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Reservoir Modelling and Production Forecasting for Zubair Formation in the Kifl Field

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Abstract

Kifl is a small exploratory field located in central Iraq. This field was not developed, and the reservoir behavior under production conditions was not explored. Building a reservoir model is essential in developing an oil field as it enables the prediction of reservoir performance under different production conditions. This study focused on constructing a reservoir model for the Zubair formation in the Kifl field using available reservoir data and empirical equations to fill in any gaps and then developing the field by suggesting production scenarios. It is important to validate the model to ensure its accuracy before using it in the development plan. The reservoir model was initialized with primary data, such as initial pressure, fluid properties, and datum depth. The model was validated using well-test data of well KF-4 to match the amount of oil and water produced and bottom-hole pressure. Finally, several production scenarios were proposed, involving drilling vertical, horizontal, and single lateral wells, with production gradually increasing in each case. The five cases proposed for field oil production are 3166, 5000, 10000, 15000, and 20000 STB/d, and the production stability was monitored over the proposed development period.

Keywords: Kifl oil field, development plan, well-test, theoretical equations, Zubair reservoir.

نمذجة المكامن والتنبؤ بالانتاج لتكوين الزبير في حقل الكفل

فرح طه عبد الله*، محمد صالح الجواد
قسم هندسة النفط، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

حقل الكفل النفطي حقل استكشافي يقع في وسط العراق يصنف على انه حقل صغير لم يطور هذا الحقل ولم تتم دراسة السلوك المكمني للحقل تحت الظروف الانتاجية .نتناول في هذه الدراسة بناء نموذج مكمني هو الخطوة الأكثر أهمية في التخطيط لتطوير حقل نفطي، حيث يتيح التنبؤ بأداء المكمن تحت ظروف تشغيل مختلفة. ركزت هذه الدراسة على إنشاء نموذج لمكمن الزبير في حقل الكفل النفطي باستخدام البيانات المتاحة والمعادلات التجريبية لتعويض أي نقص حاصل في البيانات ثم تطوير الحقل من خلال اقتراح سيناريوهات الإنتاج. يتعين التحقق من صحة النموذج لضمان دقته قبل استخدامه في خطة التطوير. تم تهيئة النموذج باستخدام بيانات المكمن الابتدائية ، مثل الضغط الابتدائي للمكمن وخصائص السوائل وعمق المرجع المقاس عنده الضغط. تم التحقق من النموذج باستخدام بيانات الفحص المرحلي للبئر كفل- ٤لمطابقة كمية النفط والماء المنتجة وضغط قاع البئر. أخيرا، تم اقتراح عدة خطط إنتاجية تشمل حفر آبار عمودية وأفقية

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وفرعية، حيث يتزايد الإنتاج تدريجيا في كل حالة. يتم مراقبة استقرار الإنتاج خلال فترة التطوير المقترحة في الحالات الخمس المقترحة لإنتاج النفط الميداني وهي 3166 و 5000 و 10000 و 15000 و 20000برميل في اليوم .

1. Introduction

Reservoir modelling uses mathematical equations, typically partial differential equations that consider Darcy's law, material balance, rock, and fluid properties, to represent how fluids flow through porous media [1].

The Kifl oil field is an exploratory field with a complex structure, and insufficient data is available to construct a reservoir model. However, by interpreting the structures of the seismic reflectors, it was found that there is a structural anticline in the field that extends in a northwest-southeast trend, in addition to major and minor normal faults [2].

Reservoir compartmentalization in petroleum engineering involves separating petroleum accumulation into several independent fluid and pressure compartments. This occurs due to sealed boundaries in the reservoir that prevent fluid flow [3]. In petroleum engineering, faults related to a reservoir can impact permeability and permeability anisotropy, influencing the production behavior of a reservoir with faults. According to a study by Paul et al. [4], geomechanical constraints were considered when creating the reservoir model to replicate dynamic rupture propagation. Nakajima and Schiozer's reservoir modeling with varied degrees of heterogeneity employed horizontal wells to improve the productivity of reservoirs. This approach used a numerical simulator to predict production outcomes [5].

Various methods have been employed for predicting oil production, with Decline Curve Analysis (DCA) being one of the most commonly used statistical models [6]. The Decline Curve Analysis approach has a significant limitation as it relies on interpreting the available data, which restricts the decision-maker from understanding the factors that affect the oil production rate and reservoir performance [7]. Another approach is well-test analysis, which Liu introduced, and Homea involved using small sections of constant-flow-rate data and data-mining algorithms to extract the reservoir model from variable-flow-rate and pressure-transient data [8].

Our research methodology involves constructing a dynamic model that simulates the performance of the Zubair reservoir in the Kifl field. This model considers various parameters that impact this performance, such as fluid and rock properties and production data, until reaching a reasonable reservoir model that can be used in future predictions under different development strategies.

2. Field description

The Kifl oil field is situated in central Iraq, between the governorates of Najaf and Karbala, on the western side of the Euphrates River, and spans an area of 268.7 km2. Geological and geophysical studies prepared by the O.E.C. revealed that the Kifl structure is a structural anticline with the NW-SE trend. Additionally, several subsurface faults in an NW-SE direction were identified, which separate the well Kf-1 region from the well Kf-4 region [9].

The first exploration well drilled in 1960 in the Kifl oil field showed oil in several geological formations, including the Nahr Umr and Zubair formations, with an estimated production flow rate of around 5600 barrels per day. In 1962, the Kf-2 well was drilled about

13.5 km southwest of Kf-1 but did not show any oil indicators as it was outside the structural boundaries of the field. In 1975, using the results of a seismic survey, the Kf-3 well was drilled to explore the Triassic reservoir and evaluate the hydrocarbon accumulations observed in Kf-1 [10]. In 1984, the well Kf-4 was drilled 4 km west of Kf-1, with the most extended oil column of about 3 m. The Zubair Reservoir primarily consists of sandstone, with a few shaly sand deposits during the Barremian. The thickness of the formation ranges between 442 m in well Kf-3 and 486.4m in well Kf-1 [11].

3. Methodology

3.1. Grid System

The Zubair Formation was represented by a three-dimensional grid system (283×345×26) in I, J, and K directions, where the grid is a pillar, and the total number of cells is 2538510. The reservoir is subdivided into 12 units sequences (Z1 to Z12), and the faults led to reservoir compartmentalization into six segments (Figure 1), with most of the oil accumulation in the upper part of the Z1 unit, the area between KF-1, KF-3, and KF-4. In contrast, the other units are considered to be aquifers because they are fully saturated with water.

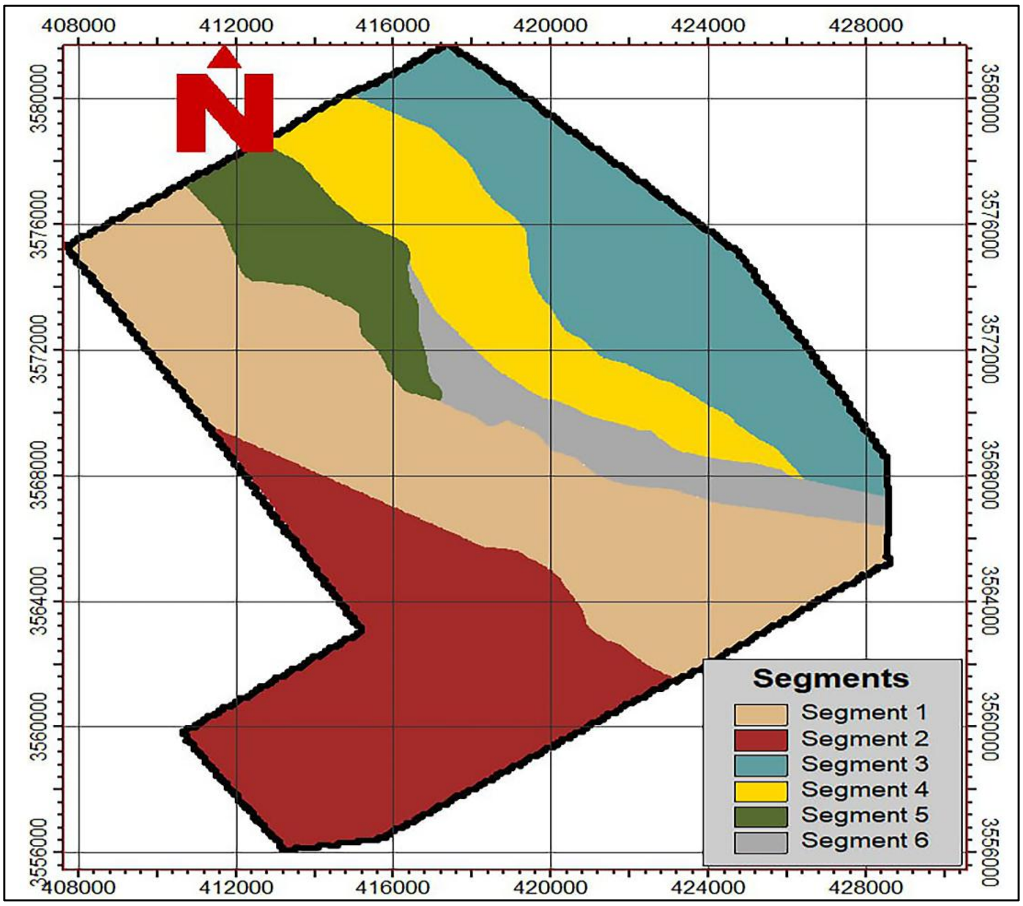

Figure 1: The segments of the Zubair reservoir.

3.2. PVT Fluid Model

The PVT report analysis of the sample obtained from well KF-4 yielded results that allowed for the identification of the fluid properties. A black oil model was constructed depending on the initial condition of the reservoir and fluid properties. Table 1 shows the initial conditions obtained from the KF-4 well at a datum depth of 1998 m, while Table 2 illustrates the PVT properties used to build the black oil model of the Zubair reservoir [12].

Table 1: The initial conditions of the fluid model in the reservoir [11].

Property	**Value**
Reservoir Pressure (psi)	3076
Reservoir temperature	170
API gravity (degree)	26.6
Bo (Rbbl/STB)	1.2399
GOR (SCF/STB)	345
Gas-specific gravity (dimensionless)	0.922475

Table 2: The PVT properties of the fluid model in the reservoir at a temperature of 170 F [11].

Pressure (psi)	**Gas to oil ratio (SCF/STB)**	**Oil formation volume factor (RB/STB)**	**Oil Viscosity (cp)**
0	0	1.0461	2.0663
142.2334331	94.21271371	1.1182	1.869665557
284.4668661	137.8941745	1.1382	1.691743355
426.7002992	171.0202181	1.1557	1.530752689
711.1671654	233.5105342	1.1823	1.253274302
995.6340315	288.5895998	1.2086	1.026094213
1223.207524	345	1.2399	0.9775
4978.170157	345	1.2023	1.573

3.3. Rock Physics function

3.3.1. Relative Permeability

As there was a lack of SCAL data for the Zubair reservoir in the Kifl field, the relative permeability curves from a nearby field were utilized with minor modifications to match the irreducible, critical, and cut-off water saturation levels in the Kifl oil field, Figure 2. The simulator was then used to import the generated curve.

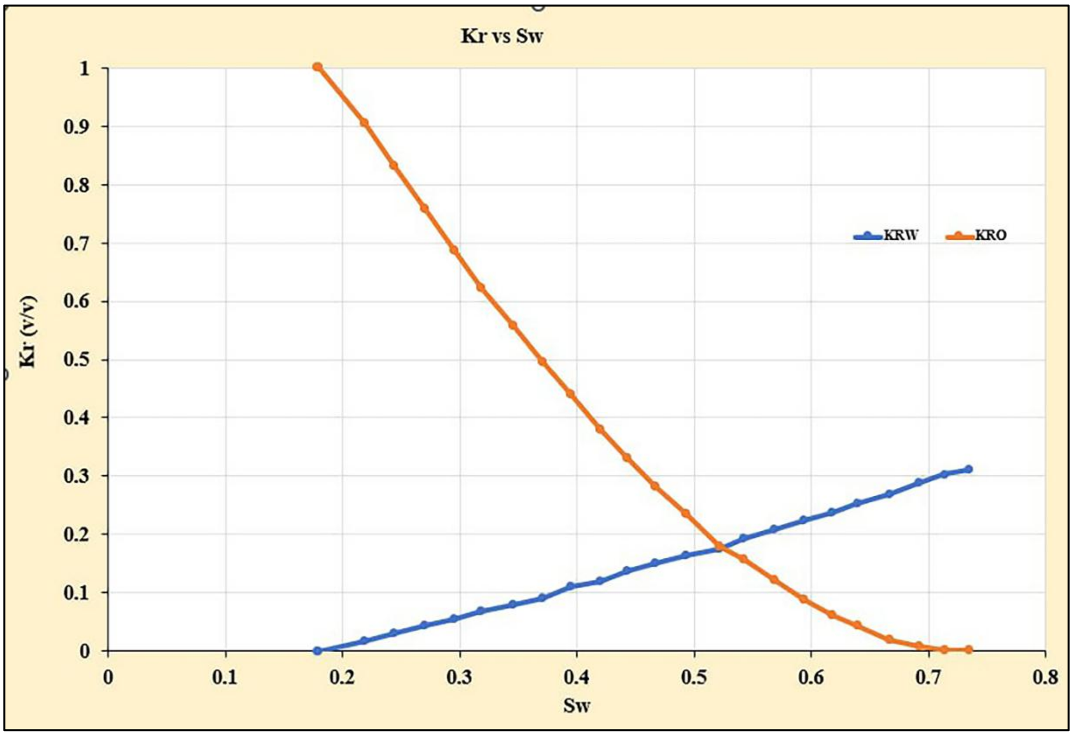

Figure 2: Relative permeability versus water saturation was used in the model.

3.3.2. Capillary Pressure

The capillary pressure data for the Zubair reservoir in the Kifl oil field was generated using the Brooks and Corey model, which establishes a linear relationship between theoretical capillary pressure and the normalized or effective wetting-phase saturation (S_w^*) when plotted on a log-log scale. The mathematical expression of this relationship is represented by Eq. (1).

$$P_c = P_e(S_w^*)^{\frac{1}{\lambda}} \quad (1)$$

$$S_w^* = \frac{S_w - S_{wr}}{1 - S_{wr}} \quad (2)$$

where P_c = capillary pressure, psi; P_e = entry capillary pressure, psi; S_w^* = normalized saturation, fraction; λ = pore size distribution index, dimensionless; S_{wr}= residual water saturation, fraction and S_w= water saturation, fraction.

The Brooks-Corey capillary pressure model states that a higher pore size distribution index indicates a homogeneous porous medium. In the case of the Zubair reservoir in the Kifl field, which is composed of sandstone, there was no available information on the pore size distribution, so a value of 1.9 was assumed to represent a homogeneous porous medium [13]. The entry capillary pressure Pe was assumed to be 0.35 psi based on the capillary pressure curve of the Zubair reservoir in the East Baghdad oil field [14]. Figure 3 shows the relationship between the water saturation (Sw*) and capillary pressure (Pc) on a log-log scale. Since not all segments have oil, the maximum Pc values were altered to modify the Pc curve for each segment. For Segment-4 and Segment-6, the maximum capillary pressure was limited to 6 psi. For Segment-2 and Segment-5, it was set to 11 psi, while for Segment-1 and Segment-3, it was not allowed to exceed 15 psi. These changes were illustrated by the curves Pc1, Pc2, and Pc3 in Figure 4.

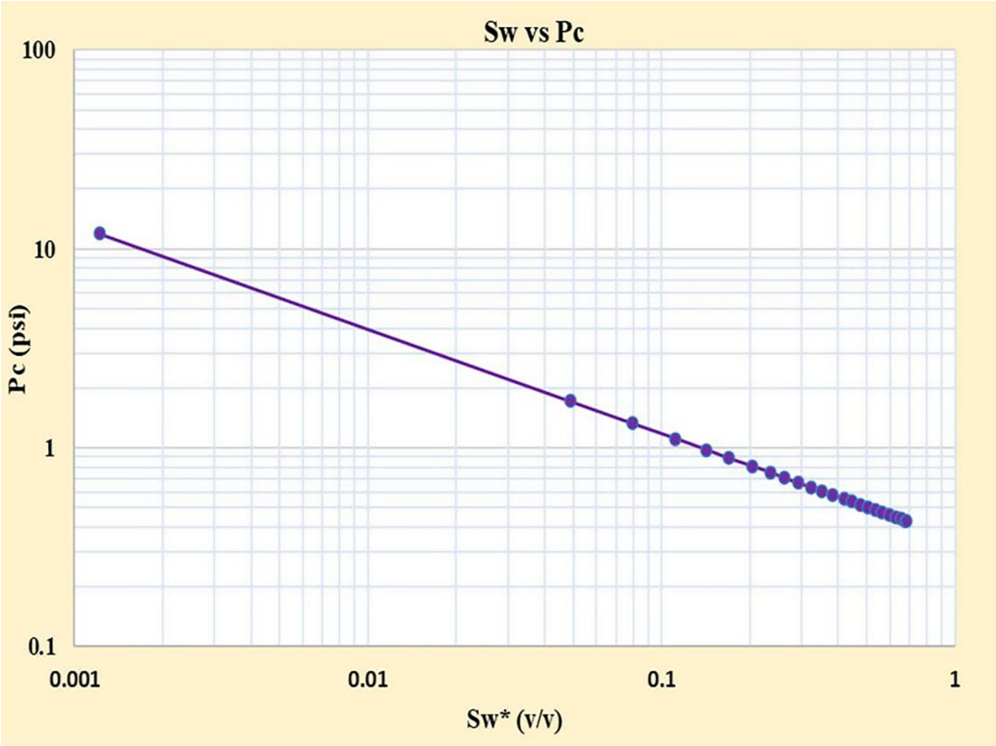

Figure 3: The calculated capillary pressure versus normalized water saturation.

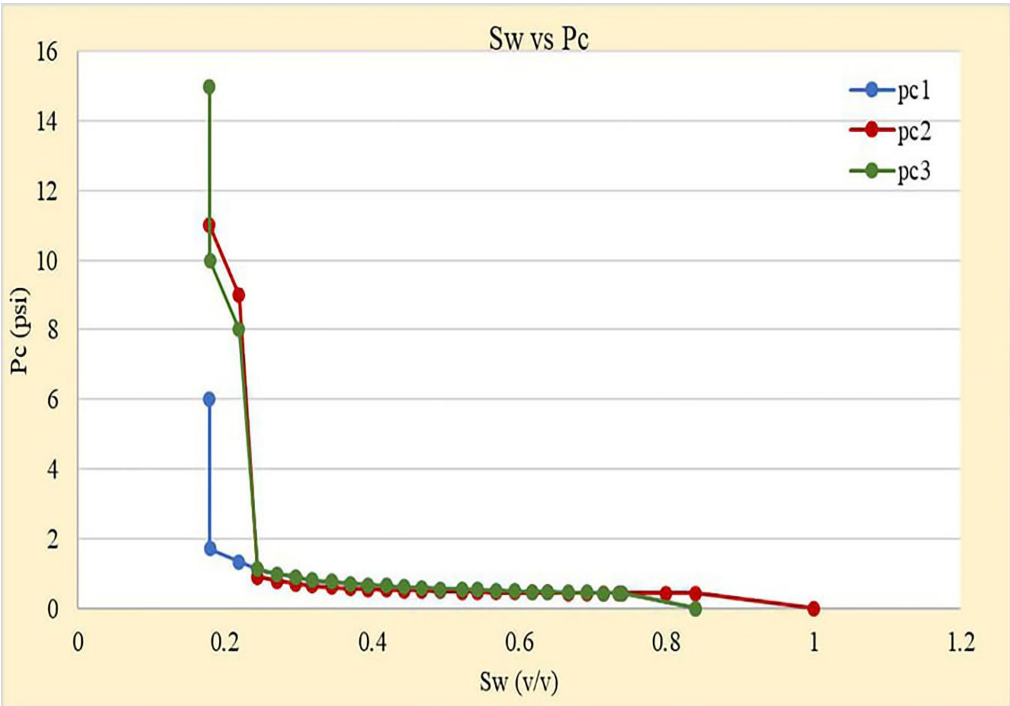

Figure 4: The capillary pressure curves were used in the model.

3.4. Aquifer model

The region of interest was defined with a top limit depth set at -1969 m, and the aquifer direction was considered in both bottom-up and grid edges (field boundary). The numerical model of the aquifer was built using a group of cells, with only the initial cell being linked to the reservoir within the field boundary. The saturation function, fluid model, porosity, absolute permeability, and transmissibility multiplier used in constructing the Zubair reservoir model were also employed for the aquifer.

3.5. Transmissibility multiplier

The Zubair reservoir in the Kifl oil field was divided into 6 segments in the geological model. Therefore, a certain value of the transmissibility multiplier must be included in the dynamic model. Since the normal faults in the Kifl field have small displacements, it is assumed that the transmissibility multiplier value is 1, and the fault behaves as a non-sealing fault [2].

4. Results and discussion

4.1. Initialization

Calculating the amount of oil initially in place (OIIP) using dynamic simulation models is crucial. In this study, the simulator employed the dynamic method, and it was determined that the OIIP for the Zubair reservoir in the Kifl field was 65 MM STB. The initial reservoir pressure distribution within the reservoir, is shown in Figure 5, where the KF-4 region has an initial pressure of 212 bar.

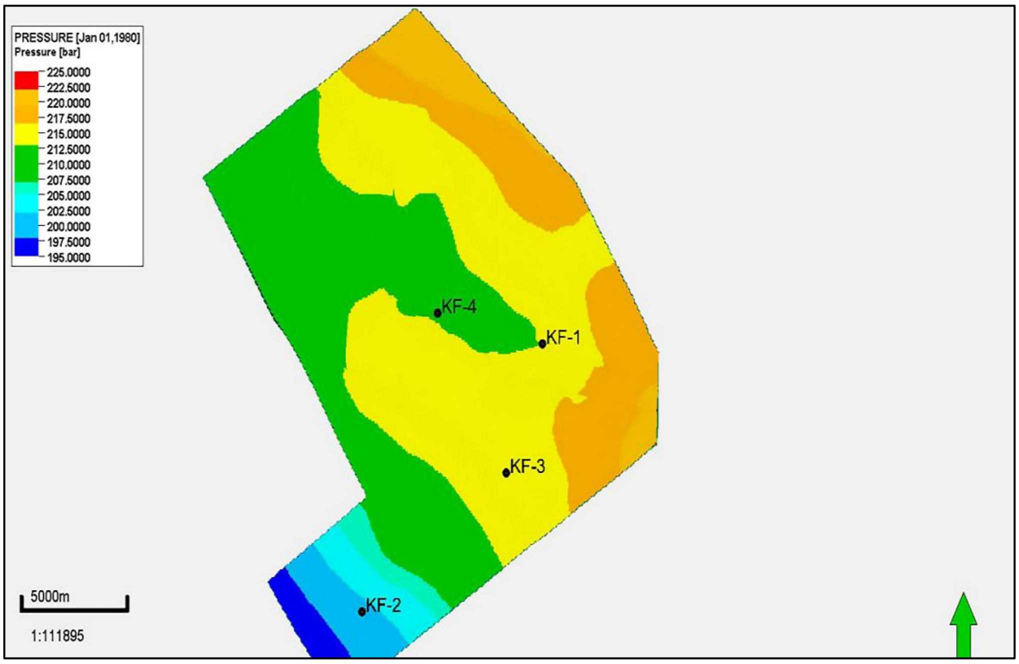

Figure 5: The top view of the model shows the initial reservoir pressure distribution within the reservoir after initialization.

4.2 History Match

The Kifl field is still in exploration and has not yet begun production. Therefore, the history-matching process relied solely on the production data results from the Drill Stem Test (DST), which provided only two days of production data, making the matching process challenging. The simulator was run multiple times, modifying the reservoir properties such as horizontal permeability and capillary pressure values until a match was achieved between the calculated data and observed historical data of the well KF-4. The bottom hole pressure, water cut, and oil production rate calculated by the simulator showed an acceptable match within the period of the observed test data, as shown in Figure 6.

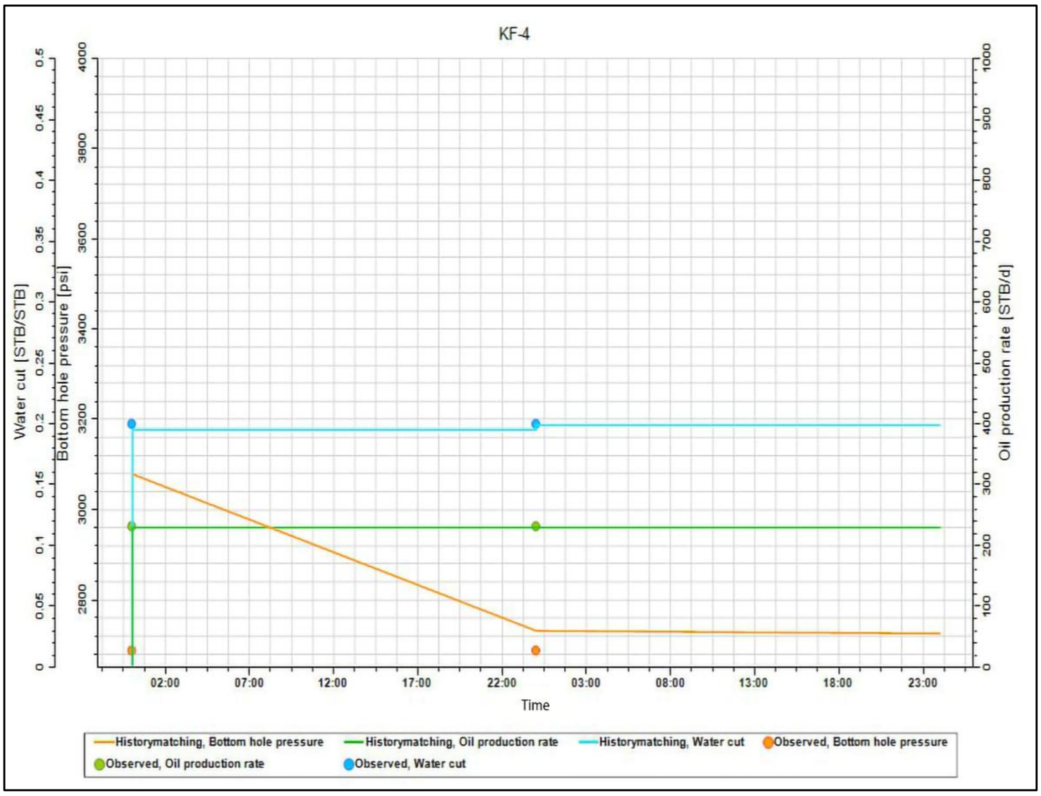

Figure 6: Results of history matching for the well Kf-4.

5.3. Prediction strategies of oil production.

The main goal of the present study was to propose various development plans for the Kifl field. The production plan involved additional wells, including vertical, horizontal, and single-lateral wells. The proposed production scenarios were subjected to constraints, such as field production rate and bottom-hole pressure. The scenarios were based on the assumption that the faults were not sealed and that the transmissibility multiplier of the faults was equal to one. The minimum bottom hole pressure was set at 1322 psi, 100 psi higher than the bubble point pressure to ensure safety. The production scenarios covered 4 years, from 2023 to 2027, and the minimum distance between drilled wells ranged from 800 m to 1000 m. The study observed the production performance under these circumstances.

Case-1: 4 Vertical wells, 3166 STB/D total production rate.

In this case, the existing four vertical wells (KF-1, KF-2, KF3, and KF-4) of the Kifl field placed in the production strategy of the field were all opened to flow with a target field oil production rate of 3166 barrels per day and a bottom hole pressure above 1322 psi. The locations of these wells are shown in Figure 7.

The production began on January 2023 and ended on January 2027. The results of this case in Figure 8 show that the field produces 3166 STB/d as the total oil production. It was found that the KF-2 well is the least productive well, so it will be excluded from the following production scenarios. The reservoir pressure dropped to 2584 psi at the end of the field life.

Case-2: 5 Vertical wells, 5000 STB/D total production rate.

In this case, the same constraints used in the basic case were used, but two vertical wells were added to bring the total number of wells to 5, as shown in Figure 9, and production rate restrictions were set for the field at 5000 STB/D for the oil production and well-pressure not less than 1322 psi, i.e., higher than the bubble pressure by 100. The results of this case are illustrated in Figure 10, which shows the field's total production is 5000 STB/D during the first three months of production, but it quickly declines after this period and continues to decline to the end of 2026 with a reservoir pressure of 2400.

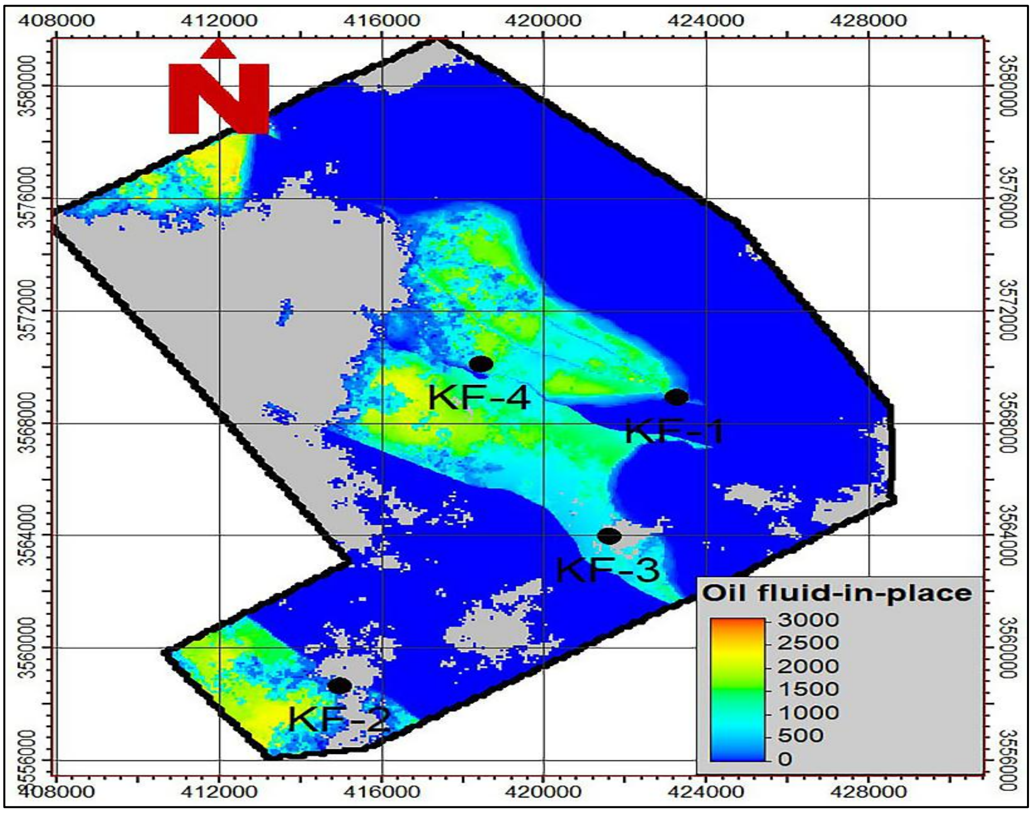

Figure 7: The locations of wells in Case-1

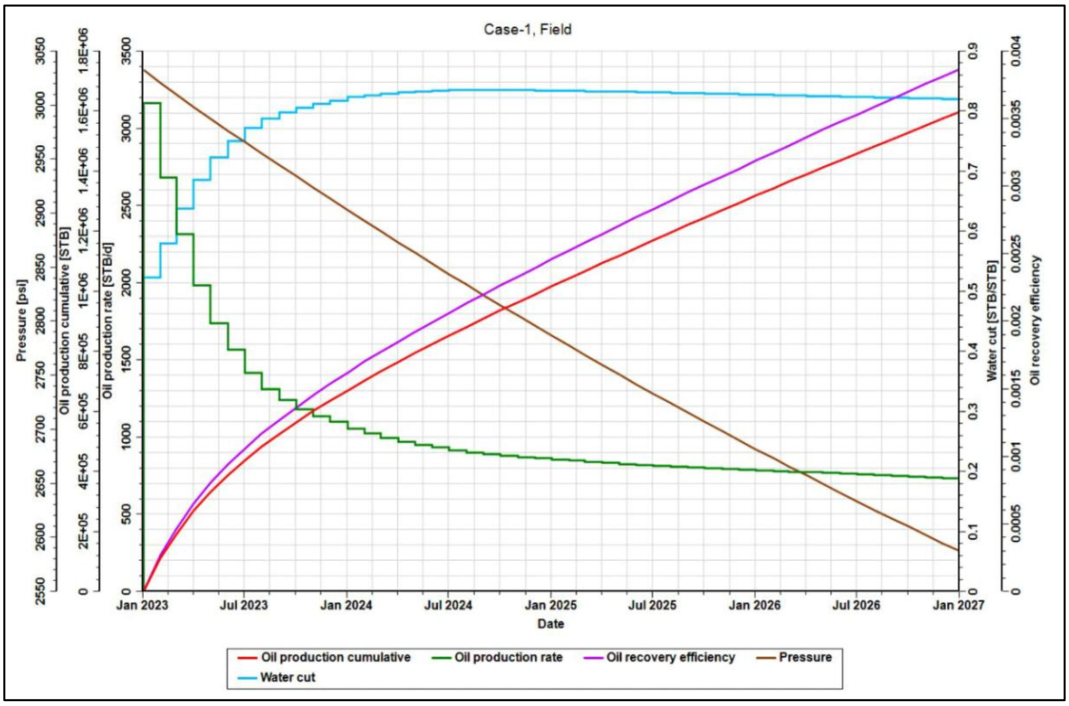

Figure 8: Oil production rate, oil production cumulative, recovery efficiency, water cut, and reservoir pressure of the field Case-1 versus Date.

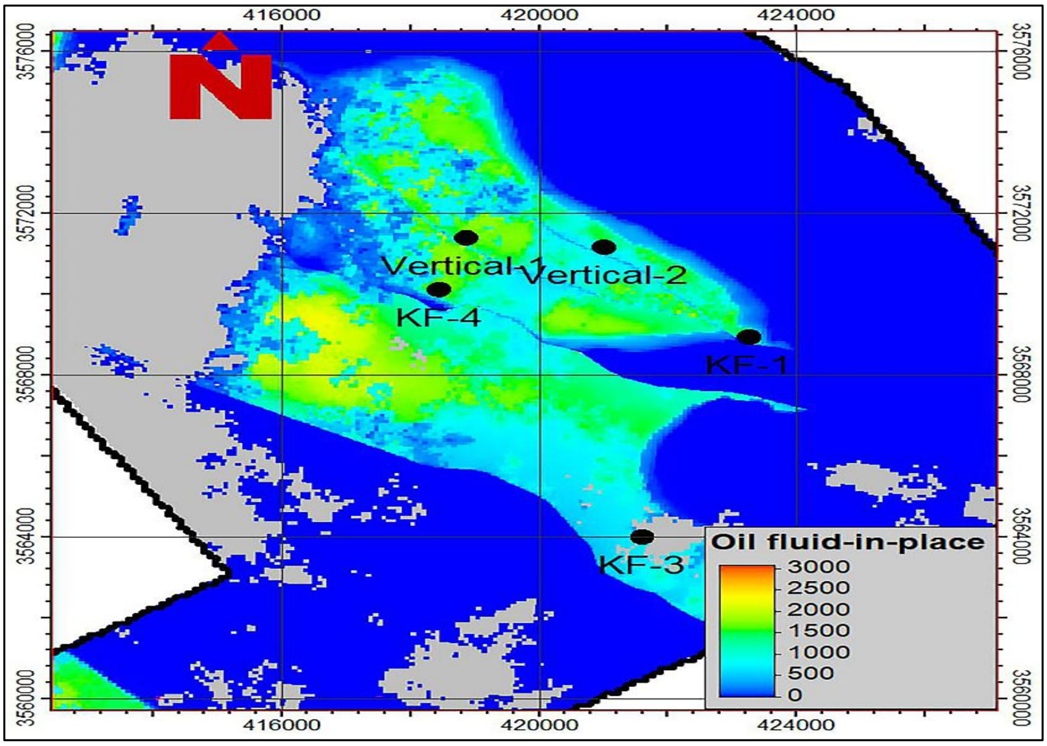

Figure 9: The locations of wells in Case-2.

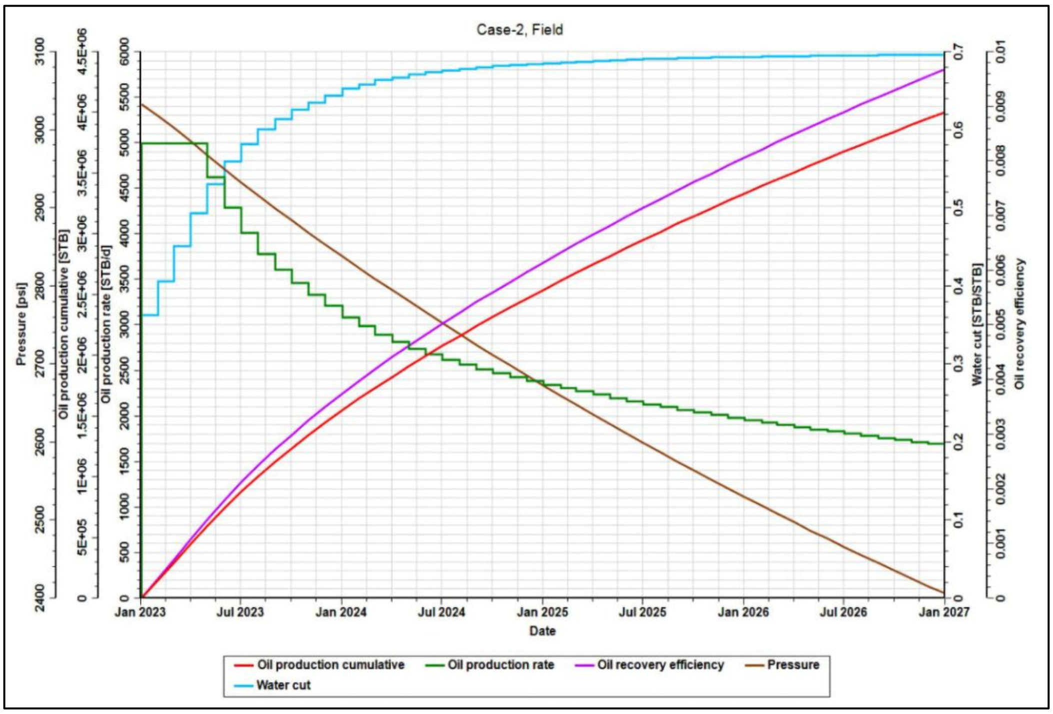

Figure 10: Oil production rate, oil production cumulative, recovery efficiency, water cut, and reservoir pressure of the field Case-2 versus Date.

Case-3: 5 Vertical wells,6 Horizontal wells 10000 STB/D total production rate.

The constraints in this scenario include well pressure control above 1322 psi and well rate control of oil production (400, 400, 1800, 500, 2400) STB/d of wells (KF-1, KF-3, KF-4, vertical-1, vertical-2), respectively, with 10000 STB/d as the target production control of the field. An additional six horizontal wells (Well 1, Well 2, Well 3, Well 4, Well 5, and Well 6) with open hole horizontal sections ranging between 700 and 1000 m were drilled in the field, as shown in Figure 11 and will be operated in 2023. The results showed that the production rate from the field continued at a rate of 10000 STB/d from January 2023 to January 2026. During this period, the water cut started at 0.14 and continued to rise, reaching 0.35 at the beginning of 2026 and a water cut of 0.38 at the end of 2026, and the reservoir pressure was recorded at 1900 psi, as shown in Figure 12.

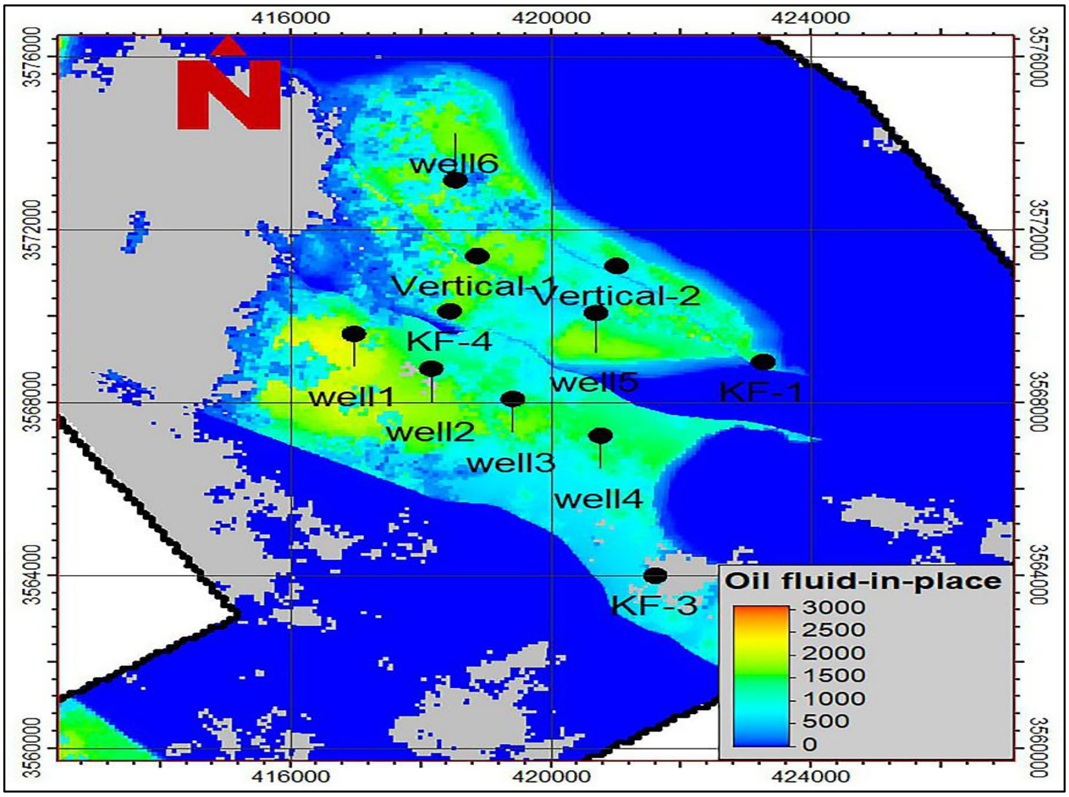

Figure 11: The locations of wells in Case-3.

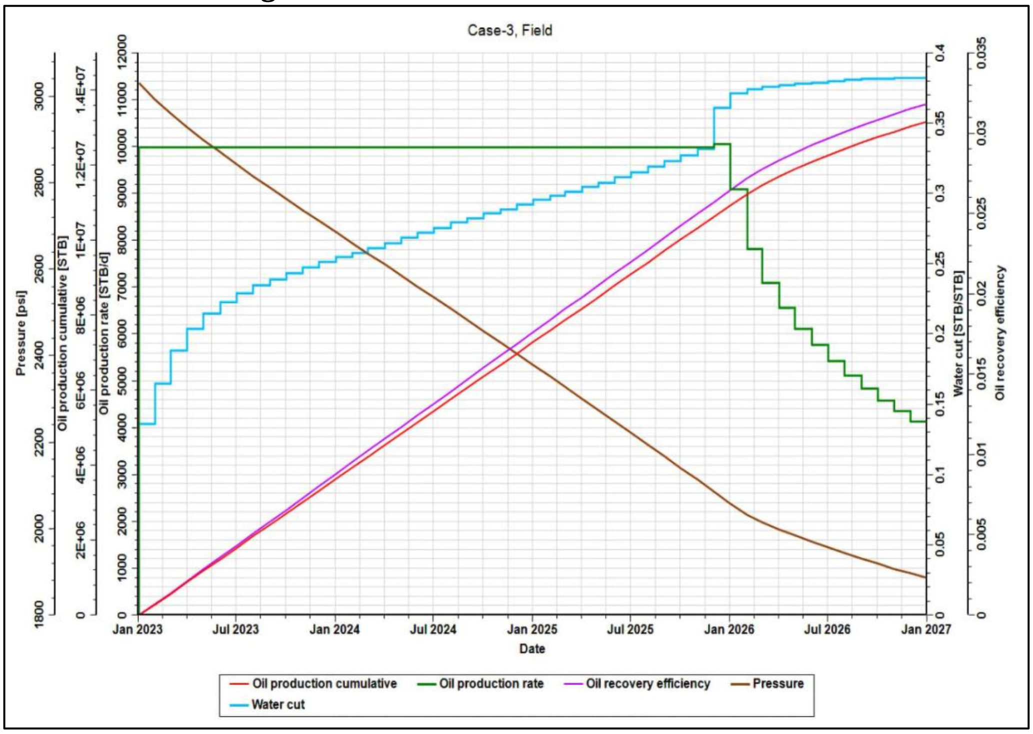

Figure 12: Oil production rate, oil production cumulative, recovery efficiency, water cut, and reservoir pressure of the field Case-3 versus Date.

Case-4: 5 Vertical wells,6 Horizontal well 15000 STB/D total production rate.

The main objectives of this case are to increase the production rate from the Zubair reservoir by increasing the control oil rate of the field. This case is the same as Case 3; the reservoir's productivity was raised to 15000 STB/D for 4 years with the same number of wells as in Case-3. The resulting charts showed that the daily production from the reservoir increased and reached 15 thousand barrels per day, but this high rate of production continued until September of 2024, so it quickly began to fall to its lowest levels and continued to decline until the end of the production period in 2026. Also, the value of the recovery factor increased to 0.038 compared to 0.036 in Case-3, meaning a slight increase in the cumulative oil production as shown in Figure 13.

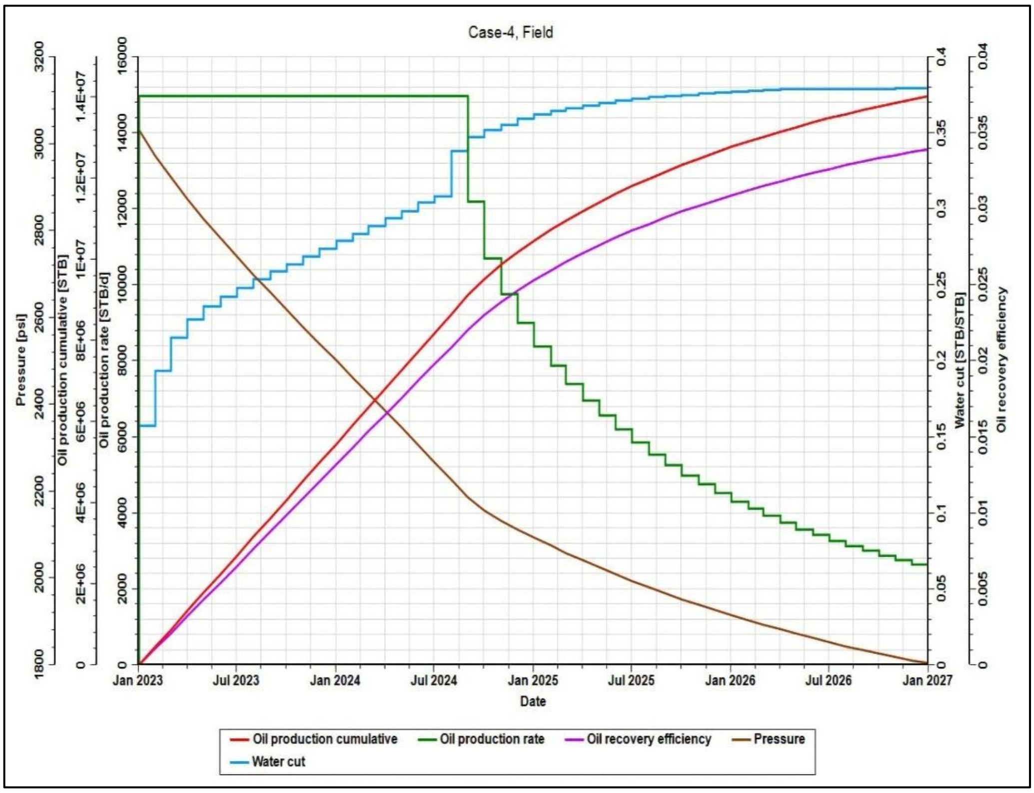

Figure 13: Oil production rate, oil production cumulative, recovery efficiency, water cut, and reservoir pressure of the field Case-4 versus Date.

Case-5: 5 Vertical wells,2 Horizontal wells, and 4 single lateral wells 20000STB/D total production rate.

In this case, four single lateral horizontal wells (L-well1, L-well2, L-well3, and L-well4) branched from well-1, well-2, well-3, and well-4, respectively and their open hole horizontal section ranged between 700 m and 1000 m in the opposite azimuth and opened to flow from January 2023 to January 2027. In this case, the total number of wells became 11, as shown in Figure 14.

According to the results of Case-5 shown in Figure 15, the production from the field at 20000 STB/d continues for one year, from January 2023 to January 2024, after which it will gradually decline until it reaches 2000 barrels per day in December 2026, a total cumulative oil production value of 1.42 MM STB and a recovery factor of 0.035.

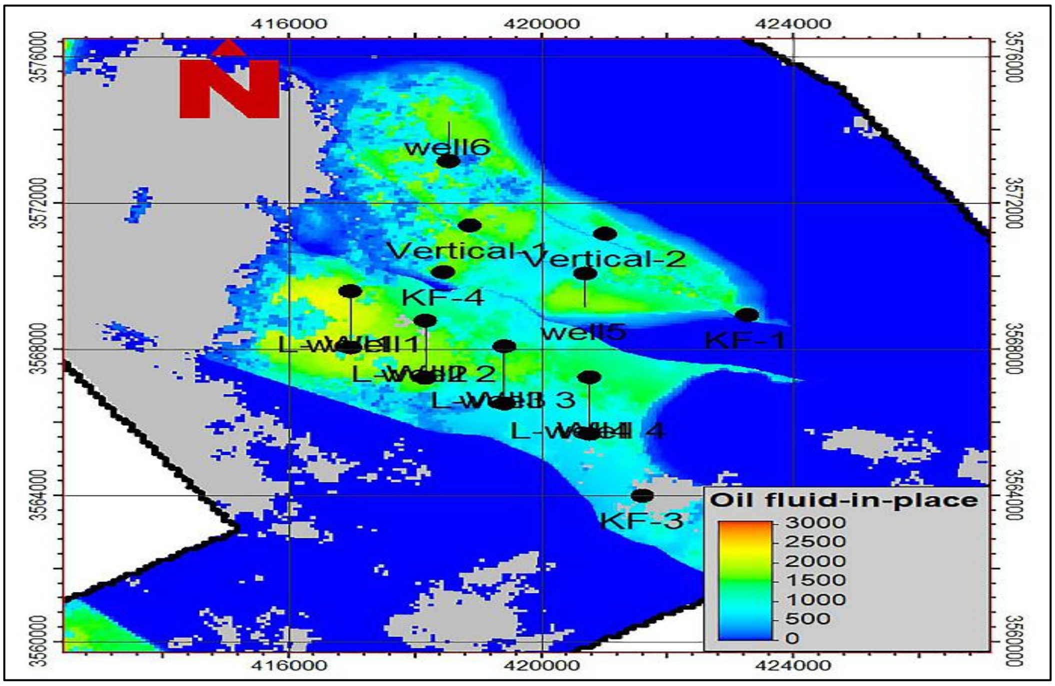

Figure 14: The locations of wells in Case-5

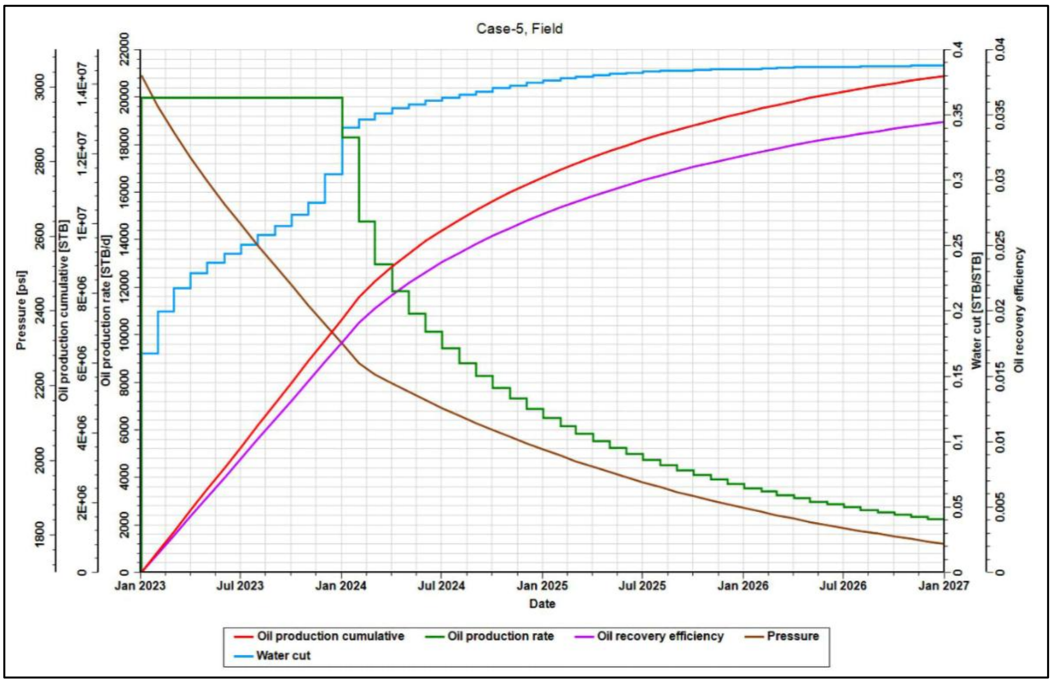

Figure 15: Oil production rate, oil production cumulative, recovery efficiency, water cut, and reservoir pressure of the field Case-5 versus Date .

5. Conclusions

The Results led to several significant conclusions that helped explain the Zubair reservoir's production behaviour in the Kifl field under bottom-hole pressure and field production rate constraints. These conclusions outline below:

1- The OIIP was calculated from the reservoir model based on the water saturation resulting from the pc curve and rock compressibility, where its value was equal to 65 MMSTB.

2- The water drive mechanism primarily drives the reservoir because it has a robust bottom aquifer.

3- By modifying the horizontal permeability of the region around KF-4 and capillary pressure, the oil production rate, bottom hole pressure, and water cut of the KF-4 well were closely matched.

4- Among the proposed scenarios, Case-3, which includes 11 wells (6 horizontal and 5 vertical), was chosen as the optimum production due to its consistent production stability of 10 MSTB/d over three years, the most stable among all the proposed scenarios.

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