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Predicting Waterflooding Performance IN A-NC186 Oil FIELD

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التنبؤ بأداء طريقة حقن المياه في حقل A-NC186

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Abstract:
Waterflooding, a critical methodology in the realm of enhanced oil recovery (EOR) of Libyan oil fields, is implemented subsequent to the depletion of primary reservoir energy. Within the framework of any waterflooding undertaking, the assessments of oil recovery are typically segmented into phases pre- and post-breakthrough. Notwithstanding, the capability to prognosticate waterflood efficiency until the point of abandonment is notably constrained. The primary objective of this investigation is to project the waterflood performance leading up to abandonment in the A-NC186 oil field under a specific water-injection scenario. Through the realization of these objectives, invaluable insights can be garnered to refine reservoir management practices and elevate the efficiency of oil recovery procedures. The outcomes delineate that after 5135 days, a WOR of 82 STB/STB is attained, necessitating the discontinuation of waterflood operations. Notably, a total of 64897 STB of oil was extracted until the breakthrough occurred. The investigation underscores the profound1842859 STB of water produced until the point of abandonment.

Keywords: Waterflooding Process, Breakthrough Time, A-NC186 Oil Field, Oil Recovery.

الملخص
تُطبَّق عمليّة ضخ المياه في المكامن النفطية، وهي منهجية مهمة وفعالة في مجال استرجاع النفط المعزَّز لحقول النفط الليبية، بعد استنفاد الطاقة الأولية للخزان. ضمن الإطار الذي تَنْفَذُ فيه أي عملية ضخ المياه في الطبقات النفطية، تُقسَّم تقييمات انتاج النفط عادة إلى مراحل قبل وبعد وقت الإختراق. مع ذلك، القليل من الدراسات تنبأت بكفاءة غمر المكامن النفطية حتى نقطة التخلي، عندما يصبح الإنتاج الكلي عبارة عن ماء محقون. الهدف الأساسي لهذه الدراسة هو توقع أداء ضخ المياه في الطبقات النفطية في حقل النفط A-NC186 قبل وبعد نقطة الإختراق (إلى حين هجران البئر) تحت سيناريو حقن ماء محدد. من خلال تحقيق هذه الأهداف، يمكن الحصول على رؤى قيّمة لتنقيح ممارسات إدارة الحقول ورفع كفاءة إجراءات استرجاع النفط. توضح النتائج أنه بعد 5135 يومًا، تتحقق نسبة WOR قدرها 82 برميل برميل، مما يتطلّب إيقاف العمليّات المتعلّقة بغمر المجاري المائية. من الملحوظ أن مجموع 64897 برميل من النفط تم استخراجه حتى وقوع الكسر. تُبرز الدراسة الوافية بأنه تم إنتاج 1842859 برميل مائي حتى نقطة الهجر.

الكلمات المفتاحية: ضخ المياه في المكامن النفطية، وقت الإختراق، حقل A-NC186، النفط المنتج.

1. Introduction

In the 21st century, there has been a steady rise in the worldwide use of hydrocarbons. To meet the growing global energy needs, significant resources have been focused on enhanced oil recovery (EOR) procedures [1, 2]. Secondary oil recovery is the process wherein additional extraction is carried out through conventional methods like water and immiscible gas injection[3]. Water injection, an age-old technique in the petroleum industry, is used to enhance recovery and maintain reservoir pressure. Before initiating a secondary recovery project, it is crucial to demonstrate the insufficiency of natural recovery mechanisms to avoid wasting financial resources. Because of the complex formations and diverse reservoir characteristics, accurately modeling fluid flow in reservoirs presents a difficult challenge that varies significantly from more uniform conventional reservoirs in various aspects such as geology, petrophysics, production, and economics[4, 5].Significant progress has been made in planning, building, and supervising waterflooding activities. However, the focus primarily lies on initial stages, emphasizing the importance of continuous surveillance to ensure the success of waterflooding projects. According to the U.S. Energy Information Administration (EIA), there is a forecasted significant surge in global energy usage, with an expected 50% increase over the next two decades[5]. This remarkable growth has attracted considerable attention from various stakeholders and researchers in the field of Enhanced Oil Recovery (EOR) worldwide. Consequently, advanced techniques for recovering oil beyond primary extraction, such as water and gas injection, have been extensively studied over the past decade to meet the rising demands for oil and gas resources. The term "waterflooding" is commonly recognized as a method to broadly describe the process of injecting water into an oil reservoir to maintain pressure levels and displace and extract additional oil after reaching economic production limitations. This approach entails displacing oil and accompanying gas with water to enhance recovery rates (U.S. Energy Information Administration, 2021).

Oil reserves, which span across vast expanses of land in the Middle East, play a crucial role in meeting today's global energy demands. The region, including countries like Libya, has been a focal point of extensive exploration and extraction activities, serving as a significant source of oil production worldwide. Various secondary recovery methods are employed to improve recovery rates and enhance production efficiencies, with waterflooding emerging as one of the most widely utilized techniques in the industry [6]. Libya, situated in the northern region of the African continent, is renowned for its expansive oil reserves, which hold significant importance in the global energy landscape[7.] The implementation of waterflooding techniques in Libyan oil fields is rapidly gaining momentum, underscoring its relevance as a pivotal operation within the oil industry. Waterflooding, a widely recognized practice in the oil and gas sector, serves a crucial role in enhancing oil recovery from reservoirs by facilitating the displacement of oil through the injection of water. Commonly referred to as water injection, this process represents a key strategy for secondary recovery, aimed at maximizing oil retrieval from existing reservoirs. The introduction of water into the reservoir assists in displacing residual oil, leading to heightened extraction rates. By injecting water into the reservoir, the process effectively propels the remaining oil towards production wells, resulting in a substantial upsurge in overall oil output and enabling more efficient exploitation of this invaluable natural resource.

Waterflooding operations are conducted to ease the introduction of aqueous solutions into the rock formations of oil reservoirs without hindering fluid flow or compromising the permeability of the rocks. This requires preventing blockages from particles, dispersing oil, preventing scale deposits, controlling bacterial growth, and avoiding clay mineral swelling [8]. In Libyan oil fields, the application of waterflooding faces unique challenges due to the region's geological characteristics, necessitating a deep understanding of the reservoir's properties like permeability, porosity, and fluid behavior. While waterflooding has been widely used in oil fields globally, its specific adaptation and effectiveness in Libyan oil fields warrant further exploration. Many reservoirs in Libya have been naturally producing oil for decades, yet it is believed that these reservoirs will be crucial in implementing improved oil recovery techniques. The key to the success of oil recovery operations lies in effectively monitoring and controlling individual well performance. Recent advancements in information technology have enabled the collection and analysis of large amounts of production and injection data, offering new insights into the dynamic behavior of reservoirs over time and space. Therefore, the proficient analysis and dissemination of high-frequency field measurements are essential for the contemporary management of oil and gas recovery projects [9].

The current strategy being considered for improving performance in many exhausted oil wells in Libya involves the use of waterflooding. Some experts suggest that refracturing techniques could be essential for enhancing oil and gas output from these depleted reservoirs. However, conflicting viewpoints exist among researchers, such as [10], who argue that increasing well lateral length, adding more fracture stages, and using higher amounts of proppant may not necessarily lead to significant improvements in oil recovery compared to the costs incurred. The urgent need to prolong the operational lifespan of numerous Libyan oil fields leaves little room for choice, forcing companies to adopt secondary recovery methods to maintain production levels. As a result, waterflooding emerges as a prominent solution for revitalizing depleted oil wells and achieving temporary increases in oil extraction. Nonetheless, the installation of new injection wells comes with considerable expenses and potential risks to the environment, as highlighted by Burrows et al. (2020) [11].

Numerous investigations on waterflood processes have been conducted over the past ten years in an attempt to extract the remaining oil from underground Libyan oil reservoirs[1]. However, these studies have been relatively constrained in their focus and have failed to fully grasp the intricate nature of real-world conditions. Important factors such as the rate of water injection, the duration until initial breakthrough, and the water saturation profile, especially in the A-NC186 oil field until abonnement have not received the necessary level of scrutiny in the analysis of water saturation patterns. Evaluating the aforementioned metrics provides insights into the efficiency of the injection process and helps monitor the effectiveness of water displacement in mobilizing and displacing trapped oil. Assessing the overall waterflooding performance until abandonment is crucial to evaluating the long-term efficacy of the technique.

2. Research Methodology

2.1 Field Overview

In the southwestern region of the NC186 block, nestled within Libya's expansive Sharara desert, lies a Field that serves as a strategic catchment of the Middle Ordovician Hawaz Formation. This geological marvel boasts two distinct peaks known as A-East and A-West. The expanse of A-East was meticulously probed and evaluated through the A-01 exploratory well from October to November in the year 2000. Similarly, the characteristics of A-West were meticulously analyzed and tested through the appraisal well A-02 in the period of March to April in the year 2001. The Field was put into production in October 2003. In November 2004 the water injection was started in order to maintain the reservoir pressure and improve the ultimate oil recovery. The peripheral water injection scheme was selected considering that laterally this field has less heterogeneity of property thus guaranteeing a good connectivity in the entire field. Figure 1 shows Al-Sharara Field.

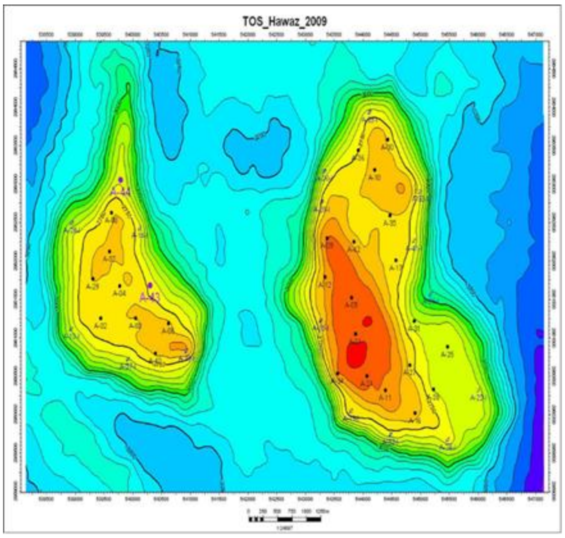

Figure 1. Al-Sharara Field Map.

2.2 Research Data

Values of water saturation (S_w), relative permeability of oil (k_{ro}) and water fraction (F_w) in the A1 well are shown in Table 1.

Table 1. Values of S_w, K_{ro}, K_{rw} and F_w of A1

S_w	k_{ro}	k_{rw}	f_W
0.100	1.000	0.000	0.000
0.300	0.373	0.070	0.2729
0.400	0.210	0.169	0.6168
0.450	0.148	0.226	0.7533
0.500	0.100	0.300	0.8571
0.550	0.061	0.376	0.9250
0.600	0.033	0.476	0.9665
0.650	0.012	0.600	0.9901
0.700	0.000	0.740	1

Table 2. Well A1 properties.

Oil formation volume factor B_o	1.20 bbl/STB
Water formation volume factor B_w	1.02 bbl/STB
Flood area	40 acres
Porosity Ø	20 %
injection rate i_w	400 bbl/day
Oil viscosity μ_o	1 cp
Water viscosity μ_w	0.5cp
Initial water saturation S_{wi}	10 %
Residual water saturation S_{or}	14%
Average permeability	31.5
Connate water saturation S_{wc}	10%
Thickness, h	5 ft
Reservoir pressure, P_r	1000 psi
Flood pattern	5 spot
Wellbore radius, r_w	1 ft

2.3 Research Steps

2.3.1 Calculation of Recovery Performance to Breakthrough

Step 1. Plot F_w vs. S_w and construct the tangent to the curve. Extrapolate the tangent to F_w=1.0 and determine S_{wBT}, F_{wBT}, $(df_w/dS_w)_{swf}$, Qi_{BT}, and S_{wBT}

Step 2. Calculate ED_{BT} by using Equation 1.

$$E_{D=}\frac{\bar{S}_{wBT}-S_{wi}}{1-S_{wi}} \tag{1}$$

Step 3. Calculate pore volume and oil volume at the start of the flood:

$$PV = 7758Ah\emptyset \tag{2}$$

Step 4. Calculate the initial oil-in-place at the start of the flood using Equation 3.

$$N_S = \frac{pv(1-S_{wi})}{B_O} \tag{3}$$

Step 5. Calculate $(N_P)_{BT}$ by applying:

$$(N_P)_{BT=}N_S E_{DBT} \tag{4}$$

Step 6. Calculate cumulative water injected at breakthrough using Equation 5.

$$w_{iBT} = (PV)Q_{iBT} \tag{5}$$

Step 7. Calculate the time to breakthrough using Equation 6.

$$T_{BT} = \frac{W_{iBT}}{i_W} \tag{6}$$

Step 8. Calculate WORs exactly at breakthrough by applying Equation 7.

$$WOR_S = \frac{B_O}{B_W\left(\frac{1}{F_W}-1\right)} \tag{7}$$

Step 9. Describe the recovery performance to breakthrough in the following tabulated form.

Table 3. Oil recovery performance to breakthrough.

T, day	$W_{inj=}iw*t$	$N_p = Wing/Bo$	$Q_o = iw/Bo$	WOR_S	$Q_W = Q_o * WOR_S$	W_P
0	0	0	0	0	0	0
	…	…	…	0	0	0
	…	…	…	0	0	0
	…	…	…	0	0	0
	…	…	…	0	0	0
	…	…	…	0	0	0
T_{BT}	…	…	…	…	…	0

2.3.2 *Calculation of Recovery Performance after Breakthrough*

Step 10. Select several values of Sw_2 between SwBt and 1- Sor.
Step 11. Determine dfw/dSw, corresponding to the S_{w2} points.
Step 12. Calculate S_{w2} avg
Step 13. Calculate the displacement efficiency E_D for each selected value of S_{w2} using Equation 1.
Step 14. Calculate cumulative oil production Np for each selected value of S_{w2}.
Step 15. Determine pore volumes of water injected, Qi, for each selected value of Sw2 from the following Equation $Qi = \frac{B_O}{Bw\left(\frac{dfw}{dSw}\right)Sw_2}$ (9)
Step 16. Calculate cumulative water injected for each selected value of Sw2 from the following Equation $W_i = (PV)Q_iE_A\ Ev$ (*10*)
Step 17. Calculate cumulative water injected for each selected value of Sw2 by applying Equation 11. Notice that E_A and E_V are equal to 100%.

$$W_{ing} = (PV)Q_i \quad (11)$$

Step 18. Use the constant water-injection rate to calculate the time to inject W_{inj} barrels of water by applying Equation 12.

$$T_{BT} = \frac{W_{ing}}{i_W} \quad (12)$$

Step 19. Calculate cumulative water production WP at any time t from the material balance equation, which states that the cumulative water injected at any time will displace an equivalent volume of oil and water.

$$W_p = \frac{(W_{ing} - NpBo)}{Bw} \quad (13)$$

or equivalently in a more generalized form: $E_{D=}\frac{W_{ing} - \bar{S}_{w2} - S_{Wi\ (PV)(EAEV)}}{Bw}$ (14)

We should emphasize that all of the above derivations are based on the that no free gas exists from the start of the flood till abandonment.
Step 20. Calculate the surface water-oil ratio WORs that corresponds to each value of f_{w2} (as determined in Step 10) from Equation 7.
Step 21. Calculate the oil and water flow rates from the following derived relationships

$$iw = QoBo + Qo * WORs * Bw \quad (15)$$

Solving for Qo gives: $Qo = \frac{iw}{B_{o+Bw}WORs}$ (16)

Step 22. The preceding calculations as described in Steps 10 through 21 can be organized in the following table:

Table 4. Calculations described in steps 10 through 21

S_{w2}	F_{w2}	dfw/dSw	$\bar{S}_{w2}$	E_D	N_p	Q_i	W_{inj}	t	W_p	WORs	Q_o	Q_w

3. Results and analysis

Using the Plot of the relative permeability ratio k_{ro}/k_{rw} vs. S_w on a semi-log paper, the coefficients a and b, intercept and slope respectively are: a = 537, b = -11.50

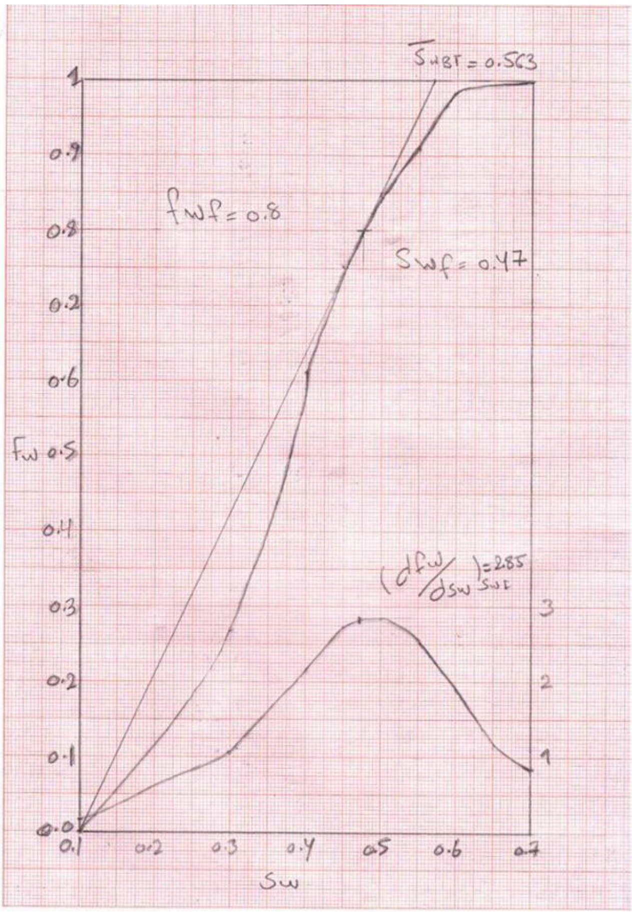

Figure 2. Water cut curve and its derivative.

Table 5. Measured values of K_{ro}, K_{rw} and d_{fw}/d_{Sw}

S_w	k_{ro}/krw		d_{fw}/d_{SW}
0.100	0.000		0.132
0.300	5.330		1.08
0.400	1.240		2.27
0.450	0.650		2.275
0.500	0.330		2.85
0.550	0.160		2.52
0.600	0.063		1.92
0.650	0.020		1.31
0.700	0.000		0.83

Table 6. Data obtained from constricting the Fractional flow curve and applying step 1 to step 7

S_{wf}	0.47
f_{wf}	0.8
$(df_w/dS_w)_{S_{wf}}$	2.85
$\overline{Sw}_{BT}$	0.563
Q_{iBT}	0.35
E_{DBT}	0.514
N_s	232740 STB
N_p	119628.36 STB
W_{iBT}	108612 bbl
t_{BT}	271.53 Days
WOR_S	4.705 STB / STB

Table 7. Recovery performance to breakthrough.

T, day	W_{inj}	N_p	Q_o	WOR_S	Q_W	W_P
0	0	0	0	0	0	0
50	20000	16666.6	333.3	0	0	0
100	40000	33333.3	333.3	0	0	0
150	60000	50000	333.3	0	0	0
200	80000	66666.6	333.3	0	0	0
250	100000	83333.3	333.3	0	0	0
271.53	108612	90510	333.3	4.705	1568.2	0

Table 8. Procedure for recovery performance after breakthrough, step 10 to step 14

S_{W2}	F_{W2}	d_{fw}/d_{sw}	Q_i	$\bar{s}_w$	E_D	N_P
0.47	0.454	2.85	0.35	0.661	0.41	95423
0.50	0.540	2.86	0.34	0.660	0.44	102405
0.60	0.787	1.92	0.52	0.710	0.55	128007
0.70	0.921	0.83	1.20	0.795	0.66	163608
0.80	0.973	0.2940	3.40	0.891	0.77	179209
0.86	0.986	0.151	6.62	0.953	0.84	145501

Table 9. Procedure for recovery performance after breakthrough, step 16 to step 2

W_{inj}	t_{day}	W_p	WOR_S	Q_o	Q_w
108612	271.51	5780	0.978	182.62	178
105508	263.7	17039	1.381	153.33	211.7
161366	403.4	76052	4.346	71.39	308.1
372384	930.97	172602	13.71	26.34	361.1
1055088	2637	823565	42.39	9.001	381.5
2054318	5135.79	1842859	82.85	4.667	386.6

4. Conclusion

The contribution of this work is to develop a better understanding of how waterflooding operations can conducted the A-NC186 oil field. The effect of waterflooding modes on bypassed-oil recovery was subsequently considered. The following are the major findings from this study:

1. The study successfully predicted the waterflood performance leading up to abandonment at a Water-Oil Ratio (WOR) of 82 STB/STB.
2. The research findings demonstrated that recovery performance before and after breakthrough are 90510 and 145501, respectively.
3. Internal mapping of the cores preceding and following waterflooding would enhance our contribution. Thus, additional research using CAT or acoustic scanning can provide appreciated insights to better validate the research findings.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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