results of different correlations.

Step 6: Perform a simulation study to conduct a sensitive run for production rate, perforation interval and anisotropy.

Step 7: Evaluate the results.

3.3. Reservoir Description

The reservoir is analysed for water coning problem for the effect of the three parameters on coning phenomena. The reservoir has a radial geometry which consist of 15 layers. Layer data are given in Table K in Appendix 3. All the data of the reservoir, including; reservoir model, rock and fluid properties, PVT data as well initial conditions and well data are listed in tables in Appendix 3. Figure 3.1 describes the reservoir model, where it shows the fluids contact and well location. The red colour represents the gas, the green colour represents the oil and the blue colour represents the water. The distribution of fluids in such a way is due to density variations among the fluids. So, below figure is an example well to show the influence of changing perforation interval, drilling a new section on water coning and gas coning problem with showing for our wells located in Khurmala oil field from North of Iraq.

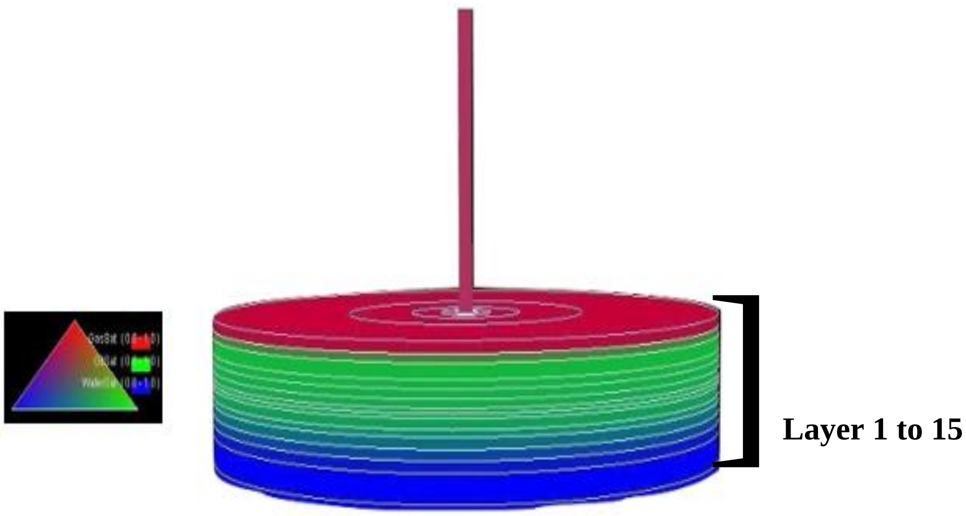

Figure 3.1: Reservoir model

3.4. Numerical Simulation

3.4.1. Determination of critical production rate

Hoyland, Papatzacos and Skjaeveland equations have been used for determining the critical production rate in this study. The results achieved as follow:

$$\mathbf{Q_{oc} = 0.924 \times 10^{-4}\, K_O(\rho_w - \rho_o)/\mu_o B_o \left\{\left[1 - \left(h_p/h\right)^2\right]^{1.325} \times h^{2.238}[\ln(r_e)]^{-1.99}\right\}} \quad \textbf{(3.1)}$$

$$\boldsymbol{r_D = r_e/h\sqrt{k_v/k_h}} \quad \textbf{(3.2)}$$

$\boldsymbol{r_e}$ = Radial extent =1200 ft

$\boldsymbol{h}$ = Oil column thickness = 196.8 ft

$\boldsymbol{h_p}$ = Perforated interval =32 ft

$\boldsymbol{k_h}$ = Horizontal permeability =256 md

$\boldsymbol{k_v}$ = Vertical permeability =36.1 md

$\boldsymbol{B_o}$ = Formation volume factor =1.09

$\boldsymbol{Q_o}$ = Oil production rate =2800 STB/day

$\boldsymbol{\mu}$ = Oil Viscosity =2.9 cp

$\boldsymbol{\rho_o}$ = Stock tank oil density =39 lbm/ft3

$\boldsymbol{\rho_w}$ = Stock tank water density =62.4 lbm/ft3

3.4.2. Determination of breakthrough time

Sobocinski-Cornelius equations have been used for determining the breakthrough time in this study. The results achieved as follow:

$$\boldsymbol{Z = 0.492 \times 10^{-4}\,(\rho_W - \rho_O)k_h h\left(h - h_p\right)/\mu_O B_O Q_O} \quad \textbf{(3.3)}$$

$$\boldsymbol{t_D = 4Z + 1.75Z^2 - 0.75Z^3/7 - 2Z} \quad \textbf{(3.4)}$$

$$\boldsymbol{t_{BT} = 20325.0\mu_O h\phi t_D/(\rho_W - \rho_O)k_v(1 + M^\alpha)} \quad \textbf{(3.5)}$$

$\boldsymbol{\phi} =$ Porosity =17 %

$\boldsymbol{h} =$ Oil column thickness = 196.8 ft

$\boldsymbol{h_p} =$ Perforated interval =32 ft

$\boldsymbol{k_h} =$ Horizontal permeability =256 md

$\boldsymbol{k_v} =$ Vertical permeability =36.1 md

$\boldsymbol{B_o} =$ Formation volume factor =1.09

$\boldsymbol{Q_o} =$ Oil production rate =2800 STB/day

$\boldsymbol{\mu} =$ Oil Viscosity =2.9 cp

$\boldsymbol{\rho_o} =$ Stock tank oil density =39 Ibm/ft$\mathbf{3}$

$\boldsymbol{\rho_w} =$ Stock tank water density =62.4 Ibm/ft$\mathbf{3}$

3.5. Comparison of Critical Production Rate Correlations

As one of the objectives of this study is to compare between different critical production rate correlations, a defined field data is used in this study to examine the correlations and compare their results in a reasonable manner. Different correlations selected to be the source of comparison, including: Chaperon, Hoyland, Papatzacos, and Skjaeveland, and Ozkan-Raghavan correlations.

3.6. Sensitivity Analysis

Schlumberger Eclipse Simulation Software used in this study to run a sensitive analysis for three parameters; production rate, perforation interval, and anisotropy. Eclipse simulation software is an Integrated Production Modelling Software for the purpose of reservoir simulation.

3.6.1. Effect of production rate

As one of the main objectives of this study is to do a sensitive analysis of certain parameters to know their impact on well performance in case where a water cone exists, a sensitive run for production rate is done by means to observe their impact on coning and well performance.

Three different production rates of 450, 1300, and 3500 stb/day are used and analysed in which their impact on well performance and coning problems has been noticed through comparing these production rates in terms of cumulative oil production, gas oil ratio (GOR), and water cut. The result has been described in figures and discussed in chapter four.

3.6.2. Effect of permeability anisotropy on well performance

Sensitive run is also done for permeability anisotropy for three different anisotropy ratios, including 0.01, 0.1, and 1, whose impact has been observed by analysing and comparing cumulative oil production, GOR, and water cut.

3.6.3. Effect of perforation interval on well performance

Lastly, the impact of the perforation interval is evaluated through a sensitive run for three different perforation intervals, in which, like the previous parameters, their impact has been observed by comparing cumulative oil production, GOR, and water cut for these three cases.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1. Result of the Study

This section provides all the results of this study, in which it involves the result of the simulation in addition to the result of the mathematical correlations to achieve the objectives of this study. Hoyland and Chaperon correlations were used in this study to investigate the critical production rate in order to reduce or eliminate the excessive water production coming from the water coning problem. Additionally, The Sobocinski-Cornelius method and the Bournazel-Jeanson method have been implemented to investigate the breakthrough time of the water cone and have been compared to the simulation result for accuracy purposes.

4.1.1. Correlation results

In this project, a statistical review was studied, which includes a distinction between critical correlations of production rate for two correlations and time breakthrough correlations for two major correlations.

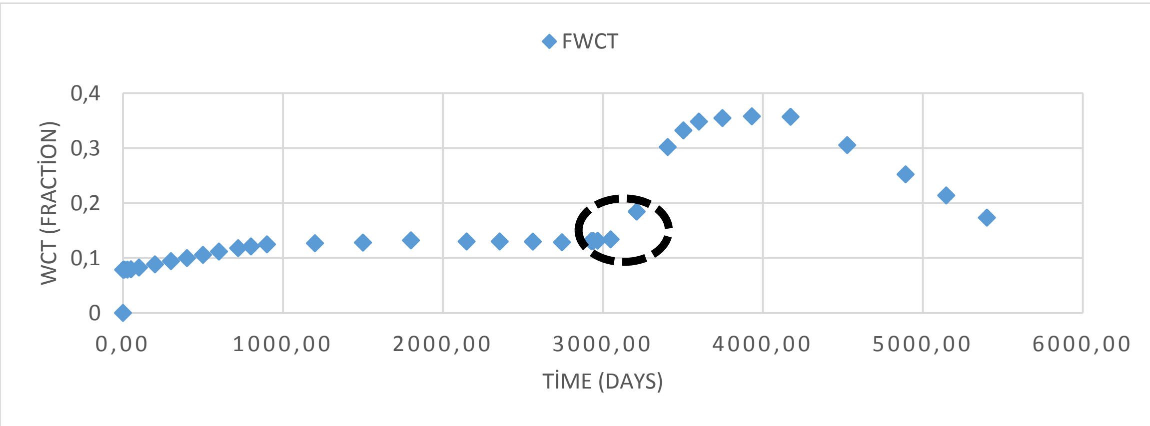

Figure 4.1: Water cone breakthrough time prediction

A simulation run is used to ensure that critical rate and water breakthrough efficiency are determined with the corresponding effects of the simulation, to conclude this analysis precisely. Figure 4.1 shows the outcome of the simulation after a plot of water cut versus time to clarify that after 3080 days, water is beginning to break through by examining the shift in water cut.

The comparison in critical production rate for this study has been made between the following correlations:

1. The Hoyland-Papatzacos-Skjaeveland Methods
2. Chaperon

The result of the comparison between the three correlations is labelled in Table 4.1.

Table 4.1: Critical production rate calculation result by Hoyland-Papatzacos-Skjaeveland and Chaperon method

Correlation	**Q_c (stb/day)**
Hoyland-Papatzacos-Skjaeveland Methods	3033.32
Chaperon	6967

The Sobocinski-Cornelius method is contrasted with the Bournazel-Jeanson method, in which associations formed both through experimentation and using dimensional parameters. The outcome varies because of the difference between their functional variables, mostly because of the dimensional breakthrough period. The findings of the distinction between the Sobocinski-Cornelius Approach and the Bournazel-Jeanson approach are shown in Table 4.2.

Table 4.2: Water breakthrough time calculation result by Sobocinski-Cornelius and Bournazel-Jeanson method

Correlation	**t_{BT} (days)**
The Sobocinski-Cornelius Method	3136.7
The Bournazel-Jeanson Method	2198.2

In order to predict the effect of these parameters on the output of a well, in cases of coning problem, by analysing the difference in cumulative oil production, gas-oil ratio and waste water-cut for each of these scenarios and comparing it with one another. Furthermore, statistical analysis is conducted to measure critical production rate and water cone breakthrough time by means of usable correlations in order to decide which procedure can correlate the effects of the simulation with the results of the simulation.

The findings for each correlation are very different since any correlation is formed to approximate the critical production rate and duration of cone breakthrough time based on different theories. The results are quite different.

The result reveals that crucial production rates in Hoyland-Papetzacos-Skjaeveland are 3033.32 STB/day, which are very similar to the results of a simulation, as the rate of 3000 bpd for the simulation is used. The observations of Chaperon (1986) and Hoyland et al. (1989) are equivalent, as seen in Table 4.1.

Chaperon (1986) has a higher critical production rate of 6967 STB per day as the well completion interval is believed to be exceedingly short. This is diminished by the greater distance between the oil-water interaction and the perforation interval.

Table 4.2 displays the outcome of cone breakthrough simulations in which two principal correlation results, namely the Sobocinski-Cornelius model and the Bournazel-Jeanson model are used to correlate their results with simulation results. The simulation reveals that after 3200 days of production the water cone will break through, as seen in Figure 4.1.

The shift in water cut by the fast growth after 3050 days has been analysed. The findings of the time measurement indicate that the Sobocinski-Cornelius mechanism is very similar to the results of simulation, since this results in a water cone spread across approximately 3136.7 days after producing. While the Bournazel-Jeanson approach reveals that the cone breaks out after 2198.2 days, about 1000 days before real effects.

4.1.2. Simulation results

This section provides all the simulation outcomes, which involve sensitivity analysis for different perforation intervals for the purpose of providing optimum scenarios to deal with the coning issue. In Figure 4.2, three different intervals were used, including intervals 5-6, 7,-8, and 9-10. The simulation has been run for 1000 days, and cumulative oil production for these cases are shown below. Interval 5-6 shows a cumulative oil production of 500,000 barrels. Interval 9-10 shows a cumulative oil production of 650,000 barrels while interval 7-8 produces the highest amount of oil with a cumulative oil production of 676,000 barrels.

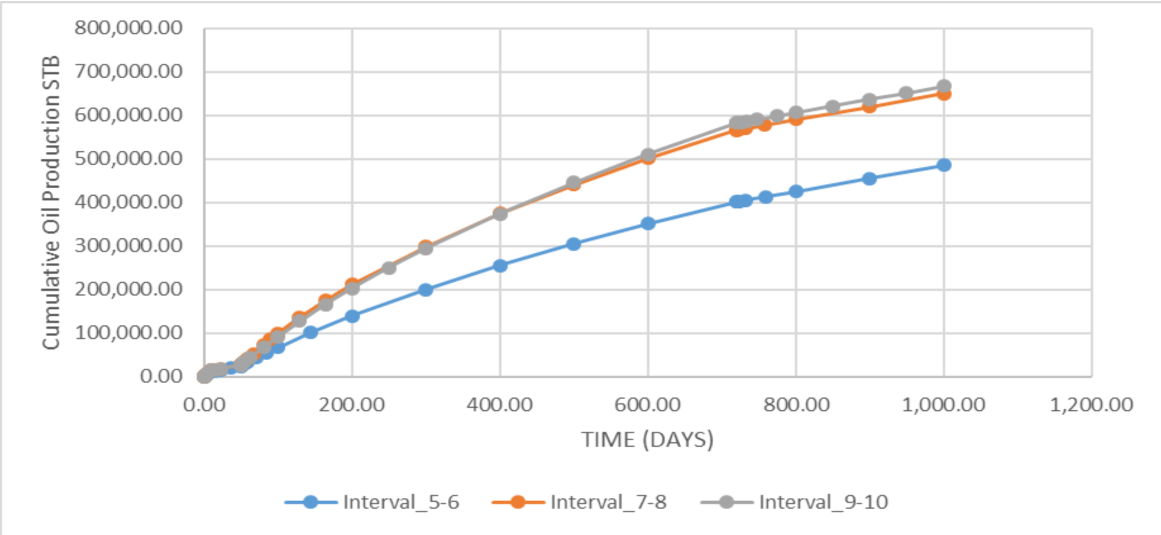

Figure 4.2: Cumulative oil production vs. time

Figure 4.2 shows the impact of the perforation interval on water-cut. Based on the simulation result, perforation interval 5-6 produces the lowest amount of water, while interval 7-8 produces a water cut of 44%. However, higher perforation intervals result in a water-cut of 58%. The result that has been obtained is due to the fact that lower perforation interval is farther from the WOC, while higher perforation interval results greater water-cut due to the fact that it is much closer to WOC.

Figure 4.3 shows the plot of the perforation interval on GOR. The GOR for perforation interval 9-10 is lowest, because it is far away from the GOC. The orange colour represents perforation interval 7-8 and it produces a maximum GOR of 3 MSCF/STB, while the higher perforation interval 5-6 produces the greater GOR of 3.5 MSCF/STB due to the fact it is much closer to GOR compared to the other intervals.

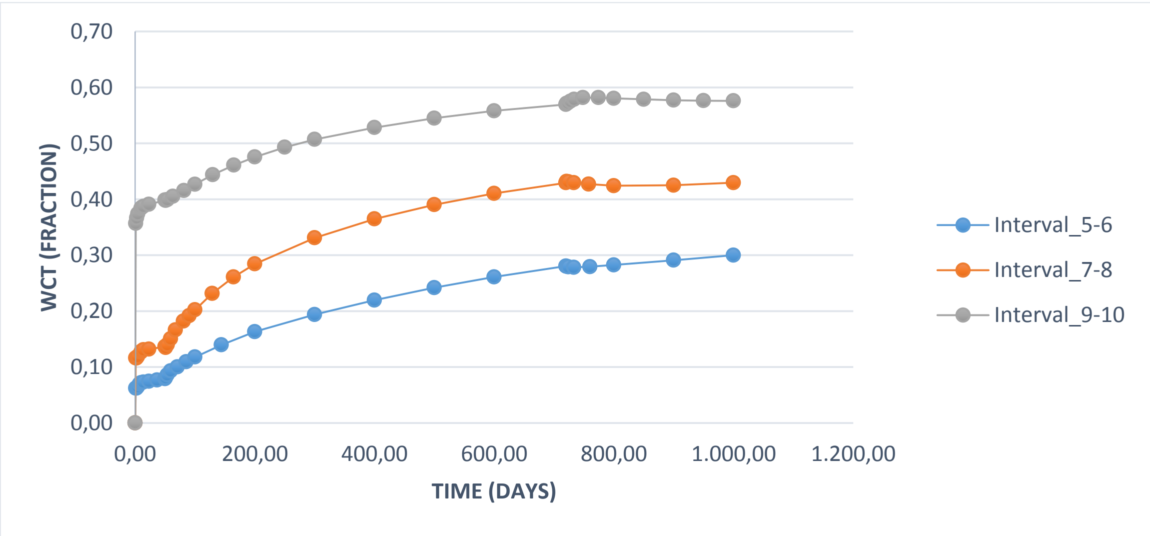

Figure 4.3: Water-cut vs. time

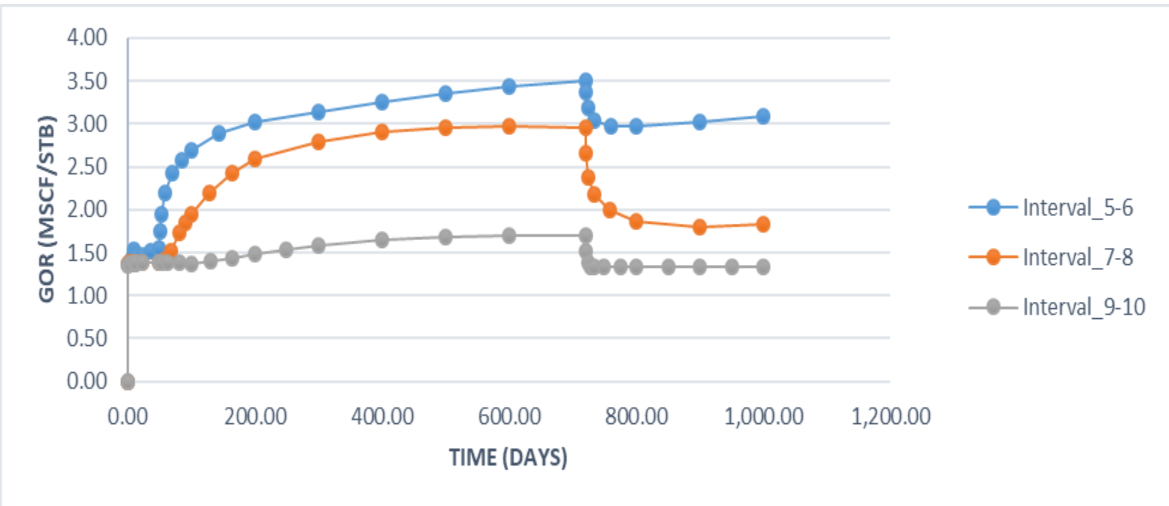

Figure 4.4: GOR vs. time

The perforation interval effect on coning output was explained in Figures 4.1, 4.2 and 4.3 and contrasts its impact on total oil production, the water cut and GOR of 3 perforation intervals 5-6, 7-8 and 9-10. The outcome of the simulation shows that the influence of the perforated interval on total oil production is larger, as is shown by the greater distance between this interval and WOC, with the perforation interval 5-6. While GOR in the 5-6 interval tends to be very high compared with other perforations, as this interval is near GOC, a higher production of gas has been expected. Layer 7-8 perforation interval results in lower water and gas as the condition compares to a 5-6 and 9-10 production interval. Since it is finished from the OWC and GOC point.

4.1.3. Well production result before and after workover operation

As it has been discussed earlier, workover operations aim to improve production performance. This result is tabulated in table 4.2, 4.3 and 4.4 in the appendix section. Figure 4.5 shows oil production rate before and after workover for well A. based on the plot, the oil production rate before implementing the workover operation is around 600 bpd while after implementing workover operation, the oil production rate increases to 2500 bpd, 5 times production rate before implementing the workover operation. This result proves that workover operations are required and very important to improve oil production rate.

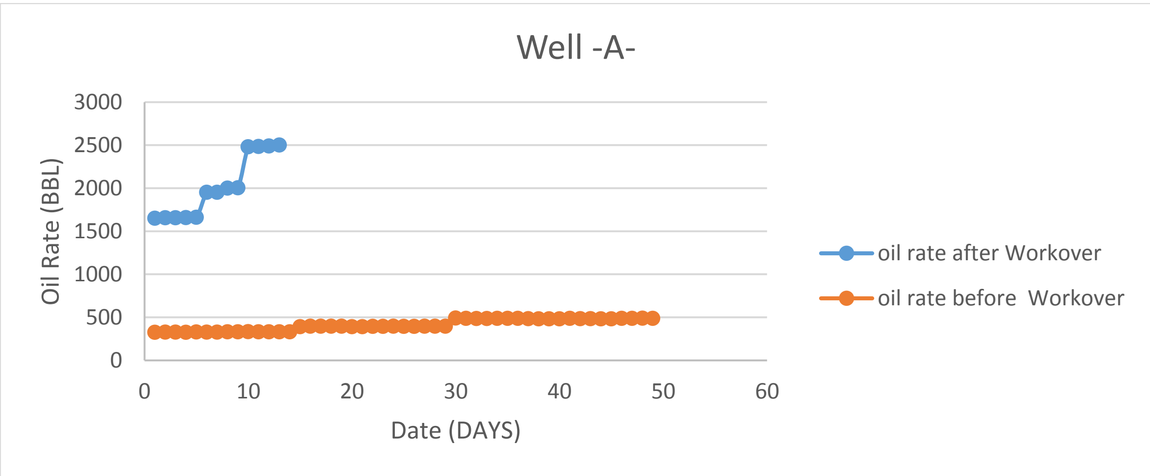

Figure 4.5: Well (A) oil production rate before and after work over

Figure 4.6 shows the amount of gas produced before and after workover operation. The result shows that gas production rate has decreased after implementing workover operation. In terms of water-cut, Figure 4.7 shows the result of before and after implementing workover operation and its impact on water-cut. The result proves that water-cut significantly reduced from 15-20% to a water-cut of 1.5%. The result shows that after implementing workover operation, the water-cut and gas production reduces.

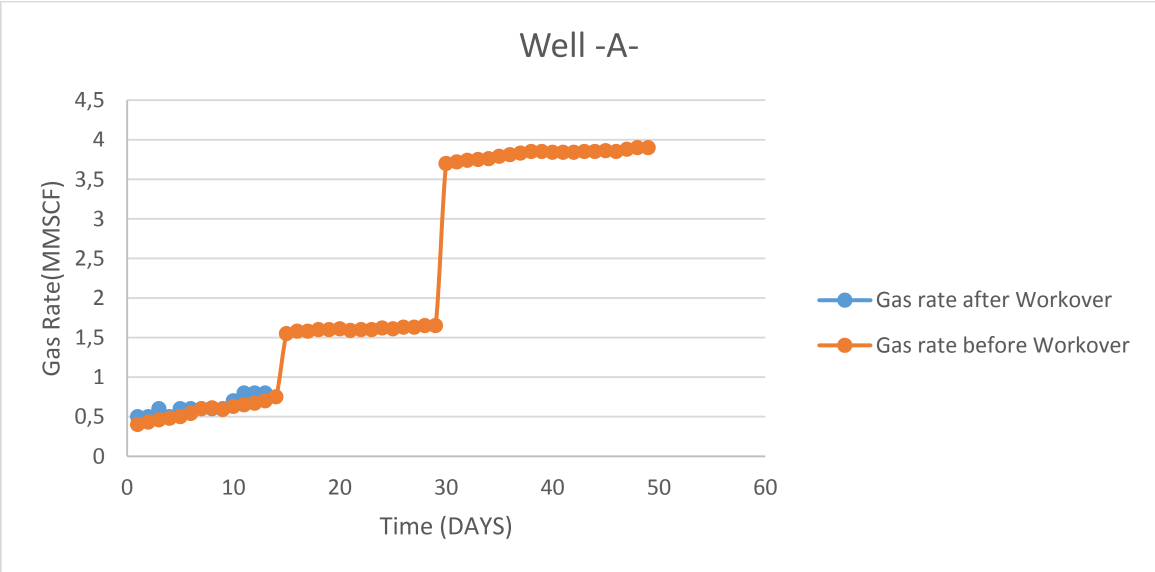

Figure 4.6: Well (A) gas production rate before and after work over

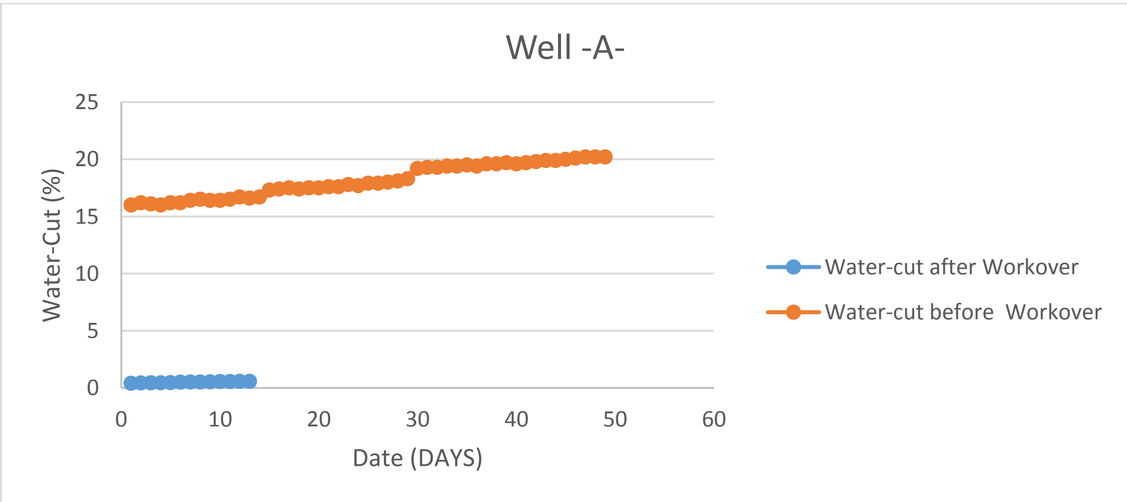

Figure 4.7: Well (A) water cut before and after work over

The impact of workover operation on GOR is shown in Figure 4.8. based on the plot, the GOR has reduced after implementing workover operation from 3000-4000 MMSCF to 800 MMSCF. This means that workover operation reduces the produced gas and results in solving gas coning issues.

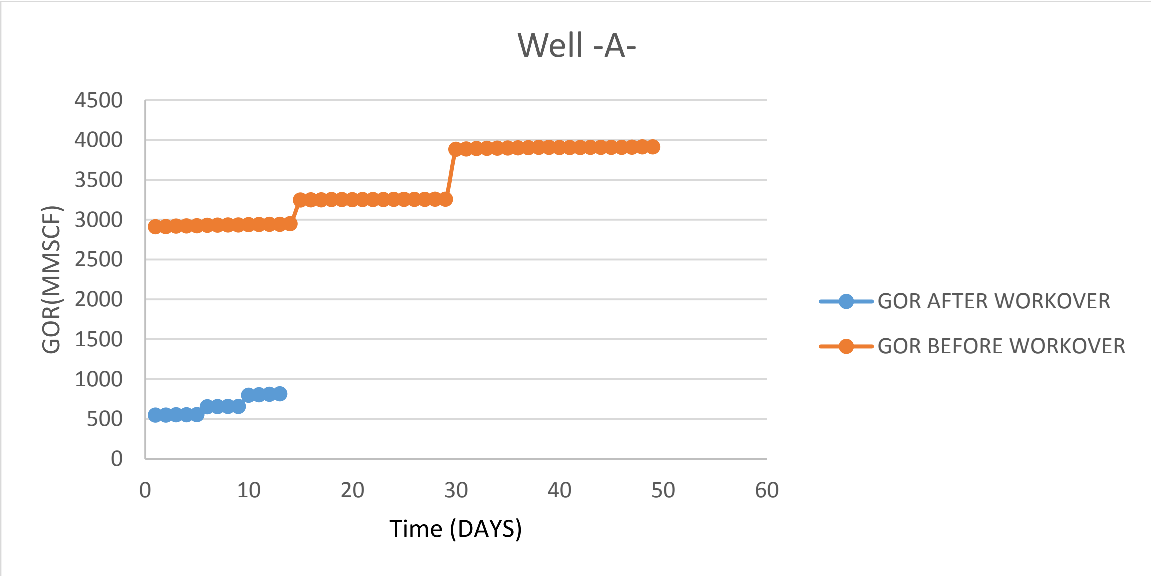

Figure 4.8: Well (A) GOR before and after work over

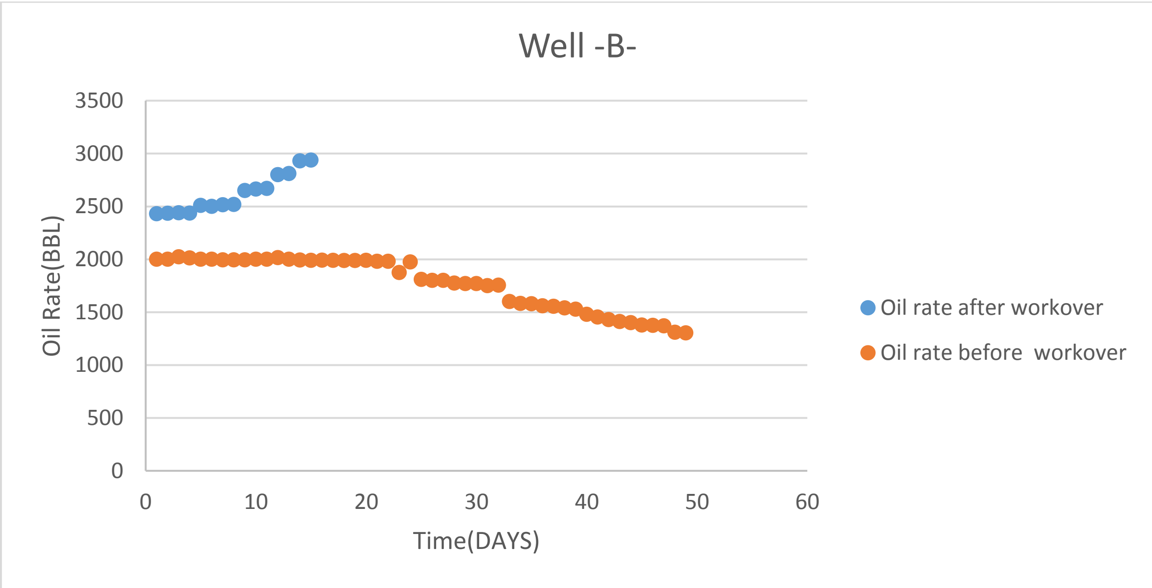

Figure 4.9: Well (B) oil rate production before and after work over

Figure 4.9 shows the result of implementing workover operation and its impact on oil production rate for well B. Based on the figure, the oil production rate is indicated in red colour, and it starts from 2000 bpd to 1300 bpd. After implementing workover operation, the oil production rate increases to 3000 bpd, which means it’s an effective operation. Figure 4.10 shows the impact of workover operation on GOR. The result shows that the GOR has reduced significantly to 200 MMSCF from 2200 MMSCF.

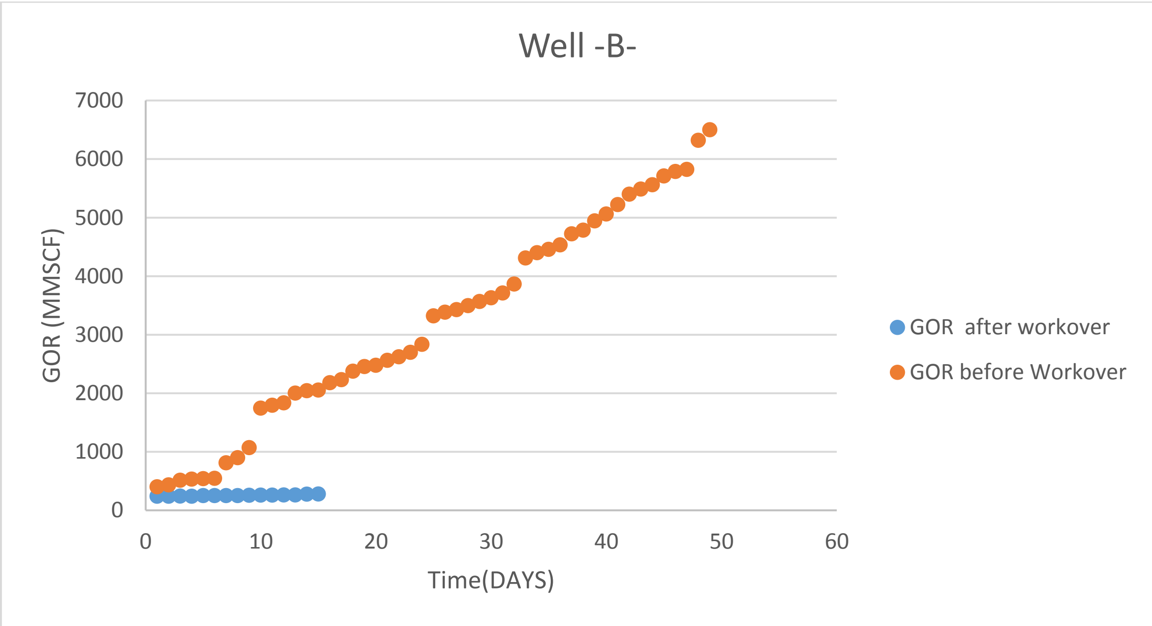

Figure 4.10: Well (B) GOR before and after work over

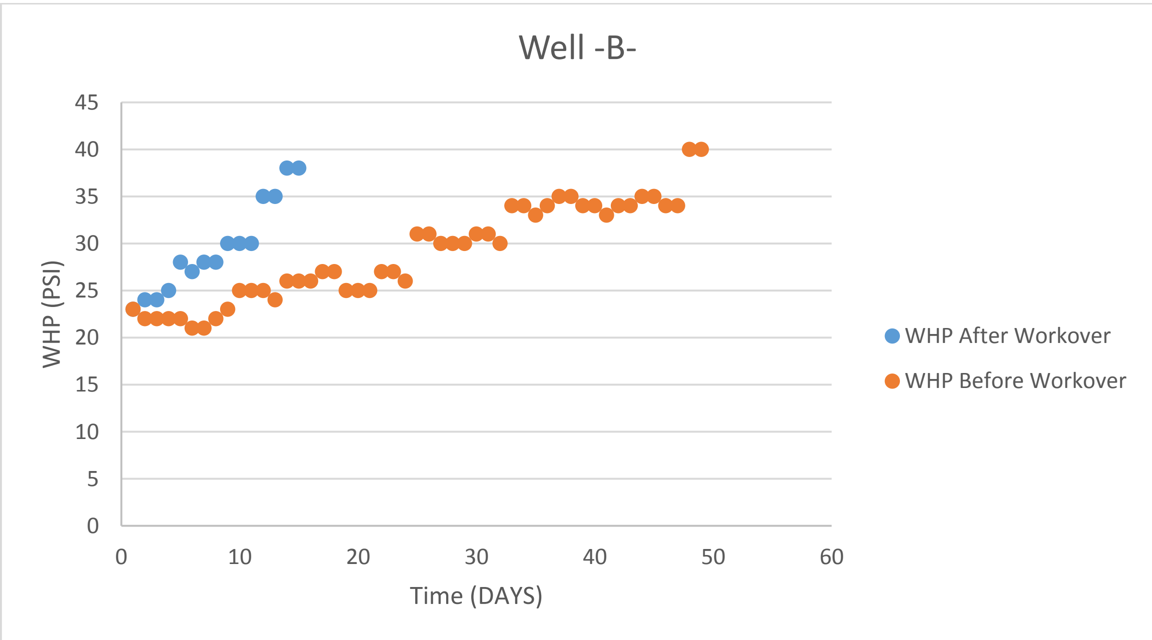

Figure 4.11: Well (B) WHP before and after work over

Additionally, WHP before and after work over operation is shown in Figure 4.11. The result indicated that the well-head pressure has increased after implementing wellhead pressure (WHP) from 27 psi to 38 psi.

Figure 4.12 shows oil production rate before and after workover for well C. based on the result, the oil production rate before implementing the operation is around 1000 bpd while after implementing workover operation, the oil production rate increases to 4000 bpd, 4 times production rate before implementing the workover operation. This result proves that workover operations are indeed important and required to eliminate coning issues and improve production performance.

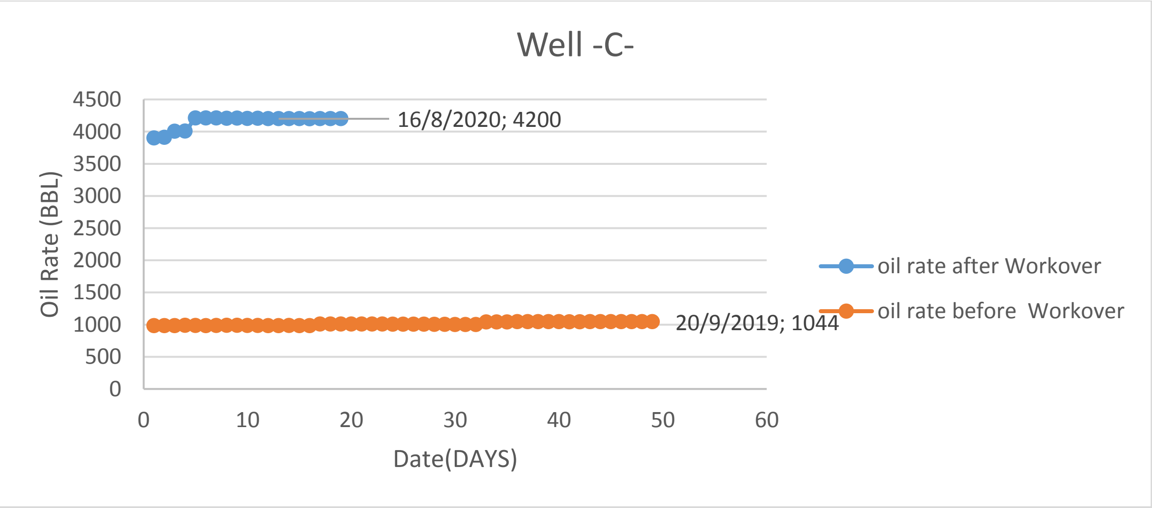

Figure 4.12: Well (C) oil rate production before and after work over

Figure 4.13 shows the plot of GOR vs. Time for well C before and implementing workover operation. The result shows that the GOR has reduced significantly to 1250 MMSCF from 4300 MMSCF. Which proves that gas coning is reduced and oil production is increased after implementing workover operations.

Figure 4.14 shows the plot of WHP vs. Time for well C before and after implementing workover operation. The result shows that the WHP reduced from 40 psi to 30 psi.

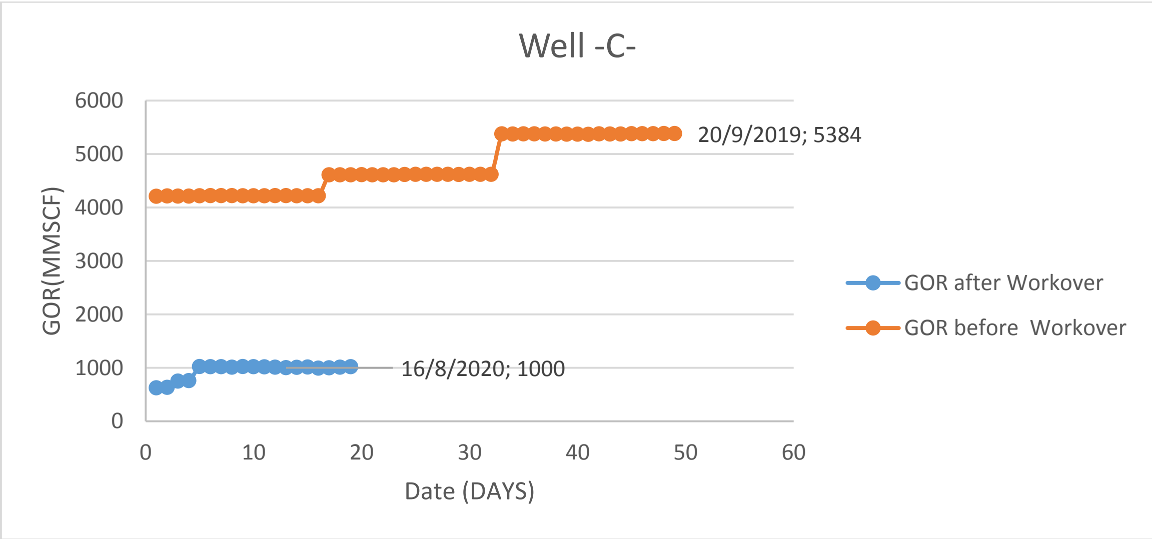

Figure 4.13: Well (C) GOR before and after work over

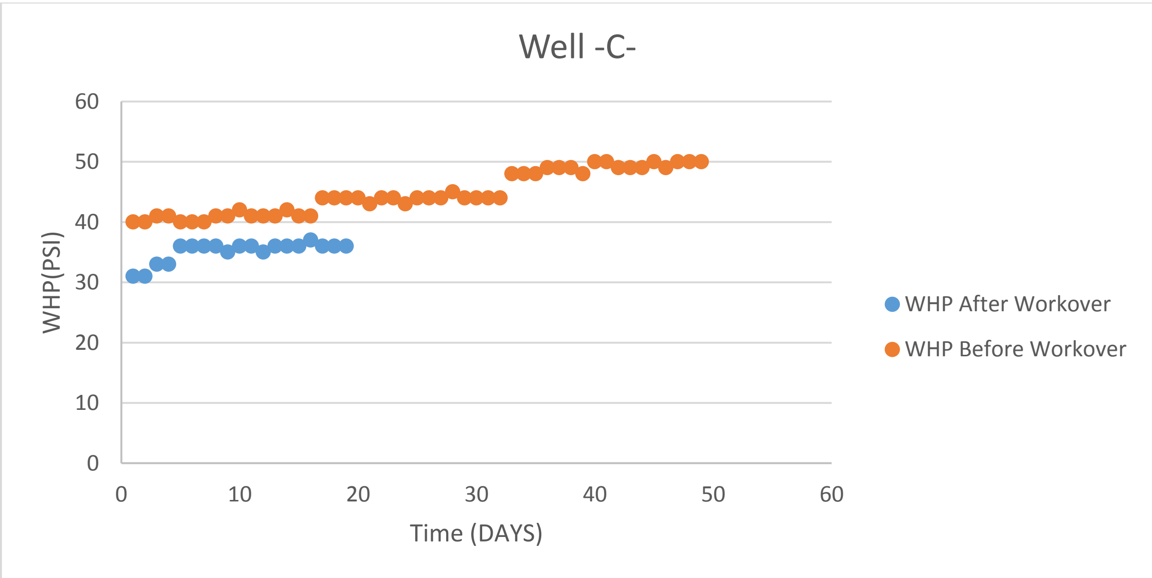

Figure 4.14: Well (C) WHP before and after work over

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The following are the main conclusive remarks of this study:

1. Coning issue is a dangerous production problem resulting from depletion of reservoirs and rise of WOC level.
2. Work over operations proved to be very effective in solving water and gas coning problems after noticing the increase in production rate and reduction in water-cut and GOR. Especially in Figure 4.7 water-cut significantly reduced from 15-20% to a water-cut of 1.5%.
3. The distance between the perforation interval and the OWC has a significant effect on the coning issue, since shorter perforation intervals yield more oil and less water, while longer perforation intervals produce more water and less oil.
4. A comparison of two critical rate correlations was conducted, with the result revealing that the Hoyland-Papatzacos-Skjaeveland correlation yields the most accurate critical rate, which is nearly identical to the simulation outcome. Chaperon method produces a critical rate higher than Hoyland method due to the assumptions of being the perforation interval very short, so less expectations of water coning due to the assumption used in their study, which they assumed that the well is completed from the top.
5. When comparing the Sobocinski-Cornelius method to the Bournazel-Jeanson method, the result reveals that the Sobocinski-Cornelius method produces longer days and is more reliable than the Bournazel-Jeanson method since it is very similar to simulation results.
6. Implementing workover lead to increase oil production and collecting more profit, as an example oil production in Well-A increased from 485 bbl/day to 2500 bbl/day which was five times bigger before implementing the workover operation. Similarly, in well B and well C oil production increased by three times and four times (1303 to 2938) bbl/day and (1044 to 4200) bbl/day, respectively.

5.2. Recommendations

The following are the main recommendations of this study:

- Wells in oil fields that operate on a reservoir underlain by a water aquifer must be perforated farther away from the OWC.
- Critical rate estimation can begin early in the field's life to ensure that oil-free water is obtained.
- After predicting QC, it is important to forecast when the water cone will begin to break through into the well, so that potential situations can be anticipated.
- More studies need to be considered to investigate the impact of workover operations on carbonate fractured reservoirs or heavy oil reservoirs and enhance production in mentioned kinds of reservoirs.

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APPENDICES

APPENDIX 1

WELL PRODUCTION DATA BEFORE AND AFTER WORKOVER OPERATION

Table A: Well A production data before workover operation

#	Well test date	Choke setting of well test	Well Head Pressure (bar)	Oil (bbl/day)	Gas (mmscf/day)	GOR (mmscf/bbl)	Water %	Basic Sediment %
1	9/6/2019	18%	29	324	0.4	2908	16	Trace
2	16/6/2019	18%	29	325	0.43	2910	16.2	Trace
3	23/6/2019	18%	29	325	0.46	2917	16.1	Trace
4	30/6/2019	18%	29	324	0.48	2918	16	Trace
5	7/7/2019	18%	28	327	0.5	2920	16.2	Trace
6	14/7/2019	18%	28	325	0.54	2927	16.2	Trace
7	21/7/2019	18%	29	325	0.6	2929	16.4	Trace
8	28/7/2019	18%	29	330	0.61	2931	16.5	Trace
9	4/8/2019	18%	28	330	0.59	2931	16.4	Trace
10	11/8/2019	18%	29	331	0.63	2935	16.4	Trace
11	18/8/2019	18%	29	329	0.65	2936	16.5	Trace
12	25/8/2019	18%	29	329	0.67	2938	16.7	Trace
13	1/9/2019	18%	30	330	0.7	2940	16.6	Trace
14	8/9/2019	18%	30	330	0.75	2948	16.7	Trace
15	15/9/2019	20%	33	390	1.55	3245	17.3	Trace
16	22/9/2019	20%	33	394	1.58	3246	17.4	Trace
17	29/9/2019	20%	33	394	1.58	3247	17.5	Trace
18	6/10/2019	20%	33	395	1.6	3250	17.4	Trace
19	13/10/2019	20%	32	394	1.6	3250	17.5	Trace
20	20/10/2019	20%	33	390	1.61	3249	17.5	Trace
21	27/10/2019	20%	32	390	1.59	3250	17.6	Trace
22	3/11/2019	20%	33	393	1.6	3250	17.6	Trace
23	10/11/2019	20%	33	393	1.6	3250	17.8	Trace
24	17/11/2019	20%	34	394	1.62	3253	17.7	Trace
25	24/11/2019	20%	33	392	1.61	3252	17.9	Trace
26	1/12/2019	20%	33	392	1.63	3253	17.9	Trace
27	8/12/2019	20%	32	394	1.63	3253	18	Trace
28	15/12/2019	20%	33	395	1.65	3255	18.1	Trace
29	22/12/2019	20%	33	395	1.65	3255	18.3	Trace
30	29/12/2019	24%	37	489	3.7	3881	19.2	Trace
31	5/1/2020	24%	37	486	3.72	3885	19.3	Trace

32	12/1/2020	24%	37	484	3.74	3890	19.3	Trace
33	19/1/2020	24%	37	484	3.75	3892	19.4	Trace
34	26/1/2020	24%	36	485	3.76	3895	19.4	Trace
35	2/2/2020	24%	37	485	3.79	3896	19.5	Trace
36	9/2/2020	24%	37	485	3.81	3899	19.4	Trace
37	16/2/2020	24%	37	482	3.83	3900	19.6	Trace
38	23/2/2020	24%	38	480	3.85	3904	19.6	Trace
39	1/3/2020	24%	37	480	3.85	3905	19.7	Trace
40	8/3/2020	24%	37	481	3.84	3902	19.6	Trace
41	15/3/2020	24%	36	485	3.84	3903	19.7	Trace
42	22/3/2020	24%	37	483	3.84	3903	19.8	Trace
43	29/3/2020	24%	37	482	3.85	3905	19.9	Trace
44	5/4/2020	24%	37	480	3.85	3905	19.9	Trace
45	12/4/2020	24%	36	480	3.86	3905	20	Trace
46	19/4/2020	24%	37	485	3.85	3905	20.1	Trace
47	26/4/2020	24%	38	485	3.88	3907	20.2	Trace
48	3/5/2020	24%	38	488	3.9	3910	20.2	Trace
49	10/5/2020	24%	38	485	3.9	3910	20.2	Trace

Table B: Well A production data after workover operation

#	Well test date	Choke setting of well test	Well Head Pressure (bar)	Oil (bbl/day)	Gas (mmscf/day)	GOR (mmscf/bbl)	Water %	Basic Sediment %
1	2/8/2020	18%	21	1650	0.5	546	0.4	Trace
2	9/8/2020	18%	21	1655	0.5	547	0.42	Trace
3	16/8/2020	18%	21	1655	0.6	550	0.44	Trace
4	23/8/2020	18%	22	1656	0.5	551	0.44	Trace
5	30/8/2020	18%	21	1660	0.6	553	0.45	Trace
6	6/9/2020	20%	24	1950	0.6	650	0.5	Trace
7	13/9/2020	20%	24	1950	0.6	653	0.51	Trace
8	20/9/2020	20%	25	2000	0.6	655	0.51	Trace
9	27/9/2020	20%	25	2003	0.6	655	0.52	Trace
10	4/10/2020	24%	27	2480	0.7	795	0.55	Trace
11	11/10/2020	24%	27	2483	0.8	802	0.55	Trace
12	18/10/2020	24%	26	2488	0.8	808	0.57	Trace
13	25/10/2020	24%	27	2500	0.8	813	0.57	Trace

Table C: Well B production data before workover operation

#	Well test date	Choke setting of well test	Well Head Pressure (bar)	Oil (bbl/day)	Gas (mmscf/day)	GOR (mmscf/bbl)	Water %	Basic Sediment %
1	10/2/2019	18%	23	2000	0.8	400	Trace	Trace
2	17/2/2019	18%	22	2000	0.8	433	Trace	Trace
3	24/2/2019	18%	22	2023	0.9	512	Trace	Trace
4	3/3/2019	18%	22	2013	0.9	532	Trace	Trace
5	10/3/2019	18%	22	2000	0.8	540	Trace	Trace
6	17/3/2019	18%	21	2000	0.8	545	Trace	Trace
7	24/3/2019	18%	21	1994	0.9	810	Trace	Trace
8	31/3/2019	18%	22	1995	0.9	897	Trace	Trace
9	7/4/2019	18%	23	1994	0.9	1068	Trace	Trace
10	14/4/2019	20%	25	2000	1	1743	Trace	Trace
11	21/4/2019	20%	25	2000	1.1	1794	Trace	Trace
12	28/4/2019	20%	25	2015	1.1	1833	Trace	Trace
13	5/5/2019	20%	24	2000	1.2	2000	Trace	Trace
14	12/5/2019	20%	26	1993	1.2	2043	Trace	Trace
15	19/5/2019	20%	26	1990	1.2	2054	Trace	Trace
16	26/5/2019	20%	26	1992	1.3	2177	Trace	Trace
17	2/6/2019	20%	27	1990	1.3	2231	Trace	Trace
18	9/6/2019	20%	27	1988	1.4	2376	Trace	Trace
19	16/6/2019	20%	25	1988	1.4	2454	Trace	Trace
20	23/6/2019	20%	25	1990	1.3	2476	Trace	Trace
21	30/6/2019	20%	25	1981	1.5	2561	Trace	Trace
22	7/7/2019	20%	27	1980	1.4	2620	Trace	Trace
23	14/7/2019	20%	27	1875	1.5	2697	Trace	Trace
24	21/7/2019	20%	26	1975	1.5	2833	Trace	Trace
25	28/7/2019	24%	31	1810	1.8	3320	Trace	Trace
26	4/8/2019	24%	31	1800	1.8	3383	Trace	Trace
27	11/8/2019	24%	30	1800	1.9	3427	Trace	Trace
28	18/8/2019	24%	30	1775	2.3	3496	Trace	Trace
29	25/8/2019	24%	30	1770	2.3	3567	Trace	Trace
30	1/9/2019	24%	31	1770	2.5	3630	Trace	Trace
31	8/9/2019	24%	31	1750	2.7	3711	Trace	Trace
32	15/9/2019	24%	30	1755	2.7	3865	Trace	Trace
33	22/9/2019	28%	34	1600	3.4	4310	Trace	Trace
34	29/9/2019	28%	34	1583	3.5	4400	Trace	Trace
35	6/10/2019	28%	33	1580	3.5	4456	Trace	Trace
36	13/10/2019	28%	34	1560	3.5	4532	Trace	Trace

37	20/10/2019	28%	35	1555	3.8	4721	Trace	Trace
38	27/10/2019	28%	35	1540	3.7	4784	Trace	Trace
39	3/11/2019	28%	34	1528	3.8	4942	Trace	Trace
40	10/11/2019	28%	34	1480	3.8	5060	Trace	Trace
41	17/11/2019	28%	33	1453	3.9	5220	Trace	Trace
42	24/11/2019	28%	34	1430	4	5400	Trace	Trace
43	1/12/2019	28%	34	1411	4	5487	Trace	Trace
44	8/12/2019	28%	35	1400	4.1	5560	Trace	Trace
45	15/12/2019	28%	35	1378	4.3	5710	Trace	Trace
46	22/12/2019	28%	34	1375	4.4	5787	Trace	Trace
47	29/12/2019	28%	34	1370	4.4	5822	Trace	Trace
48	5/1/2020	32%	40	1310	4.9	6320	Trace	Trace
49	12/1/2020	32%	40	1303	4.9	6500	Trace	Trace

Table D: Well B production data after workover operation

#	Well test date	Choke setting of well test	Well Head Pressure (bar)	Oil (bbl/day)	Gas (mmscf/day)	GOR (mmscf/bbl)	Water %	Basic Sediment %
1	19/7/2020	18%	23	2430	0.3	239	Trace	Trace
2	26/7/2020	18%	24	2435	0.3	239	Trace	Trace
3	2/8/2020	18%	24	2440	0.2	241	Trace	Trace
4	9/8/2020	18%	25	2437	0.4	240	Trace	Trace
5	16/8/2020	20%	28	2510	0.4	249	Trace	Trace
6	23/8/2020	20%	27	2500	0.4	249	Trace	Trace
7	30/8/2020	20%	28	2515	0.5	250	Trace	Trace
8	6/9/2020	20%	28	2518	0.5	250	Trace	Trace
9	13/9/2020	22%	30	2650	0.7	255	Trace	Trace
10	20/9/2020	22%	30	2663	0.7	258	Trace	Trace
11	27/9/2020	22%	30	2670	0.7	258	Trace	Trace
12	4/10/2020	24%	35	2800	0.8	260	Trace	Trace
13	11/10/2020	24%	35	2811	0.7	260	Trace	Trace
14	18/10/2020	28%	38	2930	0.8	275	Trace	Trace
15	25/10/2020	28%	38	2938	0.7	276	Trace	Trace

Table E: Well C production data before workover operation

#	Well test date	Choke setting of well test	Well Head Pressure (bar)	Oil (bbl/day)	Gas (mmscf/day)	GOR (mmscf/bbl)	Water %	Basic Sediment %
1	21/10/2018	18%	40	984	4.4	4210	Trace	Trace
2	28/10/2018	18%	40	984	4.4	4215	Trace	Trace
3	4/11/2018	18%	41	984	4.4	4211	Trace	Trace
4	11/11/2018	18%	41	988	4.3	4213	Trace	Trace
5	18/11/2018	18%	40	985	4.3	4218	Trace	Trace
6	25/11/2018	18%	40	984	4.4	4220	Trace	Trace
7	2/12/2018	18%	40	986	4.4	4220	Trace	Trace
8	9/12/2018	18%	41	987	4.4	4220	Trace	Trace
9	16/12/2018	18%	41	987	4.4	4217	Trace	Trace
10	23/12/2018	18%	42	986	4.5	4219	Trace	Trace
11	30/12/2018	18%	41	985	4.4	4219	Trace	Trace
12	6/1/2019	18%	41	984	4.4	4220	Trace	Trace
13	13/1/2019	18%	41	984	4.5	4220	Trace	Trace
14	20/1/2019	18%	42	985	4.4	4218	Trace	Trace
15	27/1/2019	18%	41	984	4.4	4218	Trace	Trace
16	3/2/2019	18%	41	984	4.4	4219	Trace	Trace
17	10/2/2019	20%	44	1009	4.8	4610	Trace	Trace
18	17/2/2019	20%	44	1009	4.8	4610	Trace	Trace
19	24/2/2019	20%	44	1008	4.8	4611	Trace	Trace
20	3/3/2019	20%	44	1009	4.9	4613	Trace	Trace
21	10/3/2019	20%	43	1007	4.8	4610	Trace	Trace
22	17/3/2019	20%	44	1007	4.8	4610	Trace	Trace
23	24/3/2019	20%	44	1007	4.8	4609	Trace	Trace
24	31/3/2019	20%	43	1006	4.7	4615	Trace	Trace
25	7/4/2019	20%	44	1006	4.7	4620	Trace	Trace
26	14/4/2019	20%	44	1005	4.8	4620	Trace	Trace
27	21/4/2019	20%	44	1005	4.8	4618	Trace	Trace
28	28/4/2019	20%	45	1004	4.8	4619	Trace	Trace
29	5/5/2019	20%	44	1002	4.9	4615	Trace	Trace
30	12/5/2019	20%	44	1000	4.8	4618	Trace	Trace
31	19/5/2019	20%	44	1000	4.8	4620	Trace	Trace
32	26/5/2019	20%	44	1000	4.8	4620	Trace	Trace
33	2/6/2019	24%	48	1039	5.5	5377	Trace	Trace
34	9/6/2019	24%	48	1040	5.5	5375	Trace	Trace
35	16/6/2019	24%	48	1041	5.5	5377	Trace	Trace
36	23/6/2019	24%	49	1044	5.4	5377	Trace	Trace

37	30/6/2019	24%	49	1044	5.4	5375	Trace	Trace
38	7/7/2019	24%	49	1044	5.5	5375	Trace	Trace
39	14/7/2019	24%	48	1045	5.5	5370	Trace	Trace
40	21/7/2019	24%	50	1044	5.5	5371	Trace	Trace
41	28/7/2019	24%	50	1043	5.4	5369	Trace	Trace
42	4/8/2019	24%	49	1043	5.3	5376	Trace	Trace
43	11/8/2019	24%	49	1044	5.3	5374	Trace	Trace
44	18/8/2019	24%	49	1044	5.4	5374	Trace	Trace
45	25/8/2019	24%	50	1044	5.4	5379	Trace	Trace
46	1/9/2019	24%	49	1045	5.4	5379	Trace	Trace
47	8/9/2019	24%	50	1044	5.4	5380	Trace	Trace
48	15/9/2019	24%	50	1044	5.5	5384	Trace	Trace
49	20/9/2019	24%	50	1044	5.5	5384	Trace	Trace

Table F: Well C production data after workover operation

#	Well test date	Choke setting of well test	Well Head Pressure (bar)	Oil (bbl/day)	Gas (mmscf/day)	GOR (mmscf/bbl)	Water %	Basic Sediment %
1	24/5/2020	18%	31	3900	0.7	624	Trace	Trace
2	31/5/2020	18%	31	3910	0.7	633	Trace	Trace
3	7/6/2020	20%	33	4005	0.78	750	Trace	Trace
4	14/6/2020	20%	33	4007	0.8	758	Trace	Trace
5	21/6/2020	24%	36	4211	0.9	1022	Trace	Trace
6	28/6/2020	24%	36	4210	0.9	1020	Trace	Trace
7	5/7/2020	24%	36	4210	0.92	1018	Trace	Trace
8	12/7/2020	24%	36	4205	0.92	1011	Trace	Trace
9	19/7/2020	24%	35	4209	0.91	1022	Trace	Trace
10	26/7/2020	24%	36	4204	0.92	1020	Trace	Trace
11	2/8/2020	24%	36	4205	0.9	1017	Trace	Trace
12	9/8/2020	24%	35	4202	0.9	1010	Trace	Trace
13	16/8/2020	24%	36	4200	0.92	1000	Trace	Trace
14	23/8/2020	24%	36	4200	0.92	1008	Trace	Trace
15	30/8/2020	24%	36	4201	0.93	1012	Trace	Trace
16	6/9/2020	24%	37	4198	0.95	991	Trace	Trace
17	13/9/2020	24%	36	4200	0.94	999	Trace	Trace
18	20/9/2020	24%	36	4200	0.94	1010	Trace	Trace
19	27/9/2020	24%	36	4200	0.95	1018	Trace	Trace

APPENDIX 2
SIMULATION RESULT SUMMARY

Table G: Field hydrocarbon production

TIME DAYS	FGOR MSCF/STB	FLPR STB/DAY	FOPR STB/DAY	FOPT STB
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+00	1.39E+00	3.26E+03	3.00E+03	3.00E+03
4.00E+00	1.39E+00	3.26E+03	3.00E+03	1.20E+04
1.00E+01	1.39E+00	3.26E+03	3.00E+03	3.00E+04
2.80E+01	1.39E+00	3.26E+03	3.00E+03	8.40E+04
5.00E+01	1.39E+00	3.26E+03	3.00E+03	1.50E+05
1.00E+02	1.38E+00	3.27E+03	3.00E+03	3.00E+05
2.00E+02	1.37E+00	3.29E+03	3.00E+03	6.00E+05
3.00E+02	1.36E+00	3.31E+03	3.00E+03	9.00E+05
4.00E+02	1.35E+00	3.33E+03	3.00E+03	1.20E+06
5.00E+02	1.34E+00	3.35E+03	3.00E+03	1.50E+06
6.00E+02	1.33E+00	3.38E+03	3.00E+03	1.80E+06
7.20E+02	1.32E+00	3.40E+03	3.00E+03	2.16E+06
8.00E+02	1.32E+00	3.41E+03	3.00E+03	2.40E+06
9.00E+02	1.31E+00	3.43E+03	3.00E+03	2.70E+06
1.20E+03	1.28E+00	3.44E+03	3.00E+03	3.60E+06
1.50E+03	1.26E+00	3.44E+03	3.00E+03	4.50E+06
1.80E+03	1.23E+00	3.46E+03	3.00E+03	5.40E+06
2.15E+03	1.20E+00	3.45E+03	3.00E+03	6.45E+06
2.36E+03	1.18E+00	3.45E+03	3.00E+03	7.07E+06
2.56E+03	1.17E+00	3.45E+03	3.00E+03	7.69E+06
2.74E+03	1.15E+00	3.44E+03	3.00E+03	8.23E+06
2.93E+03	1.14E+00	3.45E+03	3.00E+03	8.78E+06
2.93E+03	1.14E+00	3.45E+03	3.00E+03	8.78E+06
2.93E+03	1.14E+00	3.45E+03	3.00E+03	8.79E+06
2.94E+03	1.14E+00	3.45E+03	3.00E+03	8.82E+06
2.97E+03	1.14E+00	3.45E+03	3.00E+03	8.90E+06
3.05E+03	1.15E+00	3.46E+03	3.00E+03	9.14E+06
3.21E+03	6.49E+00	3.68E+03	3.00E+03	9.63E+06
3.41E+03	2.99E+01	4.30E+03	3.00E+03	1.02E+07

3.50E+03	3.98E+01	4.49E+03	3.00E+03	1.05E+07
3.60E+03	4.38E+01	2.89E+03	1.89E+03	1.07E+07
3.75E+03	4.53E+01	1.64E+03	1.06E+03	1.08E+07
3.93E+03	4.52E+01	9.02E+02	5.80E+02	1.10E+07
4.17E+03	4.54E+01	4.67E+02	3.00E+02	1.10E+07
4.53E+03	3.90E+01	2.44E+02	1.69E+02	1.11E+07
4.89E+03	3.34E+01	1.40E+02	1.05E+02	1.11E+07
5.15E+03	3.01E+01	9.82E+01	7.72E+01	1.11E+07
5.40E+03	2.74E+01	7.16E+01	5.92E+01	1.12E+07

Table H: Field water production

FPR	FWCT	FWPR	FWPT
3.62E+03	0.00E+00	0.00E+00	0.00E+00
3.62E+03	7.88E-02	2.57E+02	2.57E+02
3.62E+03	7.88E-02	2.57E+02	1.03E+03
3.61E+03	7.88E-02	2.57E+02	2.57E+03
3.60E+03	7.89E-02	2.57E+02	7.19E+03
3.59E+03	7.96E-02	2.60E+02	1.29E+04
3.57E+03	8.27E-02	2.71E+02	2.64E+04
3.54E+03	8.85E-02	2.91E+02	5.56E+04
3.51E+03	9.42E-02	3.12E+02	8.68E+04
3.47E+03	9.99E-02	3.33E+02	1.20E+05
3.44E+03	1.06E-01	3.54E+02	1.56E+05
3.41E+03	1.12E-01	3.78E+02	1.93E+05
3.38E+03	1.18E-01	4.00E+02	2.41E+05
3.35E+03	1.21E-01	4.13E+02	2.74E+05
3.32E+03	1.25E-01	4.28E+02	3.17E+05
3.23E+03	1.27E-01	4.36E+02	4.48E+05
3.15E+03	1.28E-01	4.40E+02	5.80E+05
3.07E+03	1.32E-01	4.56E+02	7.17E+05
2.99E+03	1.30E-01	4.49E+02	8.73E+05
2.94E+03	1.30E-01	4.49E+02	9.66E+05
2.89E+03	1.30E-01	4.48E+02	1.06E+06
2.85E+03	1.29E-01	4.43E+02	1.14E+06
2.81E+03	1.31E-01	4.51E+02	1.22E+06
2.81E+03	1.31E-01	4.51E+02	1.22E+06

2.81E+03	1.31E-01	4.51E+02	1.22E+06
2.81E+03	1.31E-01	4.52E+02	1.23E+06
2.80E+03	1.31E-01	4.54E+02	1.24E+06
2.78E+03	1.34E-01	4.64E+02	1.28E+06
2.62E+03	1.85E-01	6.79E+02	1.39E+06
1.81E+03	3.02E-01	1.30E+03	1.64E+06
1.29E+03	3.32E-01	1.49E+03	1.79E+06
9.35E+02	3.48E-01	1.01E+03	1.88E+06
6.29E+02	3.54E-01	5.82E+02	1.97E+06
4.21E+02	3.58E-01	3.23E+02	2.03E+06
2.79E+02	3.57E-01	1.67E+02	2.07E+06
1.79E+02	3.05E-01	7.44E+01	2.10E+06
1.24E+02	2.52E-01	3.53E+01	2.11E+06
9.85E+01	2.14E-01	2.10E+01	2.11E+06
8.09E+01	1.74E-01	1.24E+01	2.12E+06

APPENDIX 3

RESERVOIR ROCK AND FLUID DATA

Table I: PVT properties of water

Pressure	Bw	Water Density	Viscosity
40	1	62	0.96
80	1	62	0.96
120	1	62.36	0.96
160	1	62	0.96
200	1	62.51	0.96
240	1	63	0.96
280	1	63	0.96
320	1	63	0.96
360	1	63	0.96
400	1	63	0.96
420	1	63	0.96
460	0.9	63	0.96
520	1	63	0.96

Table J: PVT properties of gas

Pressure	Bg	Density	Viscosity
40	5.9	2	0.013
80	3	4	0.0135
120	2	6	0.014
160	1	9	0.0145
200	1	11	0.015
240	0.98	13	0.0155
280	0.84	15	0.016
320	0.74	16	0.0165
360	0.65	19	0.017
400	0.59	21	0.0175
420	0.54	23	0.018
460	0.49	26	0.0185
520	0.45	28	0.019
560	0.42	30	0.0195

Table K: Reservoir Data

Layer	Thickness (ft.)	Ka (md)	Kz (md)	Porosity
1	20	35	3.5	0.087
2	15	47.5	4.75	0.097
3	26	148	14.8	0.111
4	15	202	20.2	0.16
5	16	90	9	0.13
6	14	418	41.8	0.17
7	8	775	77.5	0.17
8	8	60	6	0.08
9	18	682	68.2	0.14
10	12	472	47.2	0.13
11	19	125	12.5	0.12
12	18	300	30	0.105
13	20	137	13.7	0.12
14	50.19	19.1	0.116	0.115
15	100.35	35	0.157	0.157

Table L: Geometry Data

Property, unit	Value
Radial extent, ft.	2000
Wellbore radius, ft.	0.25
Radial position of first block center, ft.	0.84
Number of radial blocks	0.25, 2.00, 4.32, 9.33, 20.17
Number of vertical layers	15
Dip angle, degrees	0
Depth to top of formation, ft.	3300
Radial Block boundaries, ft.	0.25, 2.00, 4.32, 9.33, 20.17, 43.56, 203.32, 439.24, 948.92 and 2050.00

Table M: Reservoir fluid, initial conditions and well data

Property, unit	Value
Pore compressibility, psi	0.000004
Water compressibility, 1/ psi	0.000003
Oil Compressibility for under saturated oil, 1/ psi	0.000001
Oil viscosity, cp	2.9
Stock tank oil density, Ibm/ft3	39.0
Stock tank water density, Ibm/ft3	62.4
Standard condition gas density, Ibm/ft3	0.08
Depth of gas/oil contact (GOC), ft.	3309
Oil pressure at gas/oil contact, psi	361
Capillary pressure at GOC, psi	0
Depth of water/oil contact, WOC, ft.	3335
Capillary pressure at WOC, psi	0
Completion blocks	(1,7) (1,8)
Permeability thickness	341
Skin	0, 0
Minimum BHP	300
Radial extent, ft	1200
Oil column thickness, ft	196.8
Perforated interval, ft	32
Horizontal permeability, md	256
Vertical permeability, md	36.1
Formation volume factor	1.09
Porosity, %	17
Oil production rate, STB/day	2800

APPENDIX 4

ETHICAL APPROVAL LETTER

YAKIN DOĞU ÜNİVERSİTESİ

ETHICAL APROVAL DOCUMENT

Date: 01/10/2021

To the **Institute of Graduate Studies**

The research project titled “**DETERMINATION AND REDUCTION OF CONING**’’ 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.

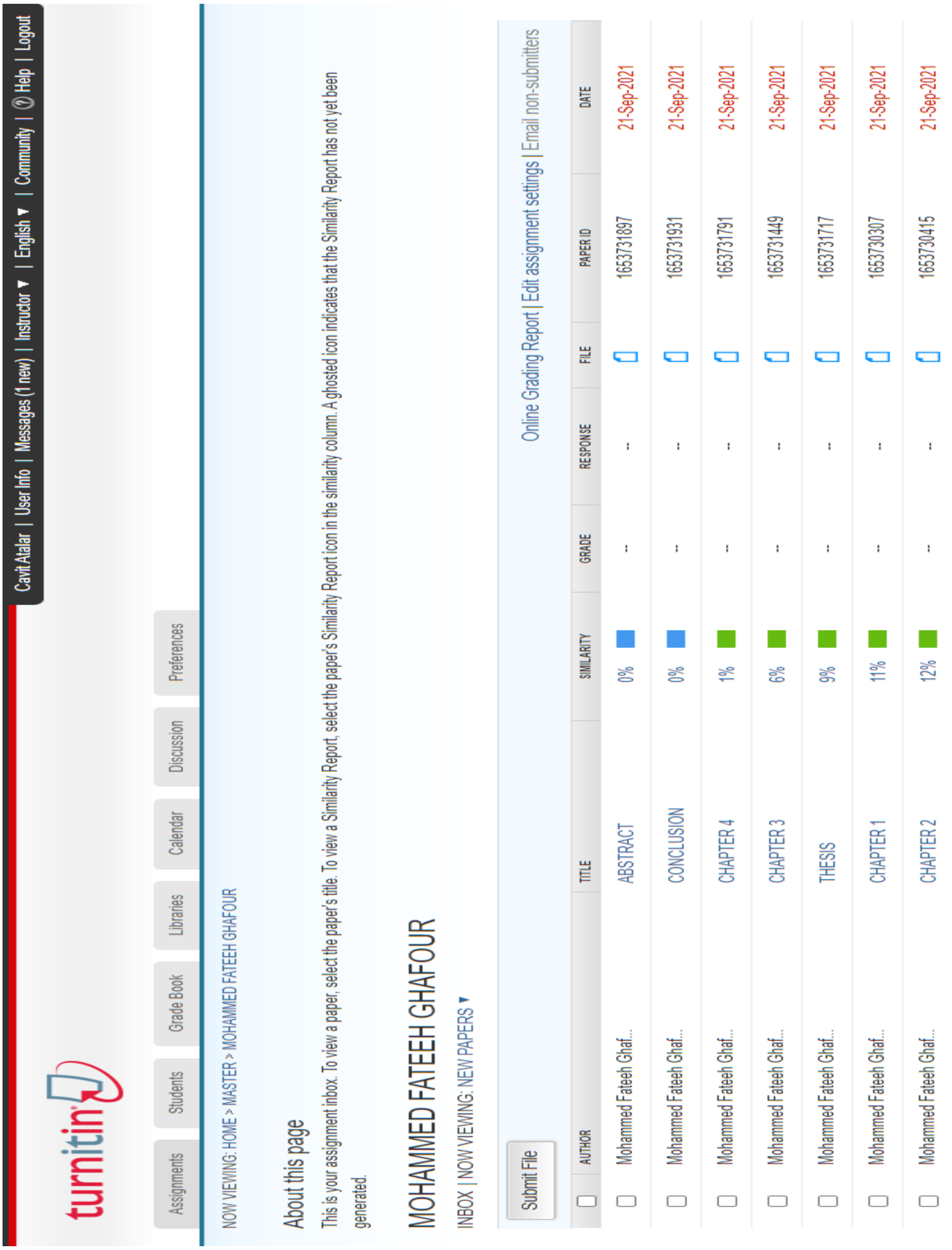
Name Surname: Ersen ALP

Signature:

Role in the Research Project: Co-Supervisor

APPENDIX 5

SIMILARITY REPORT



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