The International Journal of Engineering and Information Technology

journal homepage:www.ijeit.misuratau.edu.ly

Excessive Water Production Analysis in the Abu-Attifel Oil Field Using Chan's Diagnostic Plots

Saleh J. Arwini
Faculty of Engineering
University of Tripoli, Libya
S.Arwini@uot.edu.ly

Abstract— **Excessive water production is one of the major problems in mature Libyan oil fields. Water production has the potential to reduce the productive life of oil and gas wells while also causing serious issues such as tubular corrosion, fines migration, and hydrostatic loading. The aim of this paper is to diagnose and evaluate excessive water production mechanisms in the Abu-Attifel Oil Field using Chan's diagnostic plots. This technique was applied to seven wells in the Abu-Attifel oil field. After a strong depletion phase, water injection was set up and started in the field in 1974. The Chan's diagnostic plots method is applied using Microsoft Excel format to calculate and plot the derivative response to understand the excessive water production mechanism. [2] The diagnostic plots showed some random and noisy trends on both the WOR and WOR' plots; hence, they provide a controversial basis for characterizing water production based on surface observation of production trends. The multilayer channeling with production changes could be one reason for the excessive water production in the studied wells. The results obtained need to be verified by close monitoring using production logging tools (PLT) and well testing techniques to ensure breakthrough time and identify the main reasons for excessive water production.**

Index Terms: **excessive water production, water injection, Chan's diagnostic plots, Abu-Attifel oil field, Libya.**

I. INTRODUCTION

Produced water is the water extracted from the reservoir associated with oil and gas. Excessive water production is one of the main factors contributing to the reduction of well productivity. Worldwide, it is estimated that an average of three barrels of water are produced for each barrel of oil. In general, increasing the water cut has a negative impact on both the inflow and outflow curves. Higher water production increases the cost of fluids lifted to the surface, water treatment, and disposal. Water production is also related to scale problems at various production system components. In the oil industry, the annual cost of disposing of this water is estimated to be 40 billion dollars. This is because water is commonly co-produced with the hydrocarbons saturating the reservoir rock [1], [2].

Reservoir rocks normally contain both petroleum hydrocarbons and connate water. Once the production starts, this water, called connate water, is also produced in the wellbore comingled with oil. In addition to the connate water contained in reservoir rocks, many petroleum reservoirs are bounded by or are adjacent to 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 for the hydrocarbon reserves to move towards the production wells. Water from these various sources can flow into the wellbore and be co-produced with the hydrocarbon stream. Such water is referred to as "produced water." The ratio of produced water to produced oil is denoted as the WOR (water/oil ratio) [3]. The WOR economic limit is reached when the cost of handling and disposal of the produced water approaches the value of the produced oil. No operator wants to produce water, but some waters are better than others [1]. When it comes to producing oil, a key issue is the distinction between sweep, good (or acceptable), and bad (or excess) water, as shown in Figure 1.

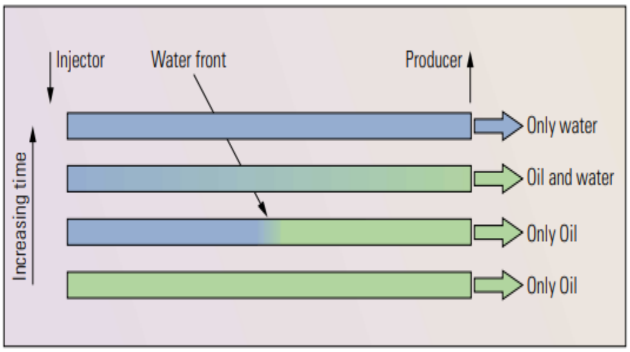

Figure 1. Bad Water vs. Good Water [1].

Excessive water production can be caused by a well problem (mechanical failure), such as a casing leak or cementing failure or a bad perforation job or reservoir-

Received 16 Feb , 2023; revised 2 June, 2023; accepted 9 June, 2023.

Available online 12 June, 2023.

related reasons, such as water channeling from the water table to the well via natural fractures or faults, water breakthrough in high permeability zones, or water coning [2]. The most common water production problems are depicted in Figure 2. In general, water production problems related to well integrity are easier to solve, and it gets more complicated to control water production if they are related to reservoir characteristics. The best completions and production practices can delay but not stop this water production. Understanding reservoir behavior provides a basis for determining whether excessive water production is a concern and if current water production is excessive. Various water control techniques were developed to shut off or reduce excessive water production. However, the rate of success of water shut-off jobs is still considered low. Obviously, the understanding of excessive water production mechanisms and identifying the water entry in the well are the two major factors that make the shut-off job successful [2], [4].

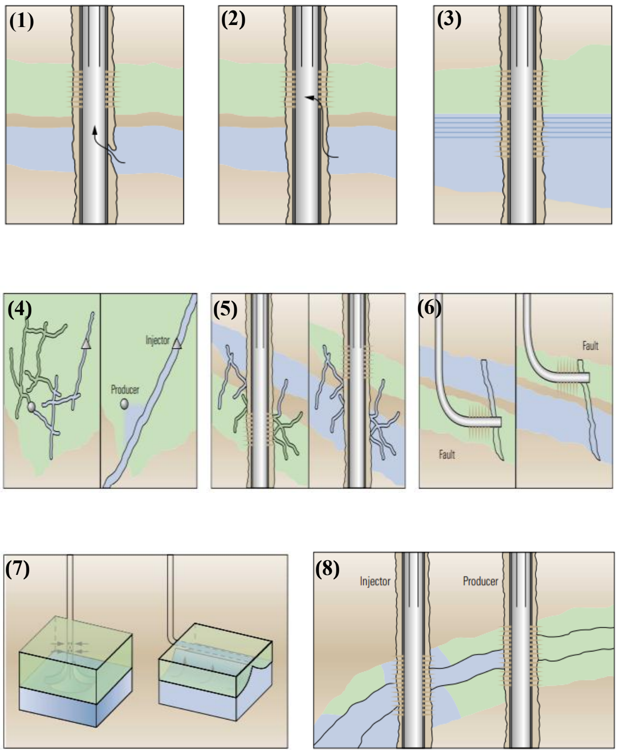

Figure 2. Common water production problems. (1) Casing, tubing or packer leaks. (2) Flow behind casing. (3) Moving oil-water contact. (4) Fractures or faults between an injector and a producer (5) Fractures or faults from a water layer (vertical well) (6) Fractures or faults from a water layer (horizontal well) (7) Coning or cusping (8) Channelling due to Water Flooding [1].

Several analytical and empirical techniques using information such as production data, water/oil ratio and logging measurements have been developed to determine the type of water production problem, locate the water entry point in the well, and choose the candidate wells to perform treatment methods. Water/oil ratio diagnostic plots (e.g. Chan's plot) are probably the most widely used technique in reservoir performance studies as it is a quick and reliable way and the least expensive of all diagnostic methods. To identify water production mechanism caused by water coning or channeling, many oil companies rely on log-log plots of WOR and its derivative against time [5], [6]. WOR diagnostic plots are easy to use and explicable for no experts. The production data required for these plots is routinely collected, and the accuracy of these data is usually reliable. Nevertheless, without taking other important reservoir parameters into account, the WOR diagnostic plots could easily be misinterpreted, and it has been demonstrated that applying these plots on their own could be misleading [7], [8].

The main purpose of this paper is to diagnose the sources of excessive water production in the Abu-Attifel Oil Field using Chan plots. In this study, the production data from eight oil wells (A1, A3, A4, A7, A64, A66, A67, and A80) were collected and analyzed based on Chan's diagnostic plots.

II. MATERIAL AND METHODOLOGYS

A. Field Overview

Abu-Attifel is located in the Sirte basin, about 300 kilometers southeast of Benghazi, just east of Jalu, as shown in Figure 3. The Abu-Attifel oil field is one of the richest and best-known oil fields in Libya; in fact, it was the first "giant oil field" discovered in Libya by ENI, which is the largest foreign player active in the country. It was discovered in the late 1960s, specifically in 1967 in the Sirte Basin [9]. About 300 km south-east of the major city of Benghazi, just east of Jalu, with an average depth of 13780 ft, the first explorative well was completed in March 1968, and it was put into production in the year 1972. The oil-bearing zone extends for about 60 kilometers. The oil production began with 14 wells, with the reservoir section having an average thickness of 820 ft. at an average depth of 13795 ft. The early-phase production caused by natural reservoir energy depletion confirmed what had been suspected, namely a lack of water drive to the bottom aquifer's limited volume [8]. After a strong depletion phase, water injection was set up and started in the Abu-Attifel field in 1974. A row of wells were drilled along the northern border of the field, which helped increase production considerably [9], [10].

Position the figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be centered below the figures; table captions should be centered above. Avoid placing figures and tables before their first mention in the text. Use the abbreviation "Figure. 1," even at the beginning of a sentence.

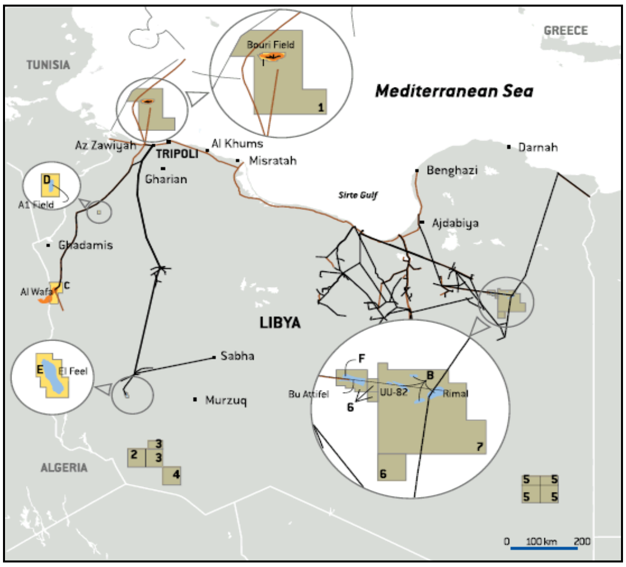

Figure 3. Location of Abu-Attifel oil field in Libya [9].

The Abu-Attifel Field trapping system is formed by a large northerly tilted fault block located in the central part of the Hameimat Trough; a northwest-southeast trending fault borders the field on its southwestern edge. It is limited on alt Bides by faults and with a low dip of 5° to the North. Another significant tectonic feature, an anti-Siberian trending fault, separates the field's main area from the west area. The synrift clastic depositional sequence of the Upper Nubian Sandstone (Lower Cretaceous) represents the reservoir unit; it is at an average depth of 15,000 ft and is one of the deepest commercially oil-producing reservoirs in Libya. Figure 4 shows the structural map of the entire field.

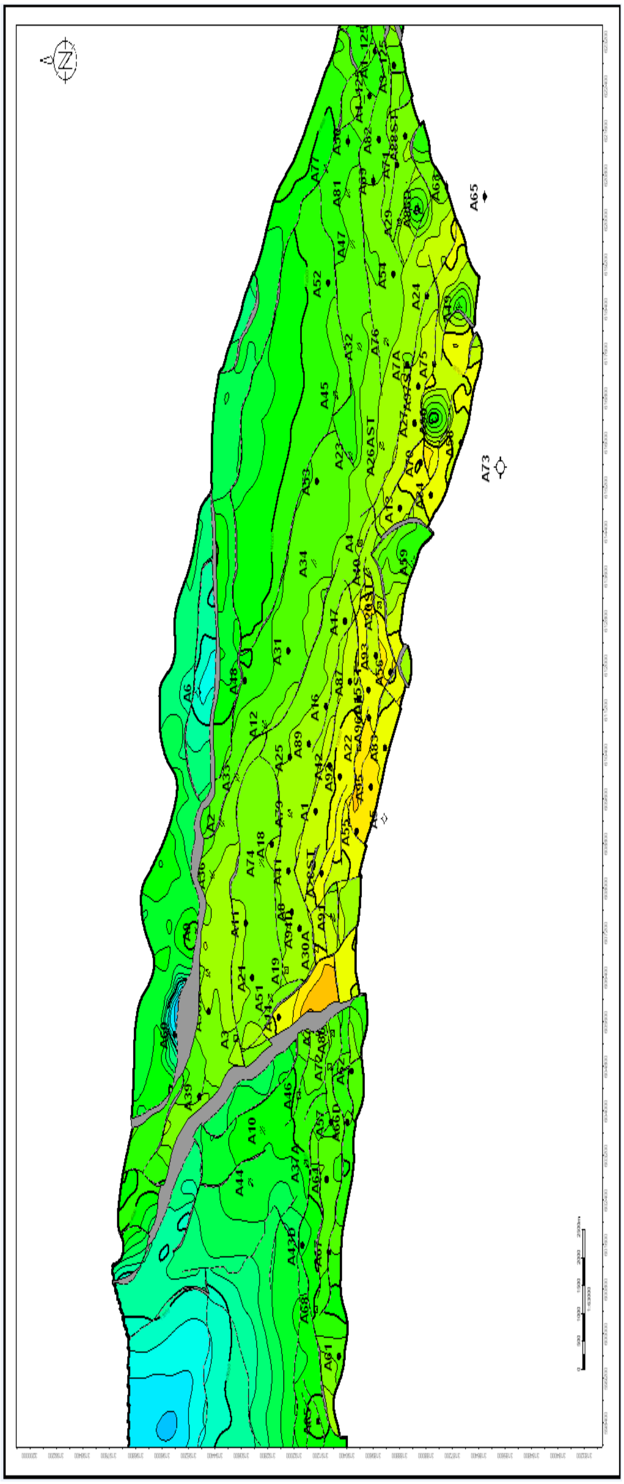

Figure 4. A structural map of the entire field [9].

The oil-bearing rock is a fine to coarse-grained sandstone with interbedded shale and shaly-siltstones; fit ranges in net thickness from 246 ft – 820 ft (75 to 250 m). The quality of this reservoir is quite impressive, with porosity ranging from 20 to 28 percent. The horizontal permeability spans from a few mD to more than 1000 mD, and the anisotropy ratio (vertical permeability/horizontal permeability) ranges from 0.48 to 1.23. The initial water saturation, which correlates quite well with the local porosity, averages 16% [8]. Its OOIP is estimated at some 3.9 MMMbbl (620 Mm^3). The oil production comes from Upper Nubian sandstones, a formation of a Lower Cretaceous age whose depth goes from 12750 – 14226 ft (3886 to 4336 m) S.S.L (SubSea Level).

At discovery, a bubble point variation with the depth was recognized, but the oil resulted under saturated at the initial pressure of 6904 psia (47.6 MPa) through the entire field. The crude has a 41 °API gravity; its base is paraffinic at high wax content (36.7%) with an upper pour point of 39 °C [8]. Table 1 lists the basic reservoir fluid properties [9], [10].

Table 1. Reservoir fluid properties [9].

Property	Main Area	West Area	Unit
Datum	13800	14150	ft (sub-sea level)
Reservoir Temperature	292.1	305.1	°F
Reservoir Pressure	6899.5	6613.7	psia
Bubble Point Pressure	5946	6605	psia
Solution Gas	2.36	1.76	Mscf/stb
Gas Formation Volume Factor	0.70	0.68	rb/Mscf
Reservoir Oil Viscosity	0.16	0.29	cp
Reservoir Oil Density	52.6	53.6	lb/cf
Oil Formation Volume Factor	2.41	2.06	rb/stb
Stock Tank Oil Gravity	41		°API
CO_2 Content (in reservoir oil)	3.06	4.26	%
H_2S Content (in reservoir oil)	0.00		%
Sulfur Content (in reservoir oil)	0.04		%

B. Diagnostic plot

Several methods can be useful in the identification of the source and nature of excess water production. In this study, the plot used is the Chan plot, which helps determine the reason behind the excessive water production.

In 1995, Chan's developed a methodology that can be used to quickly diagnose the mechanisms [11]. It uses the following data:

1. Production history of the entire period of water flood
2. WOR and its derivates
3. Cumulative oil produced or recovery efficiency – Oil and gas rate declines

Log-log plots of the WOR (rather than water cut) versus time were found to be more effective in identifying production trends and problem mechanisms. It was discovered that derivatives of the WOR versus time can be used for differentiating whether the excessive water production problem seen in a well is due to water coning or multilayer channeling [11]. The derivative value of the water/oil ratio (WOR) is calculated by equation (1) as follows:

$$WOR' = \frac{dWOR}{dt} = \frac{WOR_2 - WOR_1}{t_2 - t_1} \quad (1)$$

Figure 5 shows that the water breakthrough earlier during coning because in channel mode, due to parameters such as permeability and how the fluid saturation distribution affects the velocity of fluid flow in the channel, it delays the breakage. According to the graph lines, when the coning phenomenon occurs, the increase in water production is less than in the channeling mode. This is due to the radial expansion of the coning relative to its vertical expansion.

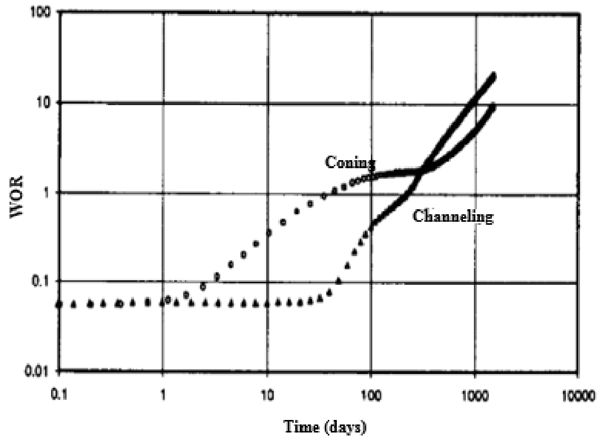

Figure 5. Water coning and channelling WOR comparison [11].

Chan (1995) also investigated the behavior of the time derivative of WOR (WOR') for channeling and coning mechanisms [11]. Coning WOR' shows a changing negative slope, while channeling WOR' exhibits an almost constant positive slope (Figures 6 and 7). Chan pointed out that the production changes could affect the appearance of the diagnostic plots, as shown in Figure 8. These changes could be a change in drawdown pressure at the production well, and changes in the injection rate and layer injection distribution at the associated injection wells. For more details and discussion, see the original paper by Chan (SPE-30775).

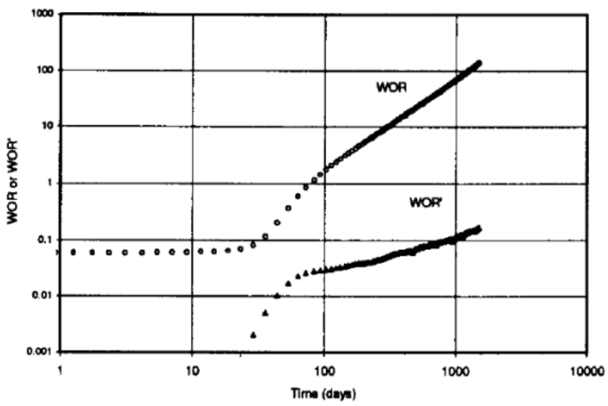

Figure 6. Multi-layer channelling WOR and WOR derivatives [11].

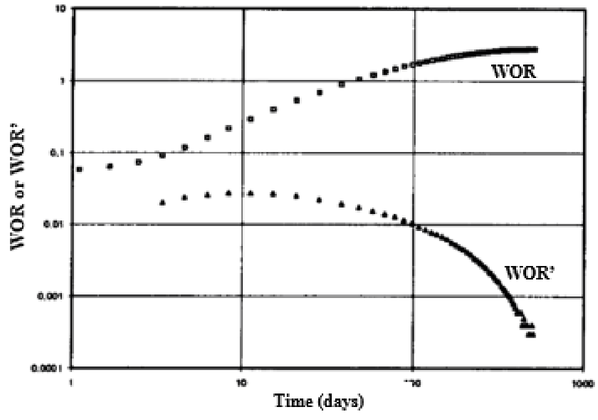

Figure 7. Bottom-water coning WOR and WOR derivatives [11].

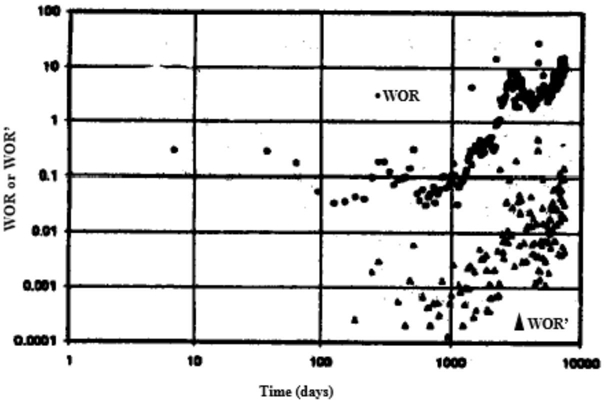

Figure 8. Multilyer channelling with production changes [11].

III. RESULTS AND DISCUSSION

After a thorough well-by-well analysis of the historical production and its effect on water production, the well diagnostic process analysis using Chan's techniques was applied to the Abu-Attifel oil field for both the main and west areas.

The results of the diagnostic analysis are shown in Figures 9 to 15. The diagnostic plots showed some random and noisy trends on both the WOR and WOR' plots; hence, they provide a controversial basis for characterizing water production based on surface observation of production trends. The WOR and WOR derivative points are generally moving upward. The authors think that multilayer channeling with production changes could be one reason for such excessive water production. The production changes are due to changes in the drawdown pressure in each layer, as water injection has been applied in this field since 1974. Such results need to be verified by close monitoring using production logging tools (PLT) and well testing techniques to ensure breakthrough time and identify the main reasons for excessive water production.

Recently, the use of Chan's WOR diagnostic plots has received significant interest in the oil and gas industry. However, the applications of the diagnostic plot to field data have indicated their limitations, especially the use of derivative plots with noisy production data. There is therefore a need to determine the validity of using these plots as a diagnostic method and see if they can be fine-tuned. Further analysis of the produced water via channeling would help determine if it is coming from the injection wells or from another source. Each problem type usually requires a different approach to control and remediate the related problem. These different approaches or techniques are applied depending on the type of problem, the extent of the problem, the geological structure of the subsurface, the type of fluid, and reservoir behavior.

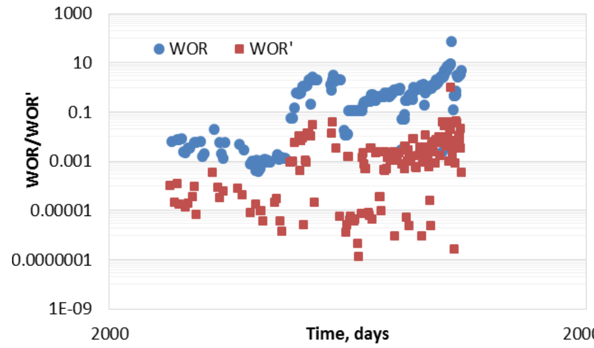

Figure 9. **Well A1**

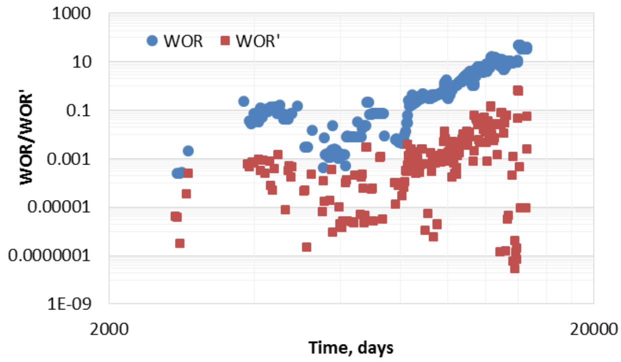

Figure 10. Well A3

Figure 11. Well A4

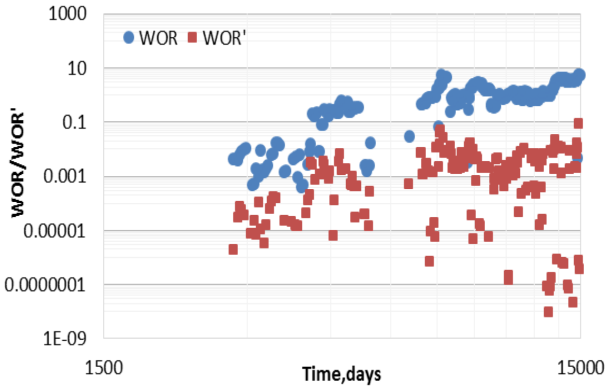

Figure 12. Well A7

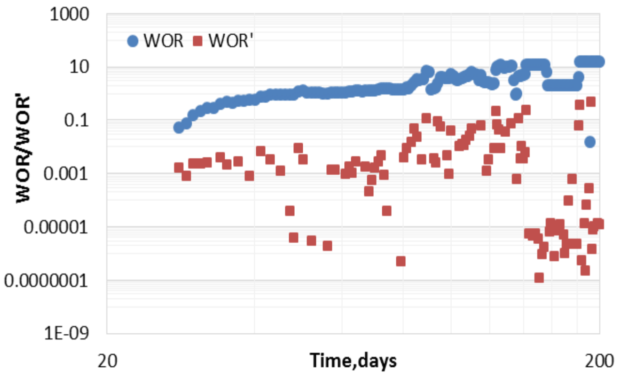

Figure 13. Well A64

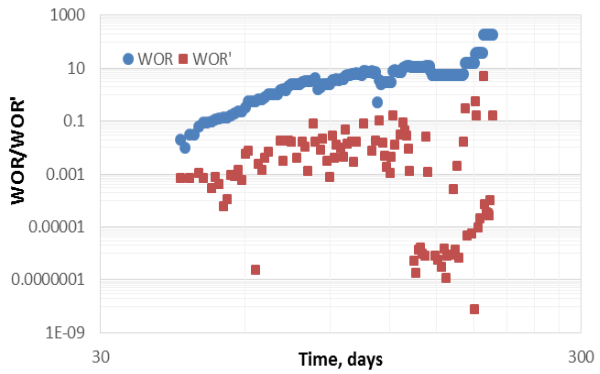

Figure 14. Well A66

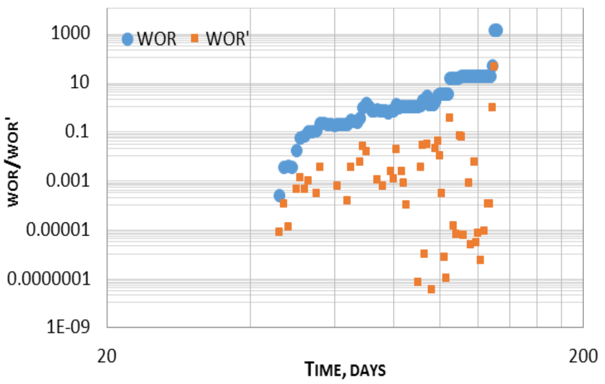

Figure 15. Well A80

IV. CONCLUSIONS

Excess water production not only negatively affects the oil production rate but also entails costly and time-consuming water management operations, from remedial actions in oil wells and oil fields to environmental considerations for waste water disposal. This study applies Chan's methodology, which can be used to quickly diagnose and evaluate water production mechanisms. Based on the dataset analyzed in this study, the following conclusions are drawn:

[1] The Abu-Attifel oil field is supported by water injection from the early period of the field and produces large quantities of produced water daily. The studied wells were located in a sandstone reservoir with high vertical and horizontal permeability and high water saturation in the formation.

[2] The diagnostic plots showed some random and noisy trends on both the WOR and WOR' plots; hence, they provide a controversial basis for characterizing water production based on surface observation of production trends.

[3] The multilayer channeling phenomenon could be one reason for the excessive water production. However, the results obtained need to be verified by close monitoring using production logging tools (PLT) and well testing techniques to ensure breakthrough time and identify the main reasons for excessive water production during the life of the well.

[4] The applications of the diagnostic plot to field data have indicated their limitations, especially the use of derivative plots with noisy production data. Therefore, the WOR diagnostic plots can be easily misinterpreted and should not be considered alone to achieve high accuracy in diagnosing the specific cause of a water production problem.

ACKNOWLEDGMENT

The authors wish to thank the Libyan Oil Corporation (NOC) and Mellitah Oil & Gas B.V for providing the data necessary to complete this work.

REFERENCES

[1] B. Bailey, M. Crabtree, J. Tyrie, J. Elphick, F. Kuchuk, C. Romano, and L. Roodhart, "*Water Control*," Oilfield Review 12, No. 1, 30, 2000.

[2] S. Seright, R.H. Lane, and R.D. Sydansk, "*A Strategy for Attacking Excess Water Production*," SPE Production & Operations, vol. 18, pp. 158–169, 2003. doi: https://doi.org/10.2118/84966-PA

[3] M. Rabiei, R. Gupta, Y.P. Cheong, and G. S. Soto, *"Excess water production diagnosis in oil fields using ensemble classifiers*," International Conference on Computational Intelligence and Software Engineering, Wuhan, China. IEEE 10.1109/CISE, pp. 1–4, 2009.

[4] R. Reynolds, "*Produced Water and Associated Issues," Petroleum* Technology Transfer Council, 2003.

[5] A., Al Hasani, A. Khayari, S. Rashid, R. Al. Maamari, and M. A. Al-Wadhahi, "*Diagnosis of excessive water production in horizontal wells using WOR plots*," International Petroleum Technology Conference, 2008.

[6] Z. Sanchez, M.A. Delgado, and V.H. Quinones, "*Water Control in Heavy-Oil Mature Field, Block 1AB*," paper SPE-108039-MS presented at the Latin American & Caribbean Petroleum Engineering Conference, Buenos Aires, Argentina, 15-18 April 2007. doi: https://doi.org/10.2118/108039-MS

[7] S. Seright, "*Improved Methods for Water Shutoff*," Final Technical Progress Report, vol. U.S. DOE Report, DOE Oklahoma 1998.

[8] M. Rabiei, R. Gupta, Y.P. Cheong, and G. A. Sanchez Soto, "*Transforming data into knowledge using data mining techniques: application in excess water production problem diagnosis in oil wells*," paper SPE-133929-MS, presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition, Brisbane, Queensland, Australia. 18-20 October 2010. doi: https://doi.org/10.2118/133929-MS

[9] MOGCO, "*Reservoir Description,"* Internal Report, Mellitah Oil & Gas B.V., Libyan Branch, Tripoli, Libya, 2019

[10] E. Causin, F. Radaelli, F. Terzi, and I. El-Ageu, "*Bu Attifel Field, Libya Gas Injection Project, Laboratory Approach*," The 9th European Symposium on Improved Oil Recovery, The Hague-The Netherlands, 1997.

[11] K.S. Chan, "*Water Control Diagnostic Plots*," paper SPE-30775 presented at the SPE Annual Technical Conference and Exhibition, Dallas, Texas, October 1995. doi: https://doi.org/10.2118/30775-MS