

بسم الله الرحمن الرحيم



Sudan University of Science & Technology
College of Petroleum Engineering & Technology
Department of Petroleum Engineering



**Research Submitted to College of Petroleum Engineering &
Technology in Partial Fulfillment of the Requirements for the Degree
of B.Sc. in Petroleum Engineering.**

**A Computer Program for Excess Water
Production Diagnosis Case Study– Heglig Oil Field –
Sudan**

**برنامج حاسوبي لتشخيص إنتاج الماء المفرط - دراسة حالة حقل هجليج
النفطي - السودان**

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October 2018

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الإستهلال

سورة (الفاتحة) الجزء (١) صفحة (١)

سُورَةُ الْفَاتِحَةِ

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ ١
الْحَمْدُ لِلَّهِ رَبِّ الْعَالَمِينَ ٢
الرَّحْمَنِ الرَّحِيمِ ٣ مَلِكِ يَوْمِ الدِّينِ ٤
إِيَّاكَ نَعْبُدُ وَإِيَّاكَ نَسْتَعِينُ ٥ أَهْدِنَا
الصِّرَاطَ الْمُسْتَقِيمَ ٦ صِرَاطَ الَّذِينَ أَنْعَمْتَ
عَلَيْهِمْ غَيْرِ الْمَغْضُوبِ عَلَيْهِمْ
وَلَا الضَّالِّينَ ٧

Dedication

We would like to donate this unpretentious effort to

Our Parents;

Who have endless presence and for the never ending love
and encouragement

Our brothers and sisters;

Who sustained us in our life and still

Our teachers;

Who lighted candle in our ways and provided us with light
of knowledge

Finally; our best friends;

Our Classmates

Researchers...

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Thanking to Allah before and after...

First and foremost; the greatest thanking to **our teachers** for their continuous support... and for their great efforts, they were the best guide and ad monitor...

Special thanks to Eng. **Hamza Ahmed** for their assistance, providing technical support whenever we needed...

Finally; thanking to our colleagues and workers at College of Petroleum Engineering & Technology for their cooperation...

ABSTRACT

Heglig oil field is suffer from massive water production which is not only negatively affects the oil production rate, but also entails costly and time-consuming water management operations in order to be able to tackle the excess water production problem effectively, it is vital to identify the source of the problem first. and therefore accurate methodology required to diagnose and evaluate water production mechanisms.

In this work, a new developed program was presented for quickly diagnose of water production mechanisms, using Chan's conning and channeling differentiation mechanism.

Different 5 wells were studied using the generated program; through which 3 wells were presented water channeling behavior while one well was presented water conning and the last well appear to be water/oil contact rising through its plot.

Key Word:

Water Production, Diagnoses, Water Conning, Channeling, Production Data

التجريد

إن إنتاج المياه المتزايد من أكبر المشاكل التي تواجه حقل هجليج النفطي في السودان. وهذه الكميات الهائلة من المياه لا تؤثر سلبيًا على معدل إنتاج النفط فحسب، ولكنها تستلزم أيضًا عمليات معالجة المياه وهي مكلفة ومستهلكة للوقت. حتى نتمكن من معالجة مشكلة إنتاج الماء الزائد بشكل فعال من الضروري جدا تحديد مصدر المشكلة أولاً، لذلك يهدف هذا المشروع إلى تشخيص ومعرفة آلية إنتاج المياه في حقل هجليج ولتحقيق هذا الهدف تم تصميم برنامج جديد عن طريق الماتلاب **MATLAB** يقوم باستخدام طريقة الرسم التفاضلية لنسبة الماء الى النفط **WOR** **derivative plot** من بيانات الإنتاج لعدد خمسة آبار سودانية ، وقد وجد أن السبب الرئيسي لإنتاج المياه في ثلاثة آبار هو ظاهرة القنوات **channeling** وفي بئر مشكلة تقمع المياه وفي الأخيرة الزيادة العالية في نسبة المياه بصورة طبيعية **Normal with high water cut**.

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NOMENCLATURE

cum days	cumulative days
Q_o	oil production flowrate
Q_w	water production flowrate
stb/d	stock tank barrel per day
T	Time
W_c	water cut
WOR	water oil ratio
WOR'	derivative of water oil ratio

Chapter1

Introduction

Excessive water production is one of the major factor contribute in reduction of wells productivity and one of the common and challenging economic and environmental problems associated with hydrocarbon production(Bailey, 2000,). When excess of water production exists, the cost associated to surface facilities, artificial lift systems, corrosion and scale problems increases. Besides, the recovery factor decreases as oil is left behind the displacement front. The best completions and production practices can delay, but not stop this water production. many petroleum reservoirs are bounded by or are adjacent to large aquifers. These aquifers can provide the natural drive for petroleum production. Once the aquifer pressure is depleted, additional water is also injected into the reservoir to provide further pressure to the hydrocarbon reserves to move towards the production wells. Water from these various sources can flow into the wellbore and co-produced with the hydrocarbon stream. Such water is referred to as produced water. The ratio of produced water to the produced oil is denoted as WOR (water/oil ratio). The WOR economic limit is where the cost of handling and disposal of the produced water approaches the value of the produced oil. Problems arise when water flows in to the oil well at a rate exceeding the economic WOR limit. Water production can be related to mechanical problems, poor completion procedures or reservoir conditions. However, reservoir related problems of coning and channeling through high permeability layers are more challenging to diagnose and treat(Seright, R. S., R. H. Lane, and R.D. Sydansk., 2003.). Nonetheless, the water production mechanism must be properly investigated and accurately diagnosed in order to design an appropriate and effective treatment method.

Numerous technologies have been developed to control unwanted water production, but the nature of the water production must be known in order to design an effective treatment. Each problem requires a different approach to find the optimum solution. Once the water production mechanism is understood, an effective strategy can be formulated to control water production.

In the original reservoir, the pores in the mineral matrix contain the natural fluids at chemical equilibrium. Because reservoir rock is largely of sedimentary origin, water was present at the time of rock genesis and, therefore, is trapped in the pores of the rock. Water may also move or migrate according to the hydraulic pressures induced by geological processes that also form the reservoirs. It is believed that the rock in most oil-bearing formations was completely saturated with water prior to the invasion and trapping of petroleum. The less dense hydrocarbons migrated to trap locations, displacing some of the water from the formation and becoming hydrocarbon reservoirs. Thus, reservoir rocks normally contain both petroleum hydrocarbons (liquid and gas) and water. Sources of this water may include flow from above or below the hydrocarbon zone, flow from within the hydrocarbon zone, or flow from injected fluids and additives resulting from production activities. This water is frequently referred to as “connate water” or “formation water” and becomes produced water when the reservoir is produced and these fluids are brought to the surface.

The sources of produced water include formation water, aquifer, and injected water. The formation water can be originated from a water saturated zone within the reservoir or zones above or below the pay zone (Bailey, 2000,). Many reservoirs are adjacent to an active aquifer and are subject to bottom or edge water drive. Water is often injected into oil

reservoirs for pressure maintenance or secondary recovery purposes. The injected water is one of sources of water production problem.

Production of oil and gas from reservoir can only be achieved by applying a pressure draw-down at the wellbore which create a pressure gradient within the formation. Production from a fully penetrating and perforated well results in a horizontal pressure gradient in the formation. However, flow from a partially penetrated well will result in a vertical pressure gradient near the wellbore as well as the horizontal gradient in the formation(Echufu-Agbo Ogbene Alexis ,, 2010,).

For water to flow through a zone, the water saturation in that zone must exceed irreducible water saturation. As water saturation increases beyond the irreducible saturation, the relative permeability to water increases and relative permeability to hydrocarbon decreases. In water-drive reservoirs and reservoir that are subject to water flooding, water sweeps the formation and displaces the hydrocarbon toward producing wells. In such situations, reservoir heterogeneity can result in water channeling through high permeability streaks. Examples of reservoir

heterogeneity that could result in channeling include fractures, faults, discontinuous layers, and layering(Echufu-Agbo Ogbene Alexis ,, 2010,).

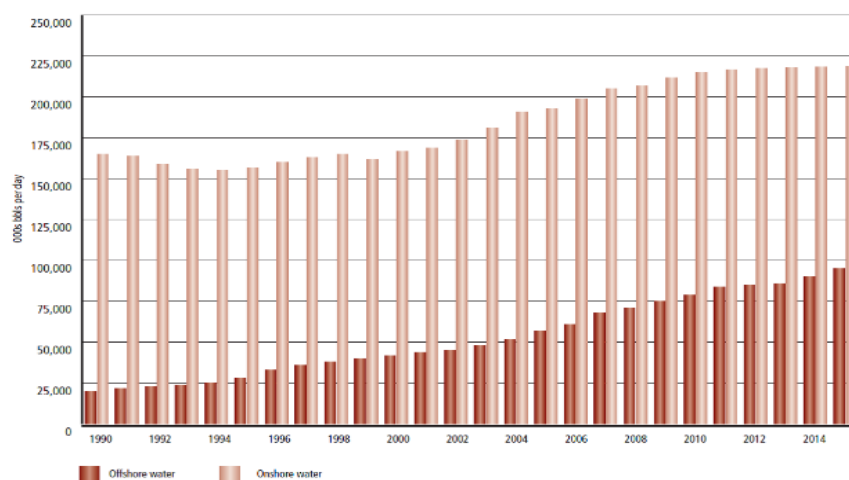


Figure 1:1- Global onshore and offshore water production (Dal Ferro and Smith 2007).

1.1 Field Background:

Heglig oil field is one of the largest fields of oil and gas deposits in Sudan. It has been the site of conventional petroleum production for more than one decade (since 1999), but recently it has become producing water exceed the economic range. Heglig field is located in southeast and middle of Block 2B, Muglad Basin, discovered by Chevron. It consists of 10 fields (Heglig main, Toma, El Bakh, El Full, Laloba, Kanga, Barki, Hamra, Simbir East and Rihan). A general structure which follows average distance between fields is about 3 to 5 km. 8 layers are developed i.e., Aradeiba main, Aradeiba B, Aradeiba E, Aradeiba F, Bentiu-1, Bentiu-2 and Bentiu-3 and Abu Gabra. First Field Devolved Plan (FDP) was carried out in 1998. Last FDP was carried out in 2011. Field development started in June 1999 with development of 29 wells i.e., Heglig main (17), Toma (4), Barki (3) , Hamra (2), El Full (2)wells and El Bakh (1) well (Fatima -2018).

The Oilfield has excessive water production and the water cut was reached 95% with non-economical oil production resulting in many operational problems

1.2 Problem Statement:

Produced water represents the largest waste stream associated with oil and gas production; the environmental impact, treating, and disposing of this water can seriously affect the profitability of oil industry. Many sources can cause water to be produced and different techniques are required to manage water according to its sources; therefore, good diagnosis required to estimate the source in order to found the suitable solution.

1.3 Research Objectives:

The main objective of this work is the diagnosis of the production of the excessive water through different wells in Heglig oil field which include:

- 1) To estimate water oil ratio (WOR) and derivative water oil ratio (WOR') for the different wells and Plotting of WOR and WOR' versus the cumulative time to identify the source of the produced water.
- 2) To design a computer program for the calculation and plotting to diagnose and estimate the source of produced water.

Chapter2

Theoretical Background and Literature review

Excessive water production is one of the major factor contribute in reduction of wells productivity and one of the common and challenging economic and environmental problems associated with hydrocarbon production (Bailey, 2000).

2.1 Water Production Mechanisms

Water production mechanisms have been classified in the literature using different criteria depending on the purpose of the author's work as follows:

2.1.1 Reasons Related to Reservoir:

Water coning and Water channeling are the two major causes of excess water production in oil wells related to reservoir problems (Seright, et.al- 2003).

Channeling occurs because of the early breakthrough in the high permeability or fractured formations especially in water flooding. Channeling is one of the more important excessive water productions. Furthermore, reservoir heterogeneities lead to the presence of high permeability streaks. Fractures or fracture-like features are the most common cause of the channeling. Water production could emanate via natural fractures from underlying aquifers. Induced or natural fracture fractures can cause channeling between wells in un fractured reservoir often stratification and associated permeability variations among various layers can result in channeling between an injector and producer or from an edge water aquifer to the producers (Seright, et.al- 2003).

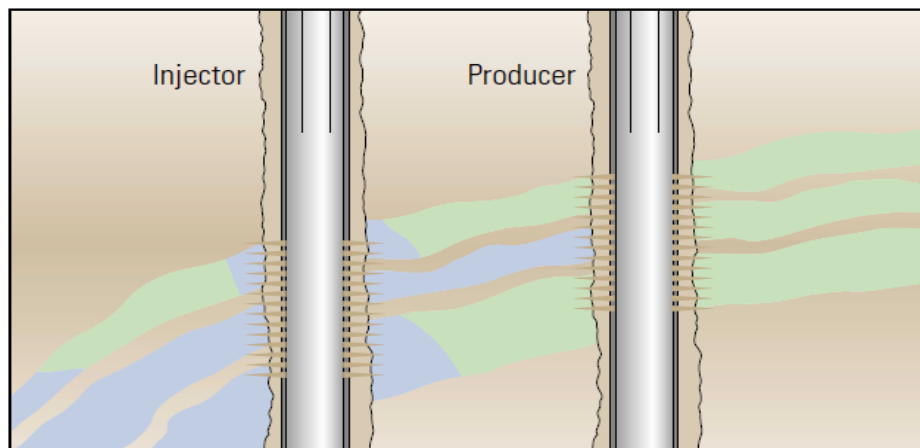


Fig2.1 Channelling due to Water Flooding (Bailey et al., 2000)

While water coning is term used to describe the mechanism underlying the upward movement of water and/or the down movement of gas into the perforations of a production well. Coning is primarily the result of movement of reservoir fluids in the direction of least resistance, balanced by a tendency of the fluids to maintain gravity equilibrium.

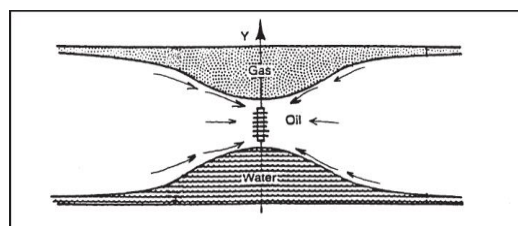


Fig 2.2:Water and Gas Coning (Ahmed, 2010)

The term coning is used because, in a vertical well, the shape of the interface when a well is producing the second fluid resembles an upright or inverted cone (Fig. 2.3).

In a horizontal well, the cone becomes more of a crest (Fig. 2.4), but the phenomenon is still customarily called coning. In a given reservoir, the amount of undesired second fluid a horizontal well produces are usually less than for a vertical well under comparable conditions. This is a major motivation for drilling horizontal wells, for example, in thin oil columns underlain by water. Coning is a problem because the second phase must be handled at the surface in addition to the desired hydrocarbon phase,

and the production rate of the hydrocarbon flow is usually dramatically reduced after the cone breaks through into the producing well. Produced water must also be disposed of. The Specific Problems of Water Coning can be summarized as follows:

1. The water is often corrosive and its disposal costly.
2. The afflicted well may be abandoned early.
3. Loss of the total field overall recovery.
4. Costly added water handling.

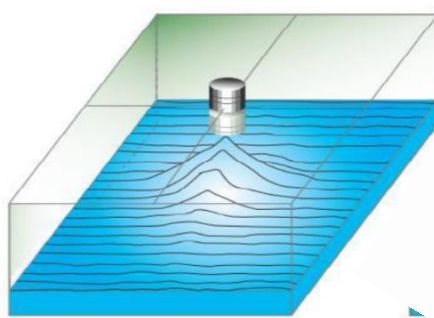


Fig. 2.3: Coning in a vertical well (Aliev,2014)

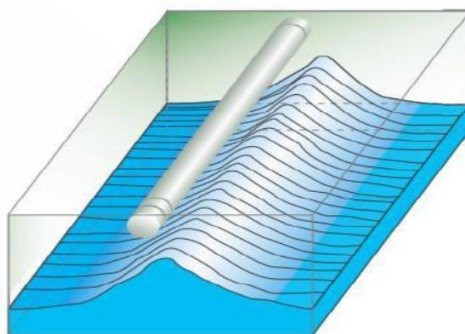


Fig. 2.4: Coning Horizontal Well (Aliev,2014)

Many factors effecting on water coning such as:

1) Capillary Pressure:

Increasing the capillary pressure (P), caused the transition zone was higher which increased water saturations near the wellbore.

2) Completion Interval Position:

The intervals closer to the Gas water contact (GWC) had earlier increased water production which is reasonable since the cone had a shorter distance to rise before reaching perforations.

3) Residual Gas Saturation:

Residual gas saturation had a strong influence on water production; water production is increases with high residual gas saturation.

4) Off Take Rate:

The reduced rates caused significant lower water production. As expected, the lower rates decreased the pressure gradient necessary for coning resulting in a smaller, later cone and lower water production. The water production increased with an aquifer size.

5) Matrix Permeability:

Changes in the matrix permeability had relatively little impact on the results. Increasing matrix permeability caused a slight rise in water volumes likely due to higher production from the matrix in the transition zone.

6) Fracture Permeability:

With the highest permeability, water production was significantly higher.

7) Vertical/Horizontal Permeability Ratio:

When k_v/k_h value is increased, the water production increase.

8) Fracture Spacing:

The degree of imbibition of water from the fractures to the matrix is strongly dependent upon the fracture spacing.

9) Viscous Forces:

The term viscous forces refer to the pressure gradients' associated fluid flow through the reservoir as described by Darcy's Law.

10) Gravity Forces:

Gravity forces are directed in the vertical direction and arise from fluid density differences.

Therefore, at any given time, there is a balance between gravitational and viscous forces at points on and away from the well completion interval. When the dynamic (viscous) forces at the wellbore exceed gravitational forces, a “cone” will ultimately break into the well.

2.1.2 Reason Related to Mechanical:

Casing leak is a failure happens in the casing because of the high pressures exerting against the casing by formation pressures or high hydrostatic pressure, Casing leak can happen by tension, collapse, biaxial loading, or casing buckling Fig 2.5. The excessive water production considered as an indicator for the casing leak often casing leaks occur where there is no cement behind the casing (Reynolds. R.R., 2003).

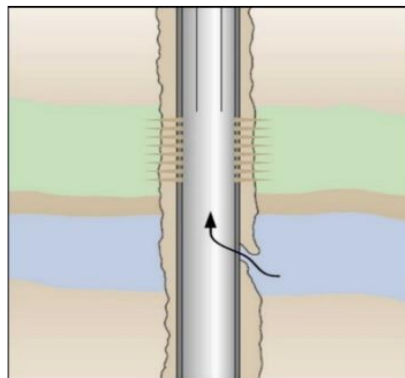


Fig 2.5 Casing Leak (Bailey et. al 2000)

2. 1.3 Reason Related to Completion:

Failed primary cementing can connect water-bearing zones to the pay zone. These channels allow water to flow behind casing in annulus. Response of Cement Failure can lead to pipe movement, contamination of fluids and mud channels (Fig 2.6).

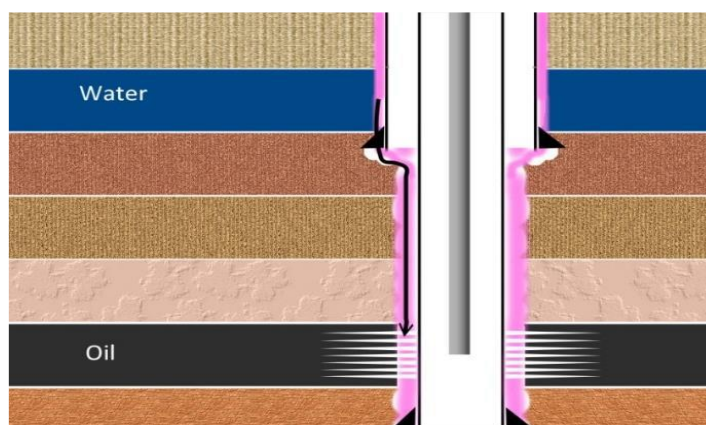


Fig 2.6: Water Production due to Cement Failure (Bailey et. al 2000)

Another factor that is the bad perforation; even if perforations are above the original water-oil or water-gas contact, proximity allows production of the water to occur more easily and quickly through coning or cresting.

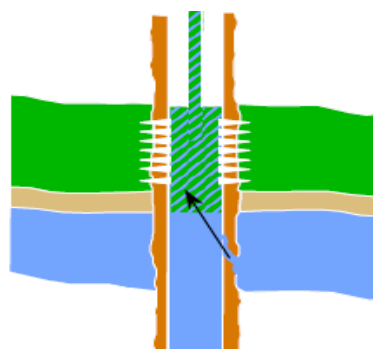


Fig 2.7: Tubing, casing and packer leak (Bailey et. al 2000)

2.2 Water Production Diagnostic:

To aid understanding excessive water mechanism (WPM) In order to evaluate the problematic situation at hand and apply the proper solution to stop or reduce the water flow. it is imperative to identify the source of excess water production first, several methods and techniques have been developed to attack and control WPMs. Majority of the techniques are specialized plots (Echufuet. al, 2010) emphasize that deficiency in understanding the source of the WPM has been the main

reason for unsuccessful and ineffective water control treatments in the industry. Conventionally, information such as production data, and various logging measurements are used in well diagnostic applications. This information is also used in deciding whether any remedial action needs to be taken. Generally, the techniques used for identifying WPMs in wellbore can be categorized into two groups. The first group mainly includes logging and survey tools for evaluating and monitoring the physical conditions of the well, reservoir and fluid flows. The second group consists of various analytical and empirical techniques based on production data. Many diagnostic tools and techniques are available in the literature as described in the following paragraphs:

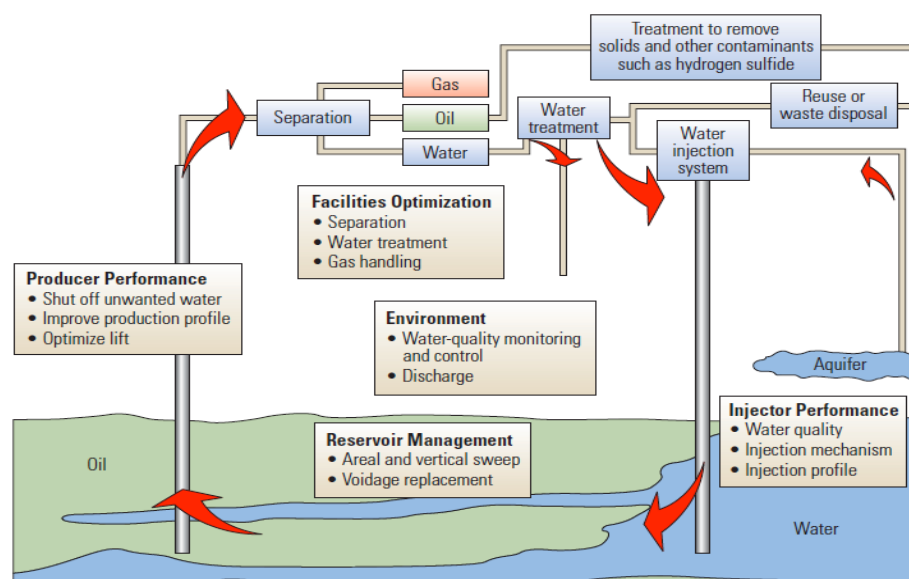


Fig 2.8: Water Management System in Oil and Gas Fields (Arnold et al., 2004)

2.2. 1 Well Testing:

Numerous well testing and logging techniques are available to observe fluids flow into the wellbore and assess the condition of the well. Radioactive tracer logs, temperature logs, cased hole formation resistivity (CHFR) tool, total dissolved solids (TDS) test are few examples of various available well testing tools and techniques. The use of such tools

and techniques can provide some insights into the WPM encountered in the well. For example, TDS tests can determine the source of the produced water and whether it is coming from the aquifer or from the injector.

2.2. 2 Well Logging:

The common practice to identify the source of excessive water production and then select design to do the job is using production logging tools(PLT). Although the PLT is a high technology available, it still has some limitations in horizontal wells due to complex fluid entry mechanisms and flow dynamics of multi-phase flow in the wellbore. Nevertheless, while these logs are vital tools in well and reservoir surveillance, their application during production is somehow limiting. The logging instruments or application of them can be expensive. Sometimes it is required to shut down the well during logging which consequently affects the production rate and revenue. Log data are often very complex and could entail costly and time-consuming data processing and log analysis and interpretation.

Different factors influence the log responses, which might lead to uncertainties in log data measurements and interpretations such as the presence of conductive clay minerals, Washouts in borehole and natural noise (corrupt Well log data).

2.2.3 Production Data Analysis

Production data analyses are the most commonly used techniques for investigating the overall performance of the reservoir as well as individual wells. The key elements of the production data are the information on the rate of the produced oil and water, collected at regular time intervals (usually on a daily basis). Production data analyses by

means of analytical and empirical techniques such as decline curve plots, and water-oil ratio (WOR) versus cumulative oil production or time is a widely usages.

1) Recovery Plot:

The plot of the logarithm of WOR against the cumulative oil production. Cumulative oil production at any particular time during the field life cycle is the total amount of the oil produced from a reservoir at that time. The recovery plot can be extrapolated to predict the future performance and estimate the ultimate oil recovery. The point where this plot reaches the economic WOR plot shows the amount of oil production without any remedial action for water production (Bailey et. al 2000)

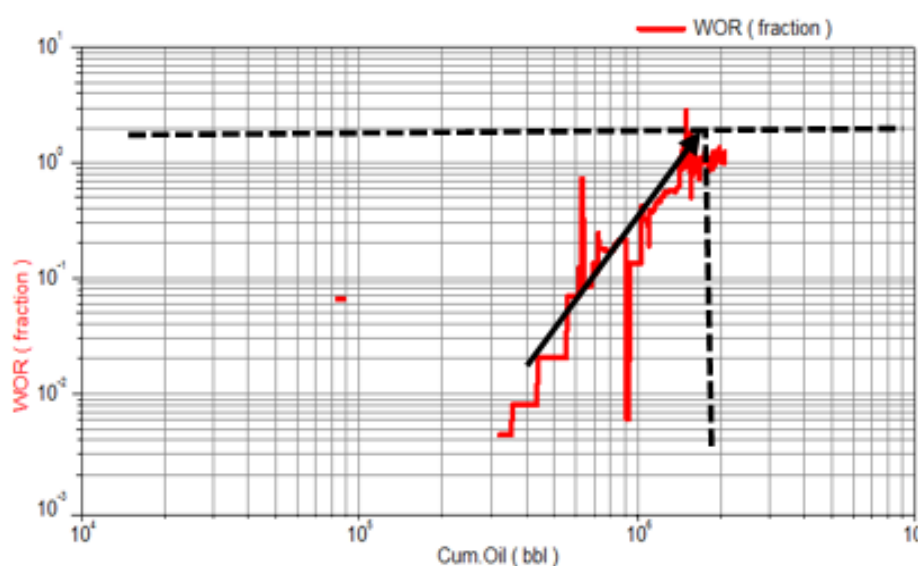


Fig 2.9: Recovery plot (Bailey et. al 2000)

2) Production History Plot:

A plot of oil and water rates against production time (Fig. 2.10) which helps in visualizing rate changes during the field life cycle and assessing any “uncorrelated behaviors” (Mattar et. al 007), such as changes in the rate without corresponding changes in pressure. Wells

with water production problem usually show a simultaneous increase in water production with a decrease in oil production.

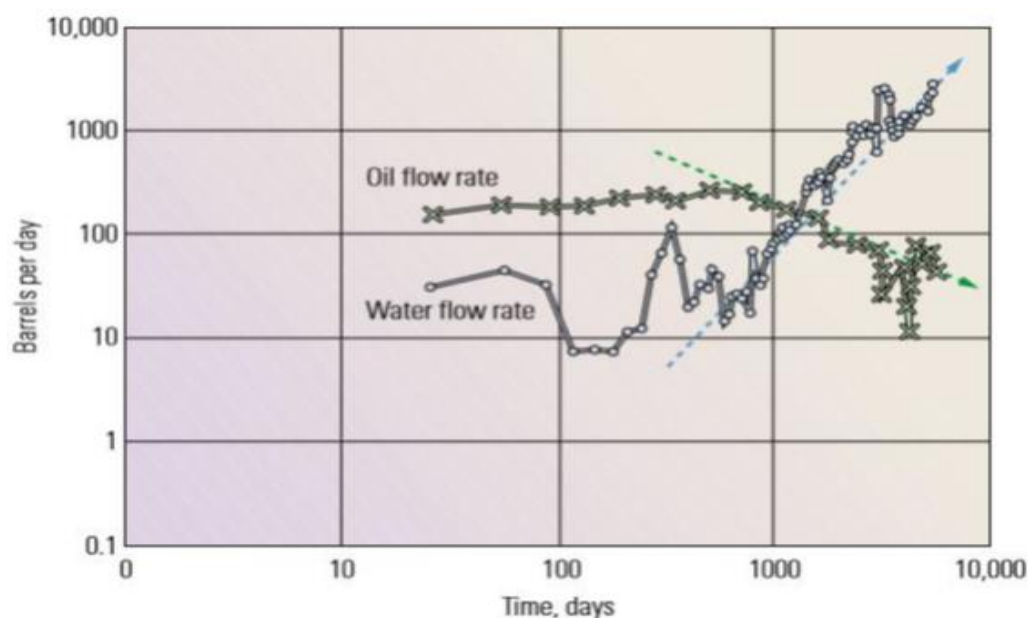


Fig 2.10 Oil and Water Rates Against Production Time Plot (Bailey et. al 2000)

3) Decline Curve Analysis:

Production decline analysis is commonly used for predicting future performance of the well and also for identifying production problems (Guo, B., W. C. Lyons, and A. Ghalambor., 2007.). A typical decline curve analysis consists of a plot of production rates against either time or cumulative production of a well or a field. The theory behind the decline curve plot is that past production trends and conditions remain unchanged and can be extrapolated to show future production behavior. A simple and straightforward way of investigating excess water production problem in the oil well is by plotting the oil production rate against the cumulative oil production. Normal depletion is characterized by a constant decline rate resulting in a straight-line. Any sudden changes in the slope of decline may be an indication of excess water production. However, any deviation from the expected estimates of the future production does

not necessarily indicate water production problem and may be a sign of other problems such as severe pressure depletion or damage build up.

4) Shut-In and Choke-Back Analysis:

Decreased WOR during choke-back or after shut-in period compared to the WOR value before the test may be an indication of water coning or water coming from a fracture intersecting a deeper water layer. On the contrary, increased WOR value is viewed as the result of water coming from fractures or faults intersecting an overlying water layer.

5) Diagnostic WOR Plot:

Chan (1995) proposed a new methodology to analyze the log-log plot of WOR and derivative of WOR against time in order to differentiate between two common and more complicated water problems of water channeling and water coning. Based on Chan's report, three behavioral periods can be observed in the WOR versus time plot for both coning and channeling. During the first period from the start of the production to water breakthrough time, the WOR is constant for both mechanisms. However, this period called the departure time is usually shorter for coning than channeling. In coning, the departure time corresponds to the time when water-oil contact (WOC) rises and reaches the bottom of the perforations. In channeling, the departure time relates to the time of water breakthrough for the highest permeable layer in a multilayer formation. After water break-through, which denotes the beginning of the second period, WOR in coning and channeling shows different trends.

In channeling, however, the WOR increase rate is relatively quick but it could slow down until it reaches a constant value. In coning, WOR gradually increases until it reaches a constant value. Thereafter, the WOR increases quite rapidly for both mechanisms during the third period.

Chan (1995) also investigated the behavior of the time derivative of WOR (WOR') for channeling and coning mechanisms. Coning WOR' shows a changing negative slope while channeling WOR' exhibits an almost constant positive slope.

Previously, different authors studied the water production and the factor affecting water cut; Khan, A. R., (1970) studied water movement in the vertical direction using three dimensional model consists of formation sand involve oil and water layers, the results found the mobility ratio effect in the water coning and water cut, if the mobility ratio increase the water coning rise.

Blades et. al (1975) presented examined water coning phenomenon in an under saturated reservoir with the bottom water drive and high viscosity crude oil. This paper presents the results of the high viscosity crude oil reservoirs being pressure maintained by bottom water drive. Crude oil viscosities of 3, 10 and 60 cp are considered. It was farther shown that the oil production without water was reduced as the well penetration was increased. Wellbore radius proved to have negligible effect on water breakthrough time and water-oil ratio. Of particular significance in this phase.

Menouar et. al (1995) used numerical method to investigate water cresting in horizontal wells. In This Study, a Simple and accurate method to calculate the critical rate is presented. Their study is depending on the observation of saturation gradient in the reservoir, which was assumed homogeneous and anisotropy ratios. The present study shows that this is true only for $0.5 < a < 1$.in fact for $0.01 < a < 0.1$ the production rate is a strongly decreasing function of the anisotropy ratio. Most of the studies describe the vertical well critical as decreasing function of the anisotropy ratio, opposite in behavior to horizontal wells.

Wu et. al (1995) water gas coning is serious problem in many oil field applications. considered the Amber Field in the Gulf of Mexico for their study. The aim of their study was to observe the probability of horizontal wells to delay water coning and enhance oil recovery.

Stanley et al. (1996) and Love et al. (1998) reported the use of WOR diagnostic plots in successful water treatment design case studies in Indonesia and New Mexico, respectively. However, it is important to notice that in both of these studies, the WOR diagnostic plots was not applied as a stand-alone technique but rather a supplementary tool with other methodologies such as production loggings and reservoir modelling.

Despite the wide use of WOR diagnostic plots in wellbore and reservoir performance investigations, Seright (1998) challenged the view of using WOR plots as a diagnostic tool for WPM identification. He conducted a research study to determine whether Chan's proposed technique (Chan 1995) in interpreting WOR and WOR' plots is generally applicable or if there are limitations to consider. Using numerical simulation and sensitivity analyses, the effects of various reservoir and fluid parameters on WOR and WOR' were investigated for both coning and channeling problems.

Jiang et. al (1998) studied empirically the movement of bottom water to a horizontal well using Hele-Shaw cell. They checked the effects of different flow rates and viscosity ratios. The results indicated that oil recovery is a decreasing function of flow rate and viscosity ratio. The results further showed that increase in flow rate and viscosity ratio makes water-oil interface sharper.

Yortsos et al. (1999), motivated by Chan's work investigated the behavior of WOR versus time under a variety of conditions (for example,

following a break through or at late times) using analytical studies. They demonstrated that the late time slope of the log-log plot of WOR against time could be associated to the relative permeability and production geometry. The effect of relative permeability was investigated by conducting a one dimensional (single layer or homogeneous formation) analysis, in which, the late time behavior of the log-log plot of WOR versus time is a straight line of slope $b/(b-1)$, where b is the exponent in the dependence of relative oil permeability on saturation.

Yang and Ershaghi (2005) developed a library of diagnostic plots of WOR versus oil recovery and/or time for a variety of rock and fluid properties with different architectural positions of high permeability zones based on analytical modelling and simulation studies.

Gasbarri et al. (2008) proposed a diagnosis technique using transient test and multiphase flow meters. They used reservoir simulations to build three base cases of WPM models of coning, water channeling and flow behind casing. Then, different ranges of production rate, API gravity, permeability ratio and diameter of the flow channel behind casing were used to generate various instances of the mentioned base cases.

Applicability of WOR plots for excess water production diagnosis in horizontal wells was investigated by Al Hasani et al (2008). They used simulation models to examine the behavior of WOR plots in water coning and water channeling problems in vertical and horizontal wells. They reported that the WOR trends in their simulated models were in agreement with Chan's diagnostic plots and concluded that these plots could be used for problem identification in horizontal wells.

M.Rabiei et al (2009) applies a Meta learning classification technique called Logistic Model Trees (LMT) to diagnose water production mechanisms based on WOR data and static reservoir

parameters. Synthetic reservoir models are built to simulate excess water production due to coning, channeling and gravity segregated flows. Various cases are then generated by varying some of the input parameters in each model. A number of key features from plots of WOR against oil recovery factor are heuristically extracted by segmenting these plots at certain points. LMT classifiers are then applied to integrate these features with reservoir parameters to build classification models for predicting the water production mechanism in different scenarios of pre and post water-production stages.

Recently, Permadi et. al (2010): Actual coning behavior in horizontal well is not fully understood suggestion a semi-empirical method for prediction of horizontal well performance after the breakthrough time. The study also established the correlation for deviation factor to estimate displacement efficiency provided by bottom water. water cresting efficiency is defined in this study by inverting the correction factor and was found systematically to rate with factors that influence the coning behavior. The study also established the correlation for deviation factor to estimate displacement efficiency provided by bottom water. In the model, it was assumed that all the forces have negligible effect.

Concerning the application of the diagnostic plots derivative method, Elradi Abass and Satti Merghany (2011) prepared a paper which provided a simplified computation and quick technique for engineers; by using Microsoft Excel format on calculating and plotting the derivative response, considering two case examples of a Sudanese oil well's data.

Chapter 3

Methodology and General Procedures

Chan (1995) method of Water/oil ratio (WOR) diagnostic plots (which conducted using a series of systematic water-control numerical simulation studies of black oil simulator) was selected to identify the source of the water in different wells through Heglig oilfield as it considered as the most appropriate methodology for identifying the source of the water production problems. A set of diagnostic plots is generated through a log-log plot of WOR versus time. The log-log plots are capable to differentiate whether a production well is experiencing water coning, channeling due to high-permeability layers, or normal with high water cut.

- 1) First, the value of water/oil ratio (WOR) is calculated using the actual oil and water production, and the equation is:

$$WOR = \frac{Q_w}{Q_o} \quad 3.1$$

- 2) Then, the derivative value of water/oil ratio (WOR) is calculated by the following equation:

$$WOR' = \frac{d(WOR)}{dt} = \frac{(WOR_{SS2} - WOR_1)}{(t_2 - t_1)} \quad 3.2$$

Where it is the time corresponding to the production rate

- 3) The value water/oil ratio and derivative value of water/oil ratio was plotted against the time for the different wells
- 4) The resulted plots were compared with Chan, diagnostic plots to identify the problem

Depending on Chan, diagnostic plots (Fig 3.1), the WOR behavior for channeling and coning is divided into three periods; During the early time period, the WOR curves remain flat showing expected initial

production. The value of the initial WOR depends on the initial water saturation and its distribution among, all Layers as well as the relative permeability functions. The time length of this period depends on the water drive mechanism and its ending is marked by, the departure of the WOR from a constant value. When water production begins, Chan presented that the behavior becomes very different for coning and channeling. This event denotes the beginning of the second time period (Minou Rabiei, 2011).

For coning, the departure time is often short depending on various parameters but predominantly on the distance between the WOC and the bottom of the nearest perforation interval, vertical-to-horizontal permeability ratio, bottom water influx rate, production pressure drawdown or rate, and, relative permeability functions (Chan, K.S., 1995). According to Chan, the rate of WOR increase after water breakthrough is relatively slow and gradually approaches a constant value. This occurrence is called the transition period.

For channeling, the water production from the breakthrough layer increases very quickly. Accordingly, the WOR increases relatively fast. The slope of the water channeling WOR depends on the relative permeability functions and initial saturation conditions. the WOR increase could actually slow down entering a transition period. This corresponds to the production depletion of the first breakthrough layer (Chan, K.S., 1995). The end of this transition period shows the WOR increase resumes at about the same rate. This corresponds to the water breakthrough at the next highest water conductivity layer.

Fig 3.2 and Fig 3.3 show the WOR and WOR['] derivatives for channeling and coning, respectively. The WOR['] (simple time derivative of the WOR) shows nearly a constant positive slope for channeling and a changing negative slope for coning. The WOR['] trend for channeling

behavior in the third period of a water coning situation is shown in Fig. 3.4. Again, the WOR' vs time plot shows a positive slop.

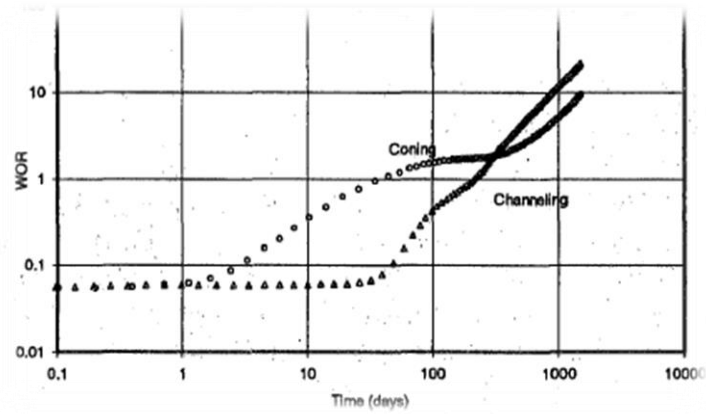


Fig 3.1 Water coning and channeling WOR comparison(Chan, K.S., 1995).

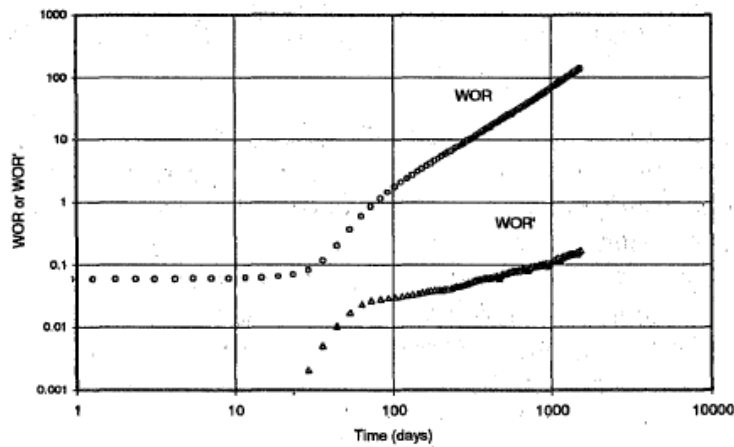


Fig 3.2. Log-log plots of the WOR and its Derivative for A Multilayer Channeling Situation(Chan, K.S., 1995).

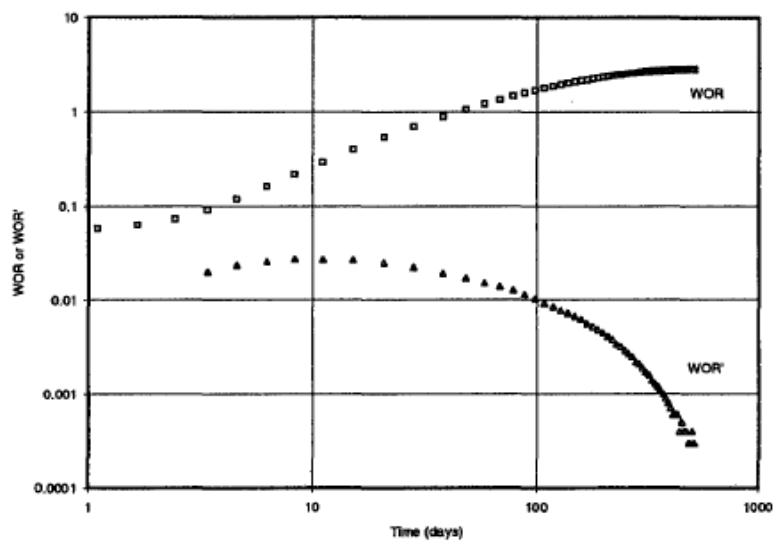


Fig 3.3. Log-log plots of the WOR and its derivative for a coning situation(Chan, K.S., 1995).

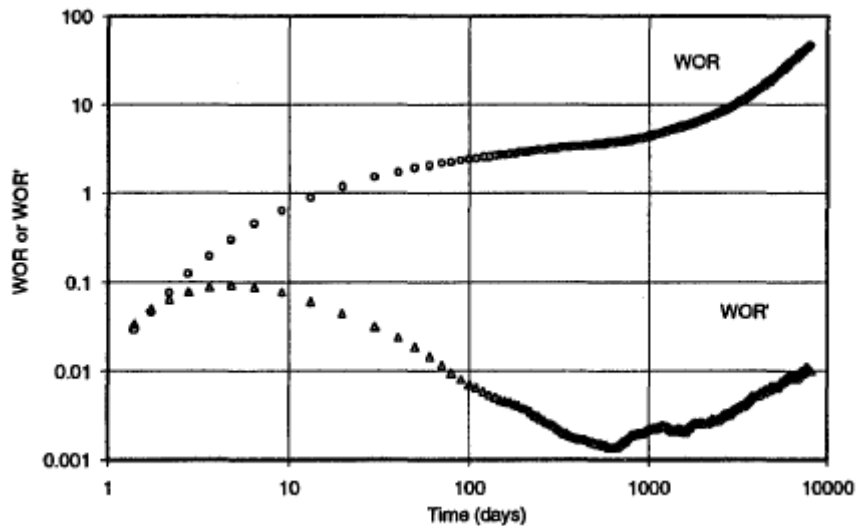


Fig 3.4. Log-log plots of the WOR and its derivative for a coning situation with a late channeling behavior(Chan, K.S., 1995).

Depending on Chan, the transition period between each layer breakthrough may only occur if the permeability contrast between adjacent layers is greater than four. After the transition period, Chan describes the WOR increase to be quite rapid for both mechanisms, which indicates the beginning of the third period. The channeling WOR resumes its initial rate of increase, since all layers have been depleted. The rapid WOR increase for the coning case is explained by the well producing mainly bottom water, causing the cone to become a high-conductivity water channel where the water moves laterally towards the well (Mohammed and Elham 2015) Chan, therefore, classifies this behavior as channeling; Table 3.1 summarizes the different categories of the curves.

Table 3.1 WOR, WOR' Slope Values

WOR Slope	WOR' Slope	Reason for Water Production
Positive	Positive	Channeling
Positive	Negative	Coning
Positive linear slope	horizontal line	water/oil contact rising

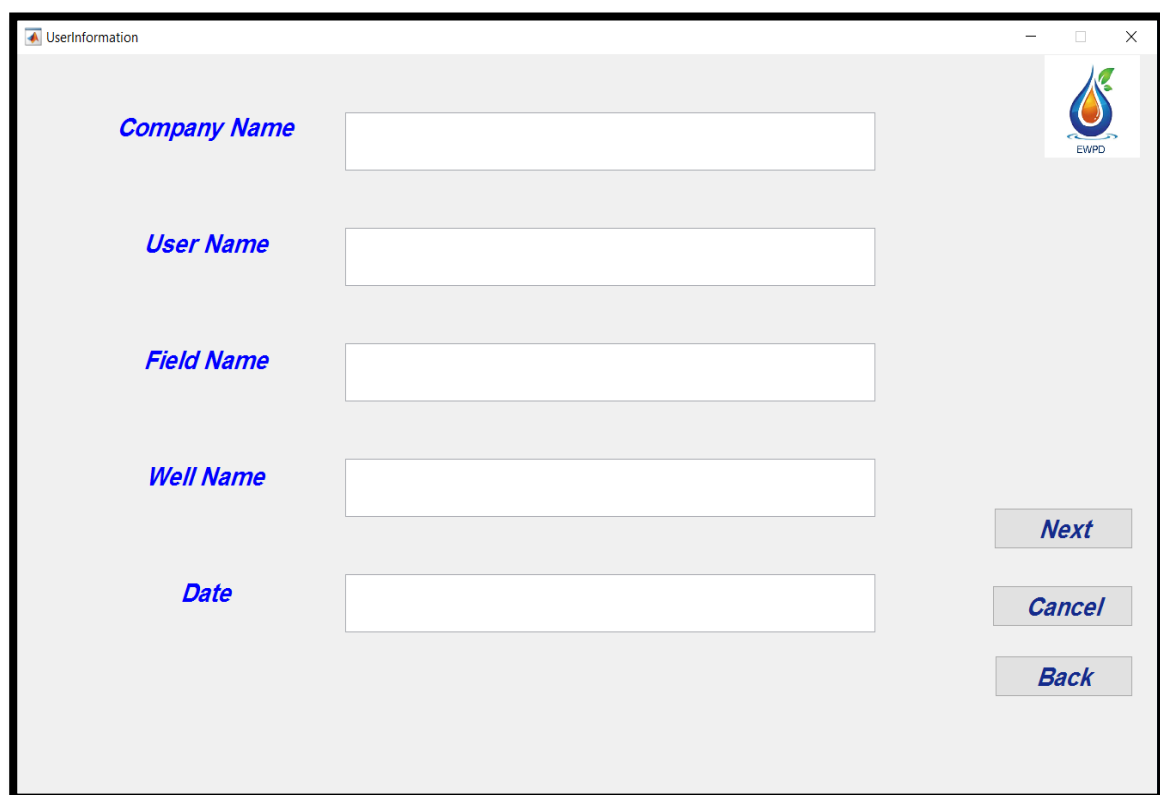
A computer program was generated to perform the work using MATLAB; four different user interface was used to insert, open and save the information and to perform the required calculations. Then the required plots were visual observation are required to compare the result with the standard plots of Chan which are also presented in the result screen.

Chapter 4

Results and Discussion

Generally, the diagnostic plot Figs show the WOR increasing with time. The rate of increase differs for a different problem mechanism. The degree of sharp or gradual rate of increase presents a striking difference between coning and channeling. The other mechanisms can be identified through derivative response.

An (Excessive Water Production Diagnoses computer program (called EWPD) was generated using MATLAB; three different user interface was used to insert, open and save the information and to perform the required calculations. The First screen is a main screen through which the user can start the job and identify the main information about the field, company and well (Fig 4.1)



The screenshot shows a software window titled "UserInformation". The window contains five text input fields, each preceded by a label in blue italicized font: "Company Name", "User Name", "Field Name", "Well Name", and "Date". To the right of the input fields, there is a logo for "EWPD" (Excessive Water Production Diagnosis) featuring a blue water drop with a green leaf. Below the logo are three buttons: "Next", "Cancel", and "Back", all in blue italicized font.

Fig 4.1 EWPD User Main Information Screen

Then the user can simply move to the next screen in which the production data introduces; the production data can be introduced as new data or an existing file can be opened (Fig 4.2).

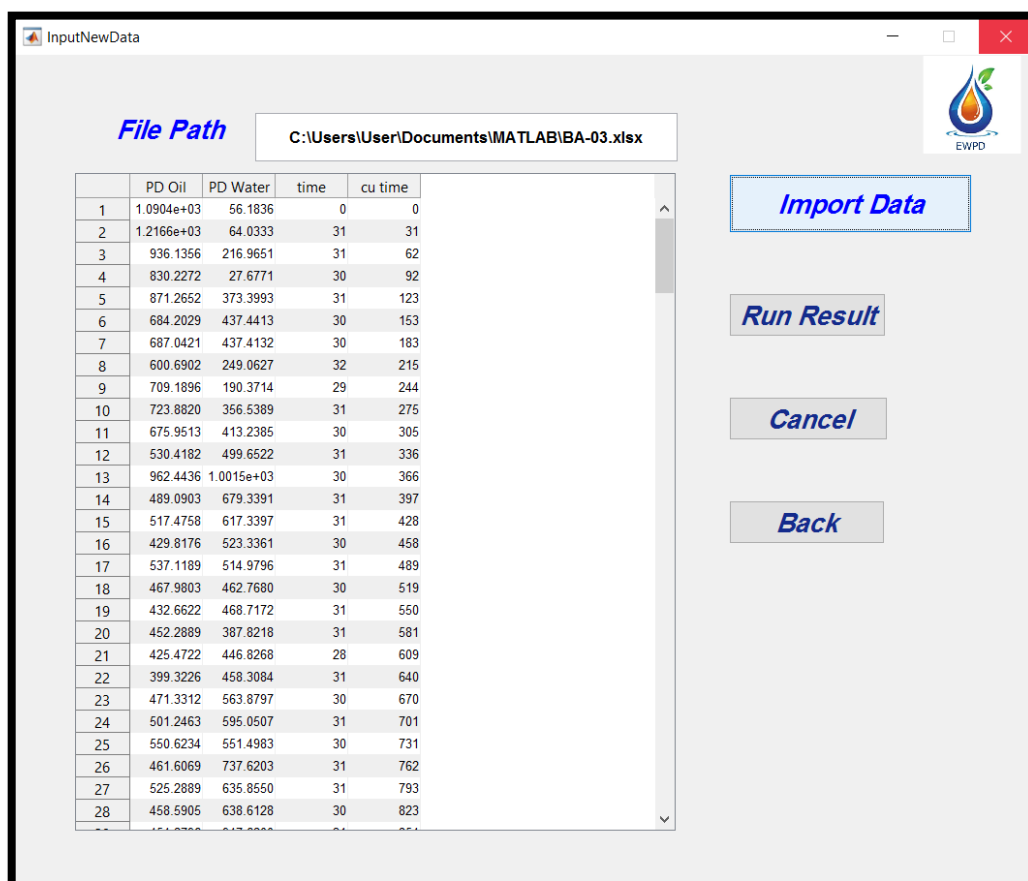


Fig 4.2 EWPD Input Data Screen

Finally, the required plots screen appears in result screen after the user continue to run calculations; her, visual observation is required to compare the result with the standard plots of Chan which are also presented in the result screen (Fig 4.3).

The results of the computer program were compared with Excel results checked and insure the accuracy of the program; the comparison indicates that the accuracy of the program is very high as no error was found and a very good matching was achieved (Fig 4.5)

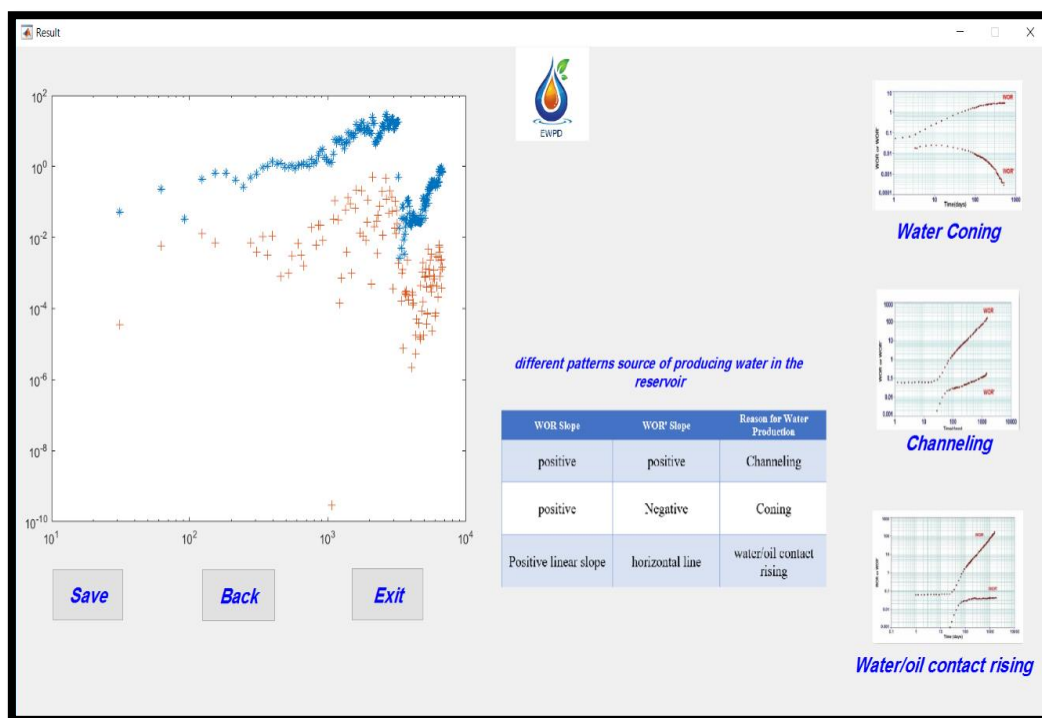
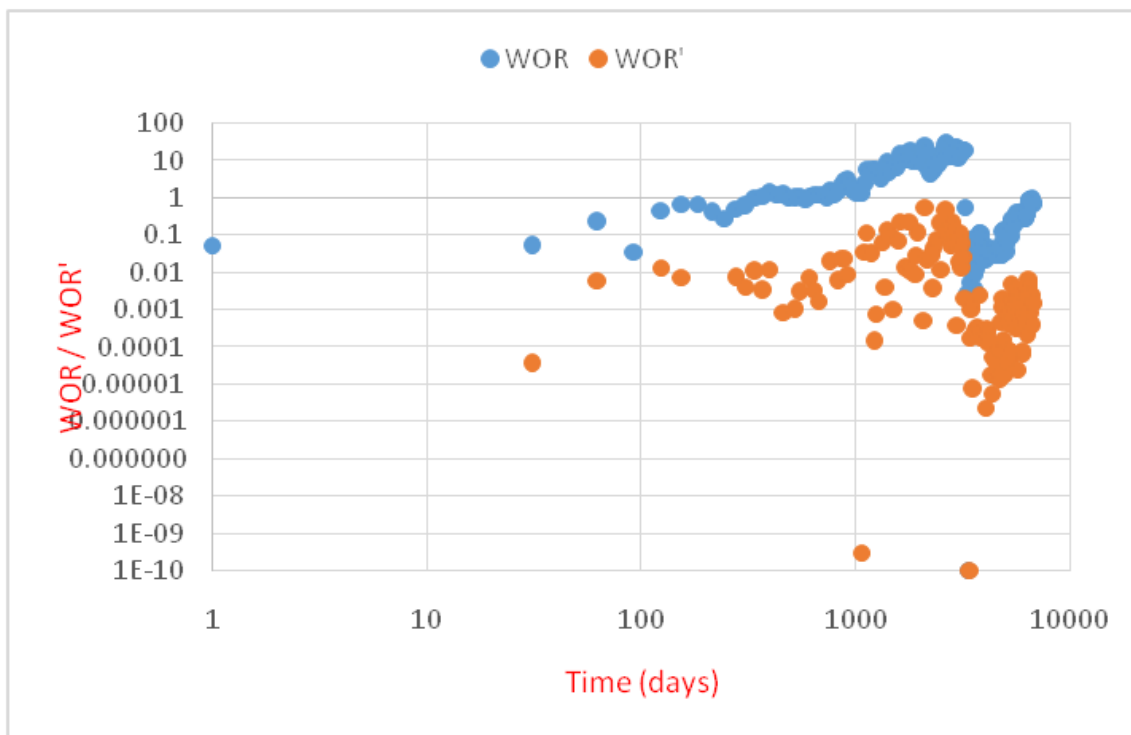
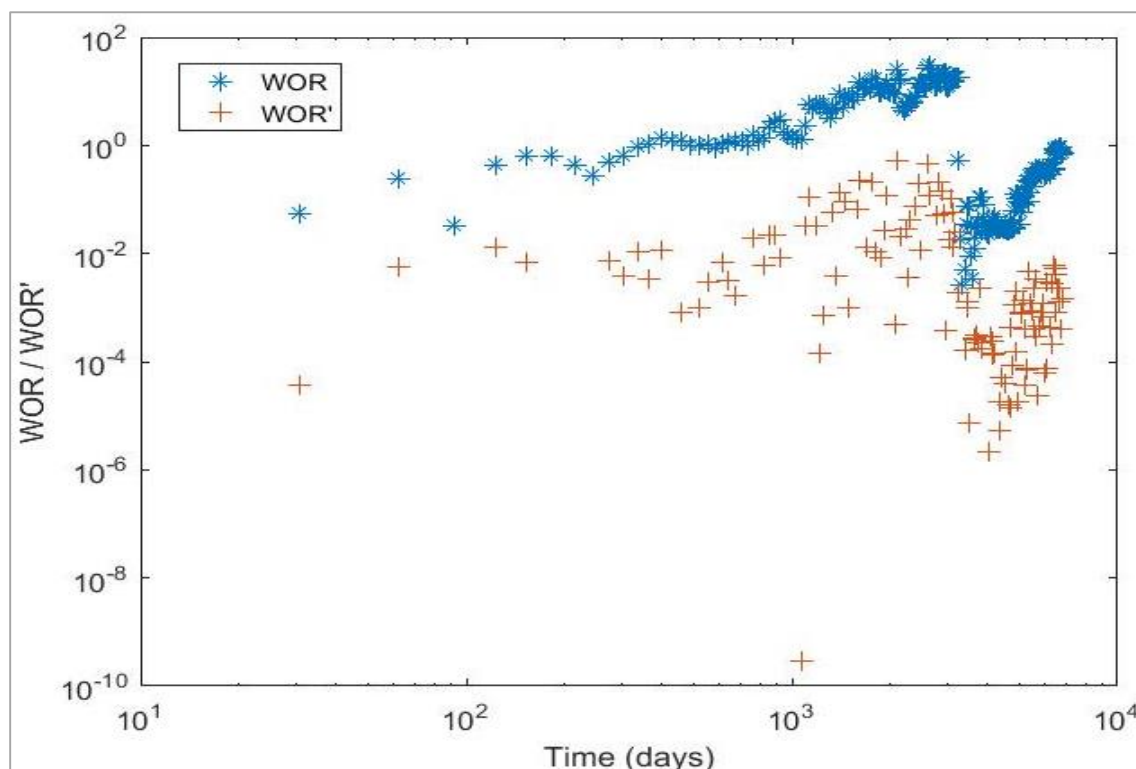


Fig 4.3 EWPDP Result Screen



(a) The Calculation Result of the Excel



(b) The Calculation Results Obtained EWPD

Fig 4.4 Comparison of the Computer Program Results with Excel Results

The program was then used to calculate and identify the water sources in 5 wells in Heglig oil field and the following paragraphs presented the results

4.1. Well BA-03:

Well BA-03 is a vertical well located in Barki - Heglig Oil Field, started production on Jun-1999 from zones (Aradeiba F, Bentiu-1A, Bentiu-1B). Diagnostic plot of BA-03 refers to the Fig 4.5; the Figure presented that up to 1584 days the WOR is t very low indicating that most percentage of fluids produced are oil. After 1584 days and up to 3227 days the WOR is relatively troubled increase. During this time, since WOR and WOR derivative vs. time showed a positive slope, it is clear that the source of produced water in the reservoir is a channeling. On Jun-2008 the zone (Bentiu-1B) was isolated and the well continuous

production from the zones (Aradeiba F, Bentiu-1A) which led to decrease in the WOR significantly. With production continuing the rate of increase of the WOR is relatively slow, WOR derivative in the positive slope which indication to another channeling.

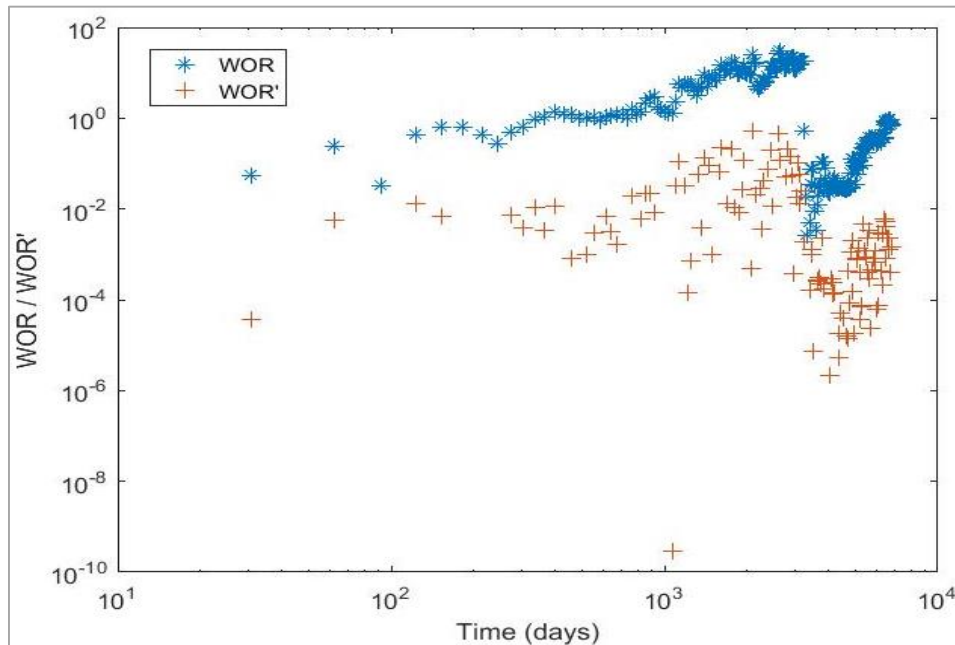


Fig 4.5: WOR and WOR' Derivatives Plot of Well BA-03

4.2. Well HE-04:

Well HE-04 is a vertical well located in Heglig Main within Heglig Oil Field, started production on Jun-1999 from zones (Bentiu-1A, Bentiu-1B). Fig (4.6) showed that the well started to produce and until (2407) days left the WOR is very low. After (2435) days the rate of increase of the WOR is relatively fast, since WOR derivative vs time showed a positive slope indicating initiation of water channeling. On Mar-2014 all zones were isolated and producing just from the zone (Bentiu-1A) which result in reducing WOR significantly.

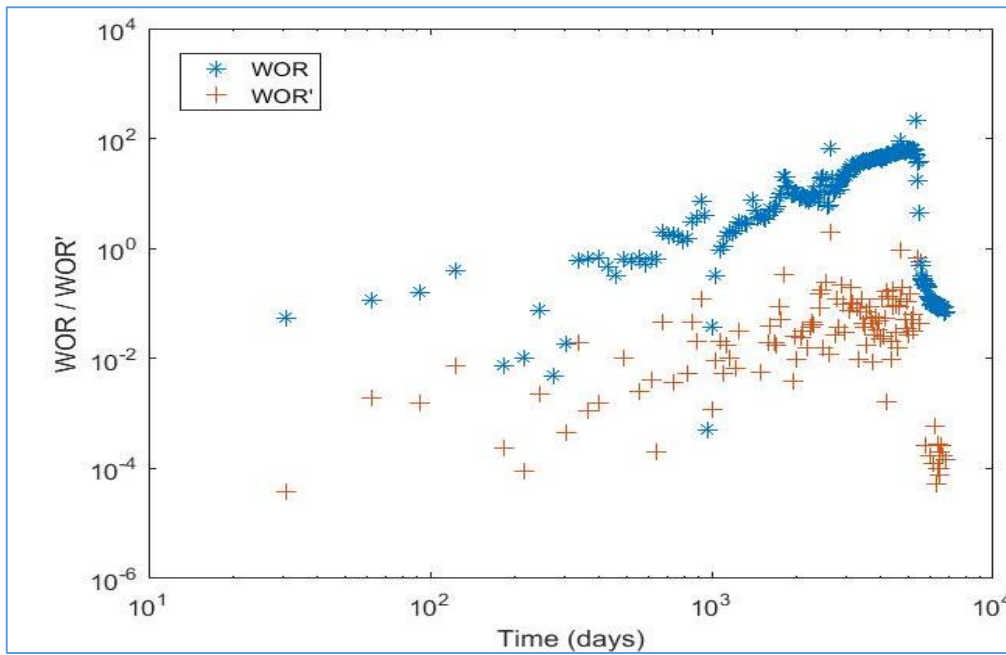


Fig 4.6 WOR and WOR' Derivatives Plot of Well HE-04

4.3. Well HE-09:

Well HE-09 is a vertical well located in Heglig Main within Heglig Oil Field, started production on Feb-2001 from zones (Bentiu-1A, Bentiu-1B). Diagnostic plot of the well HE-09 refers by the Fig (4.7) The WOR and WOR derivative plots show a positive slope, characteristics of a water channeling case.

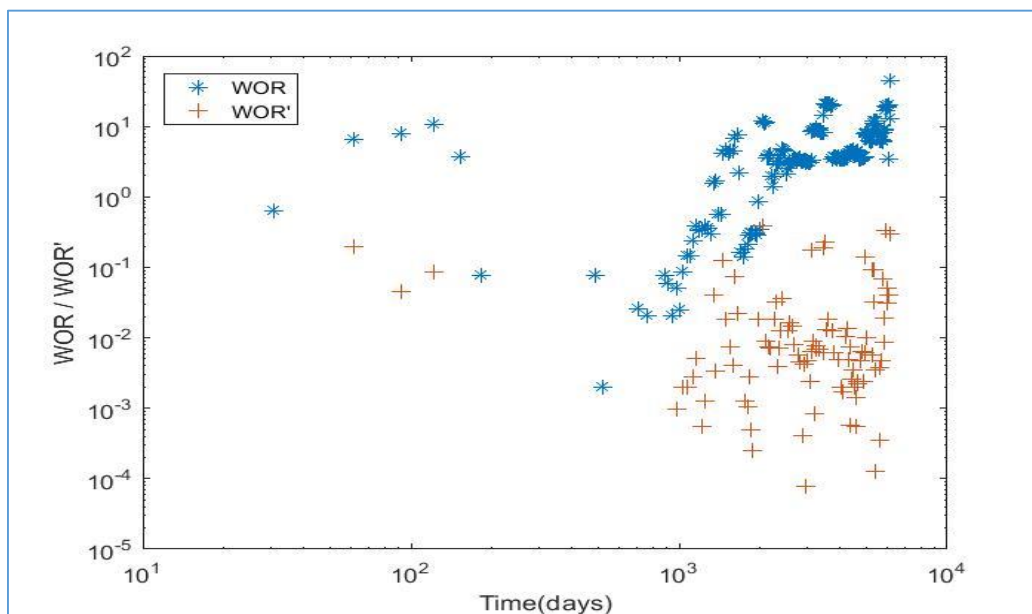


Fig 4.7 WOR and WOR' Derivatives Plot of Well HE-09

4.4. Well HE-10:

Well HE-10 is a vertical well located in Heglig within Heglig Main Oil Field, started production on Jun-1999 from the zone (Bentiu-3A). Diagnostic plot of HE-09 refers by the Fig (4.8) showed that until (4932) days left the WOR is increase very low indicating that most percentage of fluids produced are oil. During this time, since WOR and WOR derivative vs. time showed a positive slope that means the source of producing water in the reservoir is a channel. On Dec-2012 the well produced from (Aradeiba F, Bentiu-1A) which led to decrease in the WOR significantly, with production continuing the rate of increase of the WOR is relatively high, WOR derivative started to decline and showed negative slope water coning was visible.

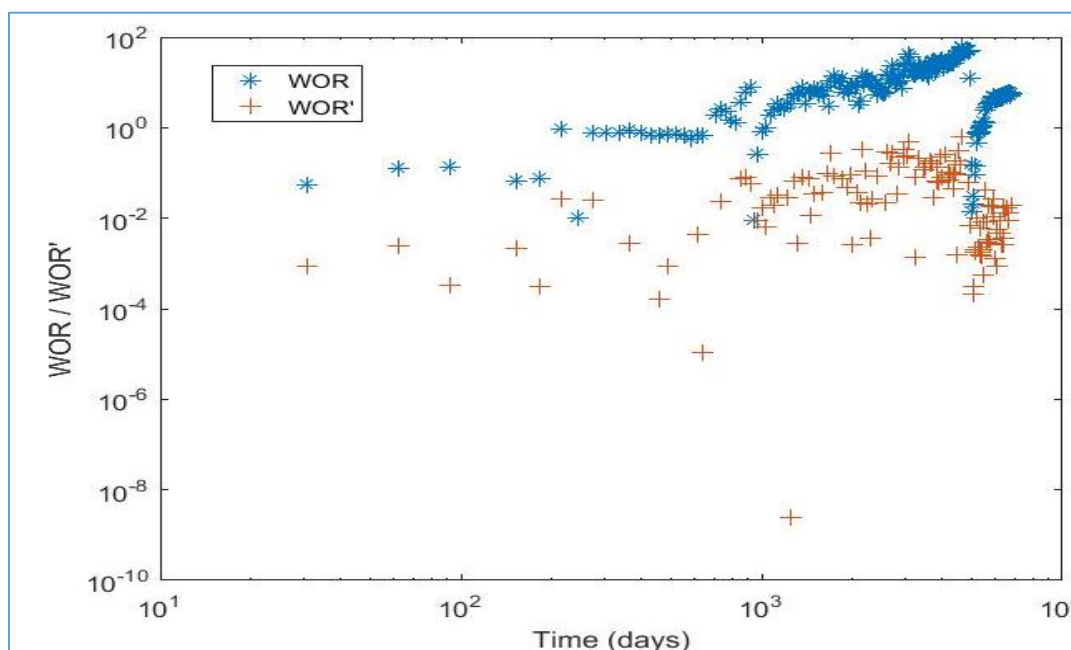


Fig 4.8 WOR and WOR' Derivatives Plot of Well HE-10

4.5. Well HE-25:

Well HE-25 is a vertical well located in Heglig Main within Heglig Oil Field, started production on Jan-2003 from zones (Bentiu-2A, Bentiu-3A). Diagnostic plot of HE-25 refers by the Fig (4.9) The WOR plot

show a linear and positive slope, WOR derivative show horizontal line which indicate the water/oil contact rising.

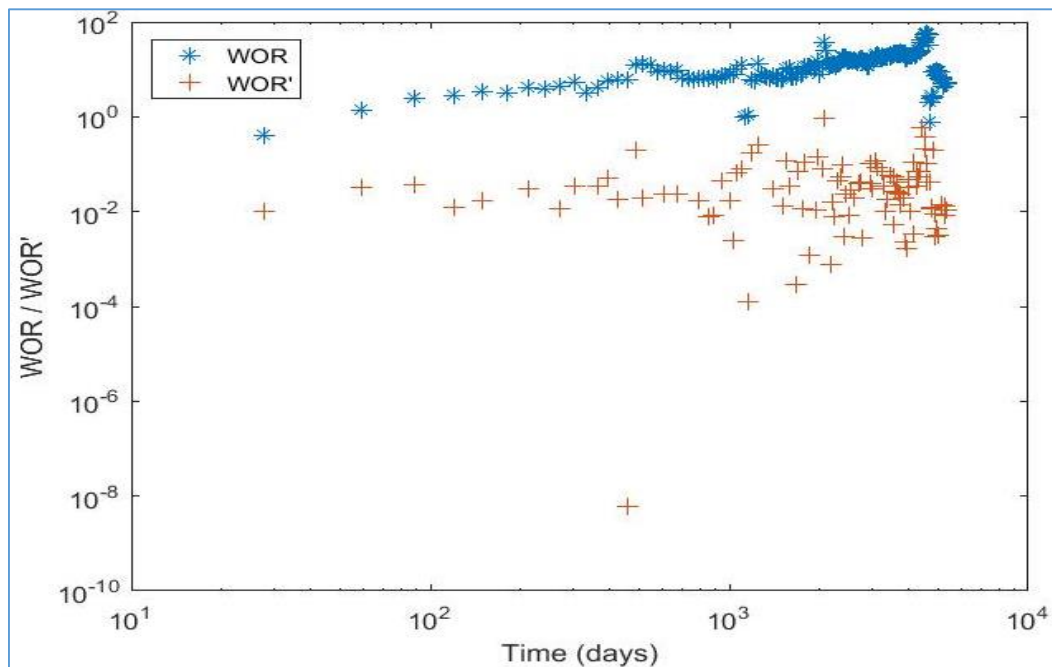


Fig 4.9 WOR and WOR' Derivatives Plot of Well HE-25

Chapter 5

Conclusions and Recommendations

5.1. Conclusions

- 1) Excess water production has always been a major issue in many oil fields worldwide and it is not only negatively affects the oil production rate but also entails costly and time-consuming water management operations.
- 2) In order to be able to tackle the excess water production problem effectively, it is vital to identify the source of the problem first as each water production mechanism (WPM) requires a specific type of treatment.
- 3) This study applied Chan's methodology to diagnose and estimate the source of produced water in different 5 wells through Heglig oilfield in Sudan which is sandstone reservoir with high permeability and high water saturation.
- 4) A plotting of the water oil ratio WOR and WOR derivative vs. time on a log-log was presented for 5 different wells using a new developed program called EWPD which stand for Excessive Water Production Diagnosis. The results were compared with manual Excel calculation to insure its accuracy; good matching was observed reflecting high accuracy.
- 5) Through the five wells, 3 wells presented channeling phenomena as the main reason of excessive water production; one well-presented water coning behavior while another well-presented water oil contact movement.

5.2. The Recommendations:

From the outcomes of the research, the following recommendations can be made:

- 1) This study focused on the problem of excess water production in vertical oil wells. A possible extension to this work is to examine the water production in horizontal wells.
- 2) Most wells in Heglig Oil Field produce using Artificial lift pumps so care should be taken, when an artificial lifting pump is set at a high rate, especially after well shutoff period.
- 3) The optimum pumping flow rate should be technically designed for each well below the critical value of forming water coning, in order to prevent early stage water breakthrough, and thus enable maximization of the oil reserves.
- 4) Include other reservoir characteristics such as pressure and temperature in the analysis and examine whether any significant relation between these new parameters and WPMs can be identified.
- 5) A preventive/proactive conformance process by using logging tools can delay or prevent excess water production. It can provide a higher hydrocarbon production without adventuring of early water breakthrough problems.
- 6) According to pervious point, one of the objectives of this research was trying to use another method for verifications of the results of derivative method, that method was using Production Logging, but because Production logging instruments or application of them can be expensive, they might impose further expenses by shutting down the well during logging which consequently affects the production rate and revenue, Log data are often very complex

and could entail costly and time-consuming data processing and log analysis and interpretation do not use in Diagnosis here in Sudan which led to lack of information of this method.

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