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The Optimum Reservoir Performance of Nahr Umr/Ratawi Oil Field

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ABSTRACT

Reservoir study has been developed in order to get a full interesting of the Nahr Umr formation in Ratawi oil field. Oil in place has been calculated for Nahr Umr which was 2981.37 MM BBL. Several runs have been performed to get matching between measured and calculated of oil production data and well test pressure. In order to get the optimum performance of Nahr Umr many strategies have been proposed in this study where vertical and horizontal wells were involved in addition to different production rates. The reservoir was first assumed to be developed with vertical wells only using production rate of (80000–125000) STB/day. The reservoir is also proposed to produce using horizontal wells besides vertical wells with production rate of (80000-150000) STB/day. The best strategy was by adding 33 new vertical wells and 5 horizontal wells beside the 11 existing wells where the results show oil plateau of 9 years and 7 months and recovery factor of 3.4%.

Key Words: reservoir model, matching, development strategies.

افضل ادائية لمكن نهر عمر مكمن نهر عمر-حقل رطاوي/بصرة

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الخلاصة

تشمل الدراسة بناء موديل مكمني لمكمن نهر عمر في حقل رطاوي في البصرة الغرض منه تطوير المكمن. من خلال دراسة المكمن تم ايجاد الاحتياطي النفطي لطبقة نهر و الذي يساوي2981.37 مليون برميل. عملية المطابقة بين البيانات المحسوبة والمقاسة قد تكررت عدة مرات لكي يتم الحصول على تطابق تام لبيانات انتاج النفط وتطابق

جيد لبيانات الضغط. للحصول على افضل اداء لنهر عمر العديد من الخطط قد اقترحت لهذا المكمن متضمنة عدة ابار عمودية وافقية مع معدلات انتاج مختلفة. لغرض الحصول على افضل طريقة بالبداية افترض استخدام الابار العمودية فقط مع معدلات انتاج تتراوح (80000-125000) برميل باليوم.بالاظافة الى افتراض استحدام الابار الافقية بجانب الابار العمودية مع انتاج يتراوح (80000-150000) برميل باليوم. افضل خطة كانت في الاعتماد على الابار الحالية (11 بئر) مع اقتراح حفر 33 بئرعمودي مع 5 ابار افقية وتشغيلها على انتاج 150000برميل باليوم وقد اعطت معدل انتاج ثابت لمدة 9 سنة و7 اشهر مع تسبة قاطع ماء 71% ومعدل استخلاص 3.4% .

**الكلمات الرئيسية:** الموديل المكمني, المطابقة, الخطط التطويرية.

1. INTRODUCTION

Reservoir simulation may be defined as a tool used to predict reservoir performance in the future using multiple keys like mathematics, physics, reservoir managing, and programming by a computer. The simulation becomes unrivaled method to describe complex heterogeneous reservoir with multiple phases. **(Alruri, et al., 2015)** studied the reservoir model of Ratawi oil field of Fawaris formation in Saudi Arabia. The study includes estimating oil in place and distributing of remaining oil. The study used dynamic model to identify the infill and injection wells. **(Dogru 2019)** simulated fluid flow in a reservoir and well production rates with horizontal well or by multiple vertical wells. (**Alireza Mollaei and Mojdeh Delshad, 2019**) proposed water injection in order to increase production and pressure maintenance. Also predicting the performance of reservoir with water flooding in future was included in this study. History matching gave good agreement between field data and forecasting results. To get optimum performance in this study several steps have been proposed.

2. RESERVOIR MODEL

Reservoir model was built using Petrel software 2015.1 Re, **(Schlumberger, 2018)** which was the gate to export the model to black oil Eclipse 100 system where the total grid after building the model was 454308 cells. To get the goal of this study many data was required like fluid properties (oil density, oil formation volume factor …etc), special core analysis data, initial conditions, irreducible water saturation, and rock compressibility.

2.1. Irreducible Water Saturation (S_{wi})

Irreducible water saturation (S_{wi}) has been determined by plotting water saturation and effective porosity obtained from well log data on the linear scale (**Morris** and **Beggs, 1967**). Hyperbola of points resulted as shown in **Fig. 1** for the data of well Rt-20. Average S_{wi} for all wells was found to be 0.21, **Table 1**.
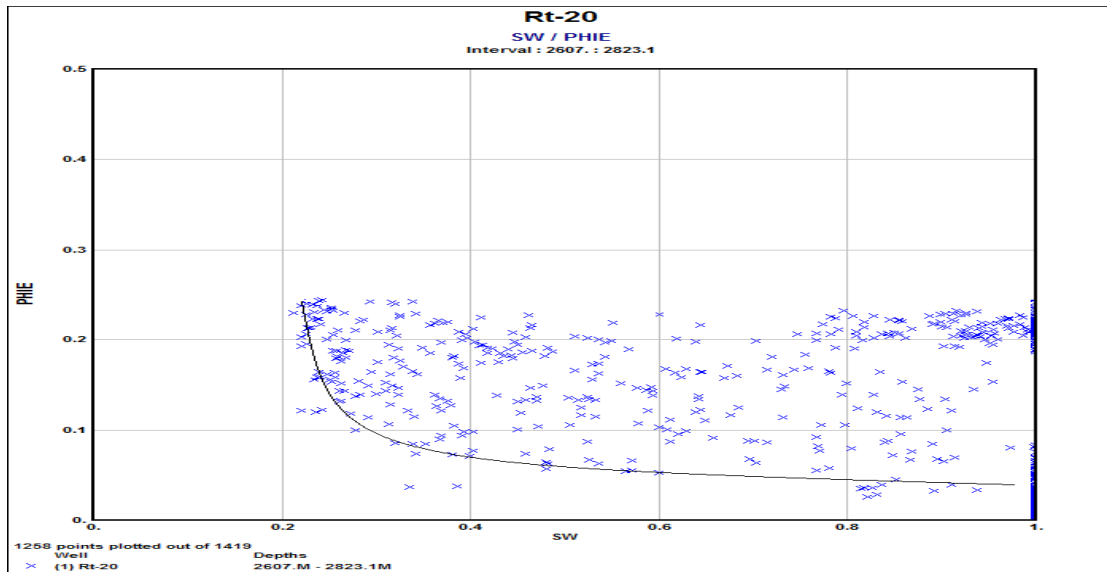
Figure 1. Irreducible water saturation determination of well Rt-20.

Table 1. Irreducible water saturation of several wells.

Well no.	Rt-16	Rt-17	Rt-18	Rt-20	Rt-21	Rt-22	Averge
S_{wi}	0.18	0.185	0.23	0.24	0.22	0.23	0.21

2.2. Initial Conditions

2.2.1 Initial reservoir pressure

Initial reservoir pressure was provided by a well test file. Well test file of Rt-16 gives a 4248 psi (292.8 bar) as initial pressure for Nahr Umr / Ratawi oil field, **(Hussian et al., 2016)**.

2.2.2 Water oil contact (WOC)

Water oil contact was determined from the interpretation process of well log data by observing the values of water saturation with depth of several wells. The WOC was found to be at -2728 m for Nahr Umr formation, as shown in **Table 2** and F**ig. 2**.

Table 2. Water oil contacts for several wells.

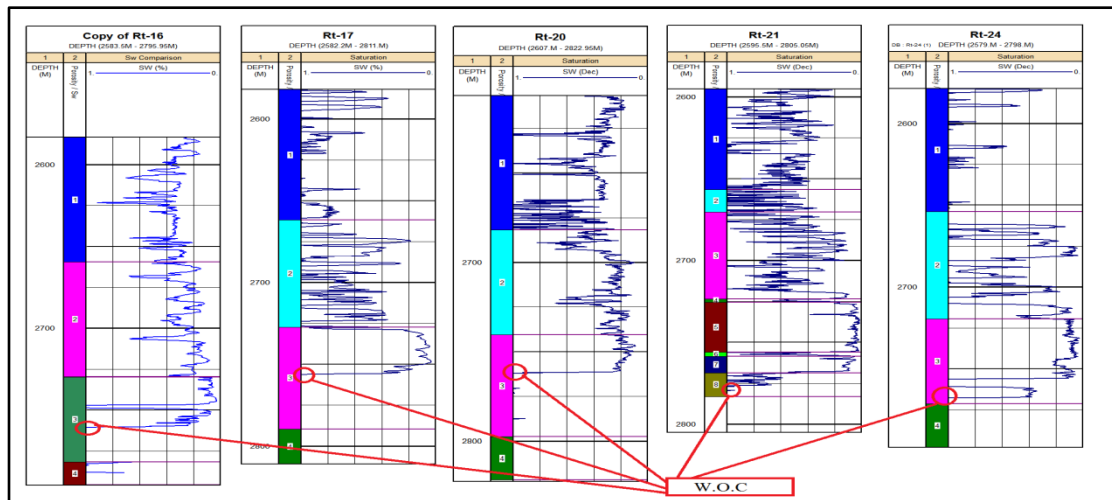| Well name	Rt-16	Rt-17	Rt-18	Rt-20	Rt-21	Rt-24
Owc(meter)	-2725.6	-2718.9	-2720.39	-2730.3	-2743.03	-2730.42

Figure 2. Water saturation vs. depth of different wells.

2.3. Relative permeability

Relative permeabilities data and capillary pressure were not available for Nahr Umr formation. Relative permeability compensated by Corey equation (1950), **(Ahmed,** and **McDkinney, 2005)** where Corey suggests several equations for oil water system. As shown in **Eq.1** and **Eq. 2**, Corey exponent for oil and water is equal to 2 and S_{orw} is equal to 0.27. Oil relative permeability at irreducible water saturation ($k_{ro}@S_{wi}$) and water relative permeability at residual oil saturation to water flooding ($K_{rw}@S_{orw}$) are assumed as 0.6 and 0.3 respectively**, (Jogemec, 2007)**, **Table 3** and **Fig. 3**.

$$Kro = (Kro)_{swi}\left[1 - \frac{Sw - Swi}{1 - Swi - Sorw}\right]^{no}$$

(1)

$$krw = (krw)_{sorw}\left[\frac{sw - swi}{1 - swi - sorw}\right]^{nw}$$

(2)

where

K_{rw}: water relative permeability md.

Kro: oil relative permeability md.

$(Kro)_{swi}$: oil relative permeability at residual water saturation.

$(krw)_{sorw}$: water relative permeability at residual oil saturation.

Table 3. Relative permeabilities of oil- water system.

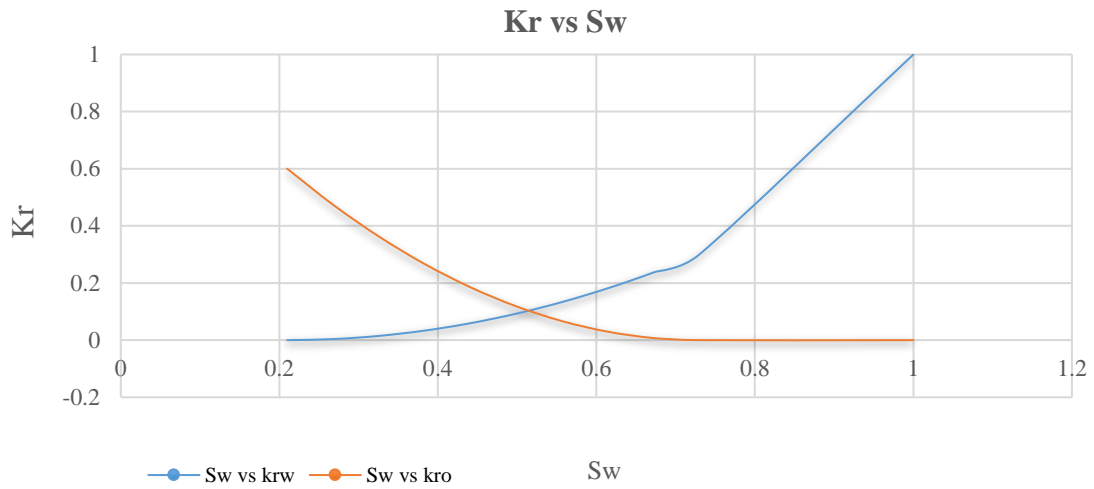| sw	0.21	0.26	0.32	0.38	0.44	0.498	0.55	0.61	0.67	0.73	1
krw	0	0.003	0.014	0.033	0.059	0.092	0.13	0.18	0.23	0.3	1
kro	0.6	0.47	0.36	0.26	0.185	0.118	0.066	0.029	0.007	0	0

Kr vs Sw

Figure 3. Relative permeabilities of oil-water system.

2.4. Capillary Pressure

As mentioned in the previous section the capillary pressure data was not available for Nahr Umr. Capillary pressure determined depending on data of Nahr Umr of Halafya oil field, (**Mahdi, 2012**), **Table 4** and **Fig. 4**.

Table 4. Capillary pressure and Water saturation of Nahr Umr formation.

Sw	0.07	0.15	0.23	0.31	0.3	0.47	0.55	0.63	0.72	0.79	0.87	0.9	1
Pc	56.88	7.01	4.03	2.85	2.11	1.42	1.34	1.25	1.168	1.08	1	0	0

Pc vs Sw
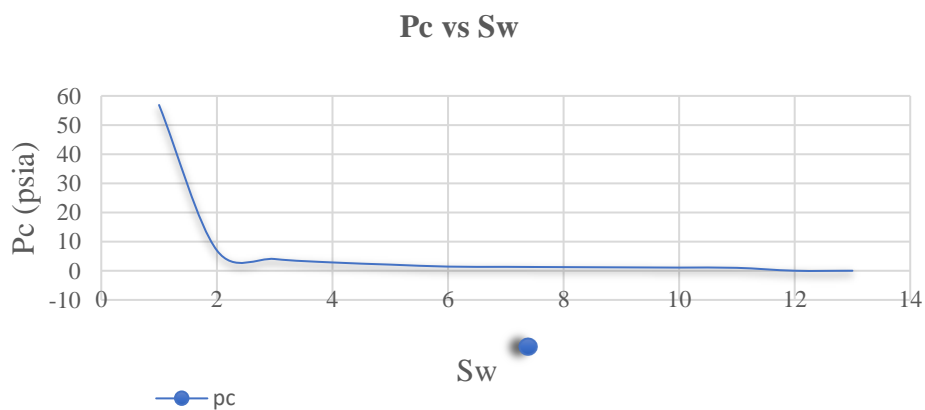
Figure 4. The capillary pressure vs. water saturation.

2.5. Fluid Model

The basic properties of the fluid model include oil viscosity (μ_o), solution gas-oil ratio (R_s), oil formation volume factor (B_o), oil density (ρ_o), API gravity and oil compressibility (C_o). These data were provided by PVT report, **(Gazi et al, 2016),** where part of these data was not available so it is obtained by different correlation. PVT data was obtained from Rt-18 file. Water compressibility (C_w) was calculated by Biggs and Brill correlation (1978). Mehan in (1980) correlation to estimate the water viscosity was used depending on water salinity (**Ahmed,** and **McDkinney, 2005), Fig. 5, Fig. 6 and Fig. 7.**
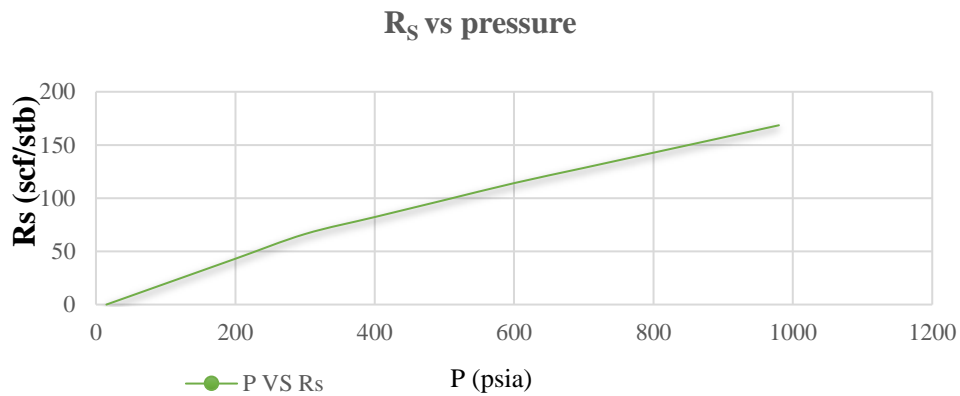
R_S vs pressure

Figure 5. Solution Gas-Oil Ratio vs. Pressure.
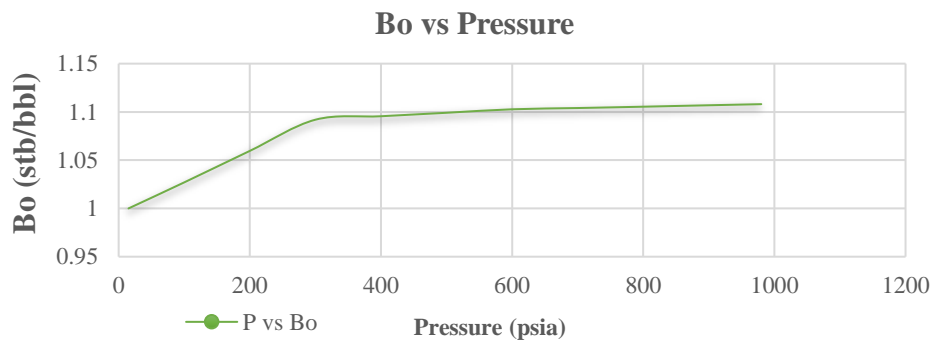
Bo vs Pressure

Figure 6. The relation between formation volume factor and pressure.
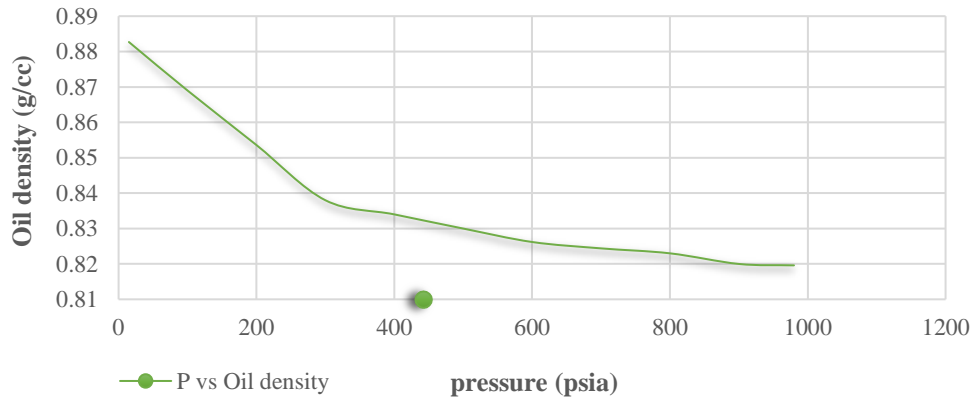
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Oil density vs Pressure

Figure 7. Oil density vs. Pressure.

2.6. Rock Compressibility

Newman correlation has been used for obtaining rock compressibility as shown in Eq(3), (**Ahmed,** and **D.McDkinney, 2005),** where average porosity equals to 0.21, so the resulted compressibility value is $2.568*10^{-6}$ psia^{-1}.

$$C_f = \frac{a}{[1 + cb\varphi]} \qquad (3)$$

Where

$$a = 97.32 \times 10^{-6}$$
$$b = 0.699993$$
$$c = 79.8181$$

3. HISTORY MATCHING

The matching process is very important to check the validity of the model. Production data has been supported from Basra Oil Company where production data include oil production rate for eight-month (from November 2017 to June 2018) for eight wells (Rt-16, Rt-17, Rt-18, Rt-20, Rt-21, Rt-23, Rt-24, and Rt-27). Several runs have been performed for this study to conduct oil production rate matching. Permeability played a significant role in matching process where the matching was done with multiplying permeability in the x-direction with 1.8, and rock compressibility also affects the matching process. In the beginning, different type of aquifers has used were the best aquifer type was bottom Tracy to get reasonable matching. The pressure matching for Rt-17 shows little difference between measured and calculated. The matching was performed for oil production rate as shown in **Fig.8 and Fig.9** for wells Rt 16 and Rt 17. The water cut data was not available for Nahr Umr. Also matching performed on well test pressure for Rt-17, **Fig.10,** where the yellow line represents the calculated values, and the red point represents the measured value. Keeping in mind the type of aquifer

used in this case was bottom Tracy aquifer. The input data for this equation was 0.21 for porosity, 200 md for permeability and 360º for angle.
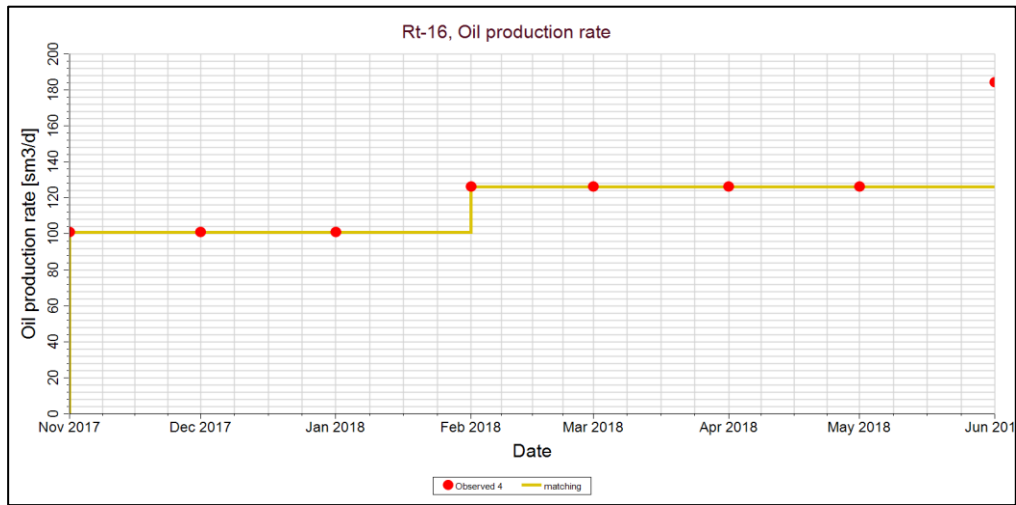
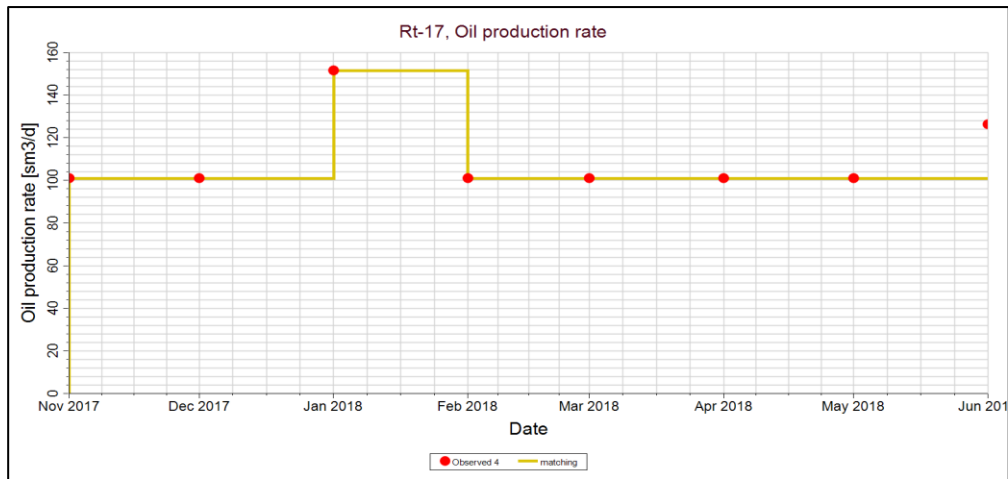**Figure 8**.Matching of the oil production rate of Rt-16.

Figure 9.Matching of the oil production rate of Rt-17.
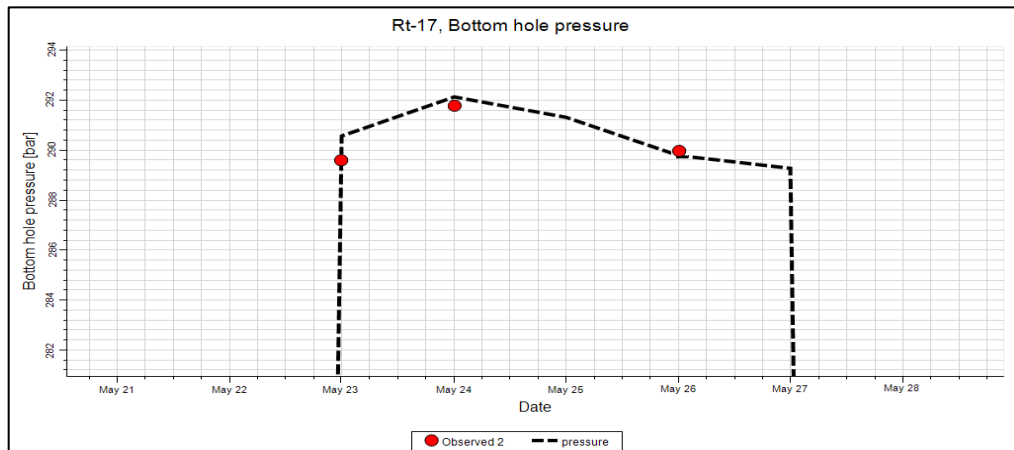
Figure 10. Matching of bottom hole pressure of Rt-17.

4. DEVELOPMENT STRATEGY

Several strategies have been proposed in this study where the prediction period was 11 years and five months. The base strategy depended on the existing wells (Rt-16, Rt-17, Rt-18, Rt-20, Rt-21, Rt-23, Rt-24, Rt-22, Rt-26, Rt-27, and Rt-31) where these wells have been run on rate of 57500 bbl/d which give oil plateau for 1 year, water cut was 16.3%, pressure drop was 600 psi and recovery factor was 0.75%, as shown **Fig.11 and Fig.12**. Other strategies are summarized below:

4.1 Case 1; Production with New 22 Vertical Well, 80000 bbl/d.

This case shows that prediction for 11 years and 6 months with 33 vertical well (22 new well and 11 original well). The case shows that oil plateau was extending for 10 years and 3 months. Water cut was 0.48 at the end of period of prediction of this case where the pressure drop was 43.28 bar (627.72 psi), and the recovery factor was 1.82%.

4.2 Case 2; Production with New 22 Vertical Well, 100000 bbl/d.

This case shows that oil plateau extended to for eight years until (1/6/2025) then the oil drops to 6887 m^3/d (43317.93 bbl/d). Water cut was 0.55 at the end of the period. Pressure drop was 54.29 bar (787.4 psi) and the recovery factor was 2%.

4.3 Case 3; Production with New 22 Vertical Well and 125000 bbl/d.

The production rate of this case was 125000 BBL/D. The oil rate plateau will end at 2/2/2022 (plateau three years and eight months), and oil rate will be 5944.5 m^3/d (37389.78 bbl/d). Water cut was 63% at the end period of prediction. Pressure drop was 66.96 bar (971.17 psi). Recovery factor was 2.08%.

Fig.13 and **Fig.14** show the results of cases 1, 2, and 3.

4.4 Case 4; Production with New 33 Vertical Well and 5 Horizontal, 80000 bbl/d.

In this case, 44 vertical well has been used (new 11 well) besides five horizontal well (H-1, H-2, H-3, H-4, and H-5) that proposed to be drilled in the reservoir. The case shows that oil plateau was extended to 11 year and 6 months, water cut was 50%, pressure drop was 43.28 bar (627.723 psi), and oil recovery was 1.85% at the end of the period of prediction.
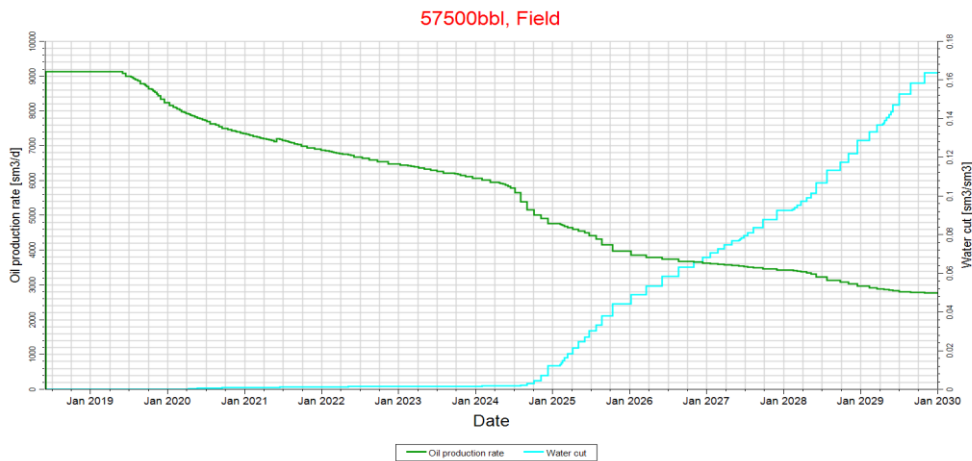

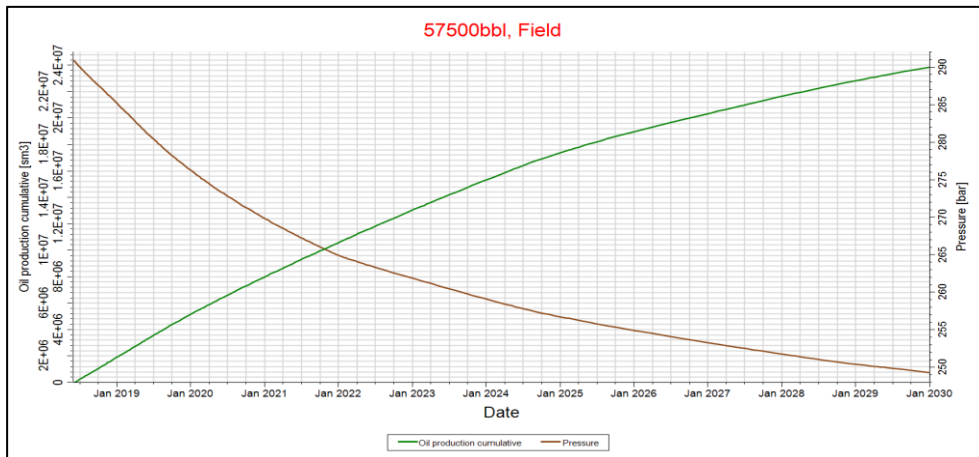**Figure 11**. The original case (oil production and water cut).

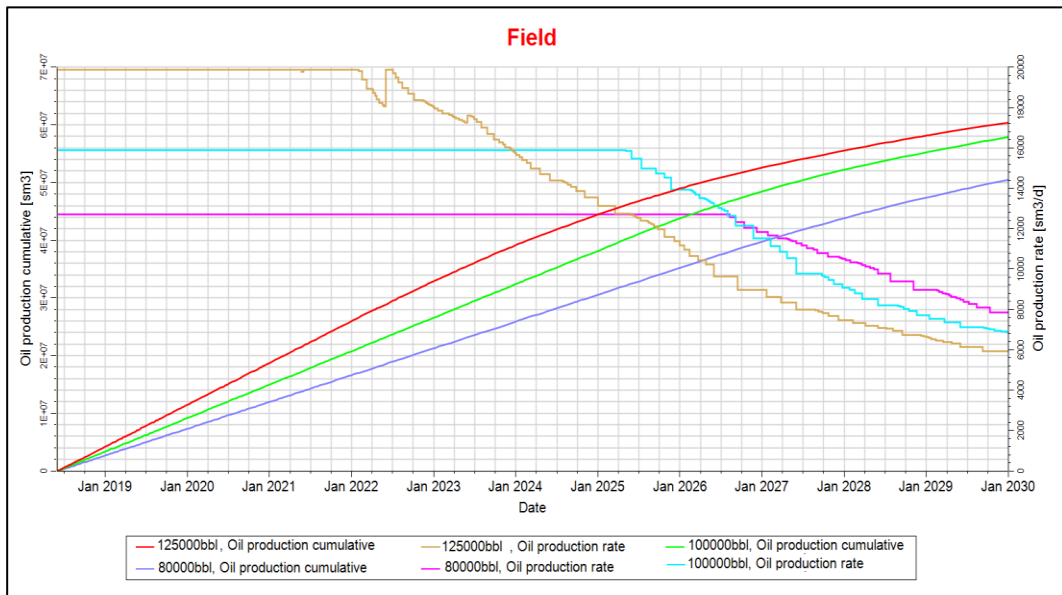**Figure12**. The original case (Pressure and Oil Cumulative).

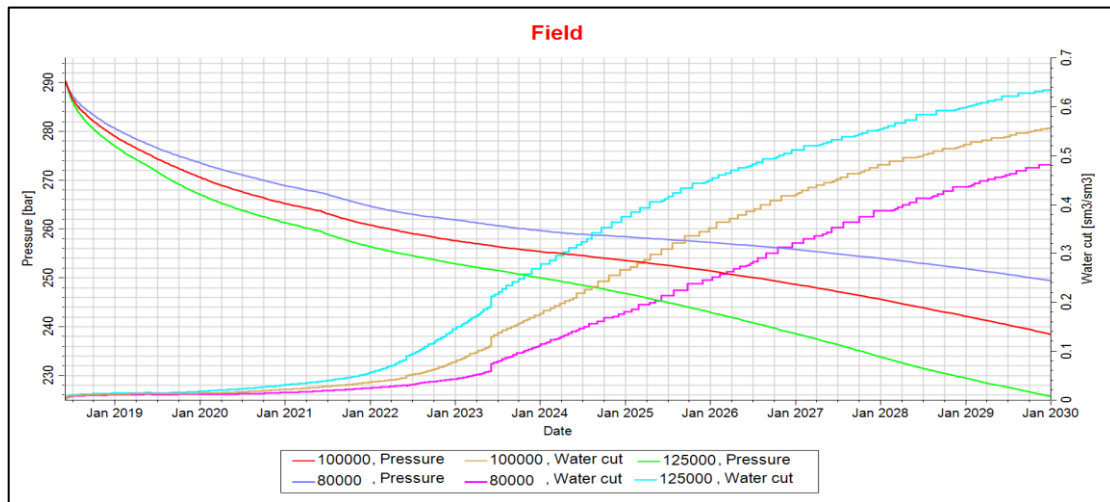**Figure 13**. Cumulative and oil production rate of Cases (1,2 and 3)

Figure 14.   Pressure and Water cut of Cases (1,2 and 3)

4.5 Case 5; Production with New 33 Vertical Well and 5 Horizontal, 100000 bbl/d.

This case shows the plateau was extended to the entire period of prediction which was 11 years and 6 months where the water cut was 60% at the end of period. Pressure dropped to 239.32 bar (3471.04 psi), and oil recovery was 2.3%.

4.6 Case 6; Production with New 33 Vertical Well and 5 Horizontal, 125000 bbl/d.

The plateau of oil also continued for 11 years and 6 months (full period) where the rest results were; the water cut was 63%, pressure dropped to 224.36 bar(3254 psi), and oil recovery was 2.9% at the end of prediction.

4.7 Case 7; Production with New 33 Vertical Well and 5 Horizontal, 150000 bbl/d.

This case shows the plateau of oil was 9 years and 7 months where the plateau of oil stopped at 5/1/2028 and became 18230 m^3/d (114663 bbl/d) at 16/9/2029. Water cut was 71%, the pressure drop was 82 bar (1189.3 psi), and the oil recovery was 3.4%.

  The results of the cases 4, 5, 6, and 7 are shown in **Fig.15**, **Fig.16**. The locations of the proposed wells can be seen in **Fig.17**.
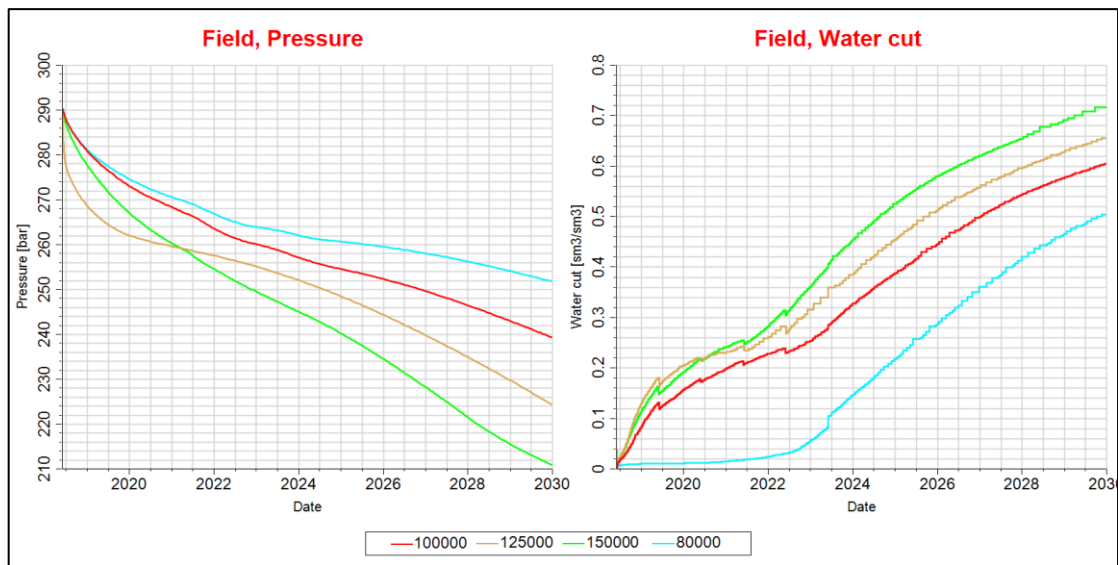
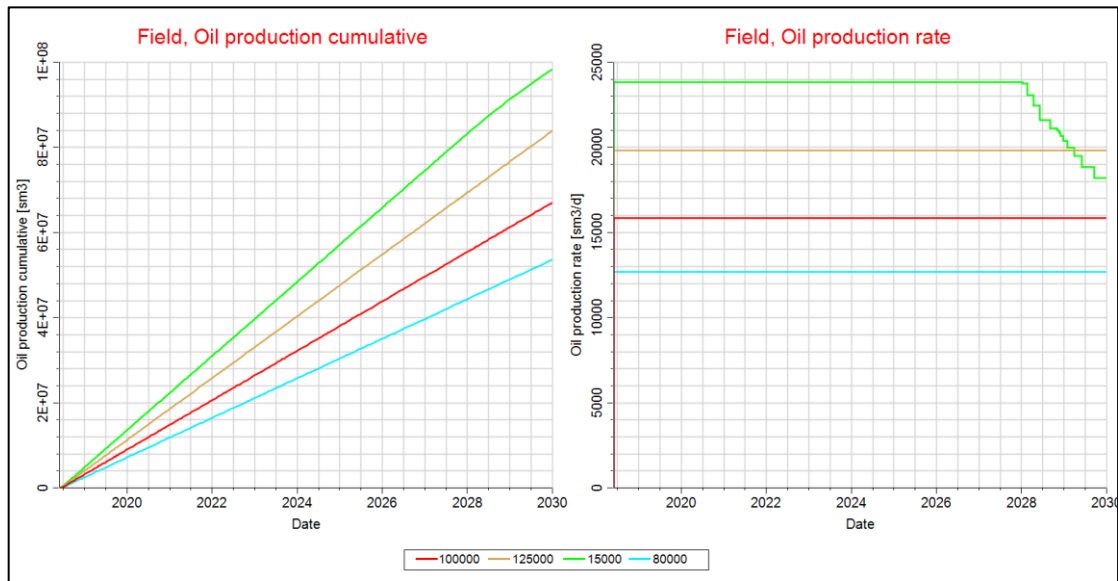**Figure 15**. Pressure and Water Cut of Cases (4,5,6 and 7).

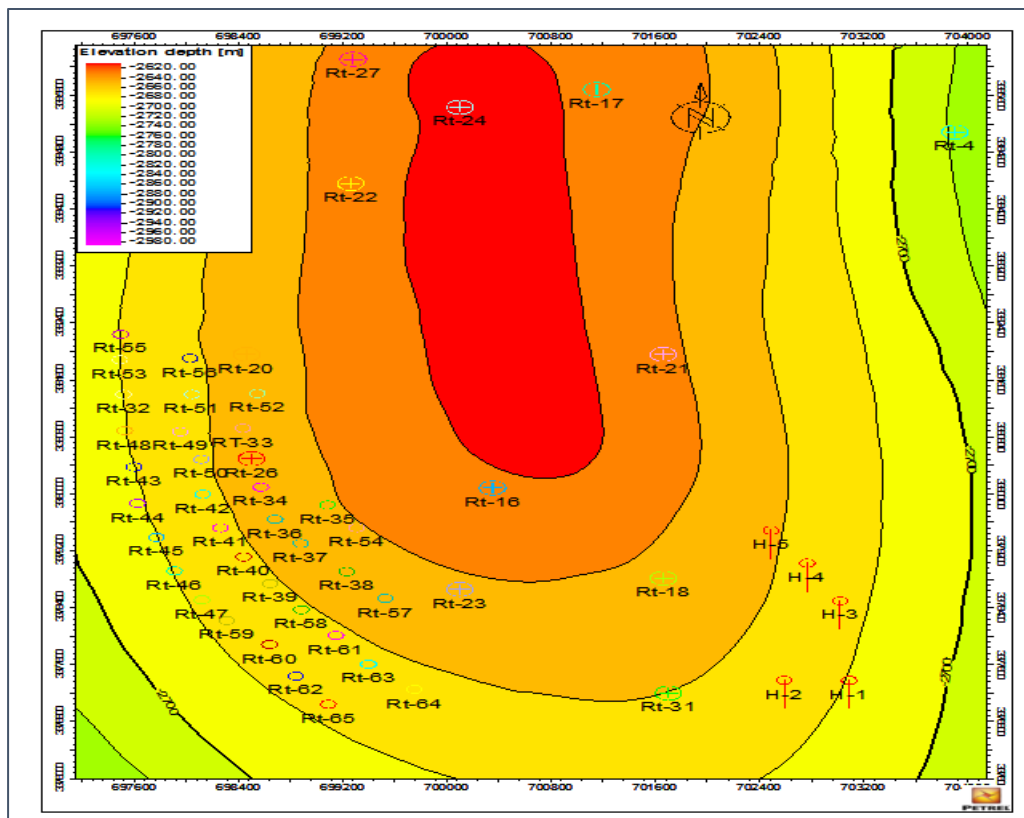**Figure 16.** Pressure and Water Cut of Cases (4,5,6 and 7).

Figure 17. Locations of original and proposed wells.

5. CONCLUSIONS

1- The permeability of the reservoir under study was found to be the most effective parameter that controls the matching process.

2- Many strategies have been proposed for Nahr Umr Formation using the existing and new wells. The best-case depended on adding 33 new to the 11 original vertical wells beside 5 horizontal wells which gave oil plateau for 9 years and 7 months where water cut, recovery factor, and pressure values were 71%, 3.4%, and 1189.3 psi respectively. The new wells have been distributed in high permeability regions.

3- Waterflooding is not recommended due to high water cut obtained during natural depletion.

NOMENCLATURE

C_f: formation Compressibility Psi^{-1}.
C_w: water Compressibility in psi^{-1}.
$(k_{ro})_{swi}$: oil relative permeability at residual water saturation.
k_{rw}: water relative permeability.
$(k_{rw})_{sorw}$: water relative permeability at residual oil saturation.
S_{wi}: irreducible water saturation
WOC: water-oil contact
Y: water salinity at ppm.
μ_w: water viscosity cp.
μ_{wd}: water viscosity at standard condition.

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