Journal Homepage: http://ijcpe.uobaghdad.edu.iq
Iraqi Journal of Chemical and Petroleum Engineering
Vol. 26 No. 1 (March 2025) 59 – 66
EISSN: 2618-0707, PISSN: 1997-4884

Development of a dynamic compositional reservoir model for enhanced oil recovery in Nahr Umr formation of Abu-Amood oil field

Mohammed Q. Abed Talib [a, *], Mohammed S. Al-Jawad [a]

a Department of Petroleum Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

Abstract

Due to the research gap in the literature regarding the Nahr Umr formation within the Abu-Amood oil field, this study aims to develop a dynamic compositional reservoir model for this formation. Located in the Dhi Qar province of Iraq, the Nahr Umr Formation, primarily composed of sandstone, lies 3025 meters below sea level and holds significant hydrocarbon potential. This research focuses on building a compositional model to predict reservoir behavior under various production strategies, ultimately maximizing oil recovery. The model was constructed using geological report data and implemented with Petrel and CMG software. Utilizing pressure-volume-temperature (PVT) data and the Peng-Robinson equation of state (EOS), an accurate fluid properties model was developed. Through reservoir and well area calculations, this study demonstrates that the Nahr Umr reservoir can be effectively drained using only six producers. This comprehensive model is crucial for designing efficient production strategies and enhancing oil recovery in the Nahr Umr Formation.

Keywords: *Original oil in place; Abu-Amood; Nahr Umr Formation; Compositional model.*

Received on 02/07/2024, Received in Revised Form on 04/08/2024, Accepted on 04/08/2024, Published on 30/03/2025

https://doi.org/10.31699/IJCPE.2025.1.6

1- Introduction

A static or geological model is utilized to identify various aspects of the subsurface structure of the earth and its features, such as faults, fractures, and facies distribution. Additionally, it is used to visualize the estimated location of hydrocarbon accumulation and its quantity to a certain degree of accuracy, depending on the available information [1]. However, it cannot predict how the reservoir would respond to a production strategy or specifically how much oil can be produced from the reservoir. The dynamic model is used to analyze the behavior of a reservoir under different production strategies and select the optimum strategy that results in the highest oil recovery [2]. Constructing a dynamic model of a reservoir is the next step taken after building the geological model.

As shown in Fig. 1 [3], the Abu-Amood oil field is situated in the Dhi Qar province, around 16 km north of the Qall'at Sukkar region and 26 km north of Refa'i. It is just 17 Km southwest of the Dejaila field [4]. The field is around 22 Km long and 6 Km wide with an azimuth of N65°W. The Abu-Amood oil field has several reservoirs with high production potential, with the Nahr Umr reservoir taking precedence in this work.

The Nahr Umr Formation of the Abu-Amood oil field is mainly composed of sandstone. The top of the formation is located 3025 meters below sea level and has an average thickness of 139 meters, based on the geological reports. The formation appears to have a stable geological structure, as no faults have been identified in it [5].

Khorshid and Khaleel [5] conducted a 3D seismic survey for Nahr Umr formation in the Abu-Amood oil field. The study revealed a semi-symmetrical structure with an axis trending NW-SE for the Nahr Umr Formation with no presence of faults, unlike the Ratawi and Yamama formations. The study also highlights the presence of Hydrocarbon in the formation.

Nasser, Al-Jawed, and Hassan [6], constructed a 3D geological model for Yamama formation using Petrel software. The authors concluded that the Yamama formation is characterized by two asymmetrical anticline domes it contains six reservoir units along the wells AAM-1, AAM-2, and AMM-5 and five reservoir units along the wells AMM-3 and AAM-4.

Mahdi and Farman [7], estimated the original oil in place (OOIP) in the Zubair Formation at the Abu-Amood oil field after dividing the formation into five distinct units. Three of these units are candidate reservoir units, while the remaining two are caprock. Among these units, unit-1 is the most promising one due to its good petrophysical properties. The estimated OOIP was around 1800 MMSTB.

This study is an extension of our previous work [8], in which a geological (static) model for the Nahr Umr Formation was created. In this work, a compositional

*Corresponding Author: Email: m.murad1708@coeng.uobaghdad.edu.iq

dynamic model for the formation will be constructed and used afterward in designing a suitable production strategy for the reservoir. The reason for choosing a compositional model instead of a black oil model is its border applications range, especially in enhanced oil recovery (EOR) processes. For example, the miscible gas injection process, which includes the chemical reactions between the fluids themselves and the fluids with the reservoir rock.

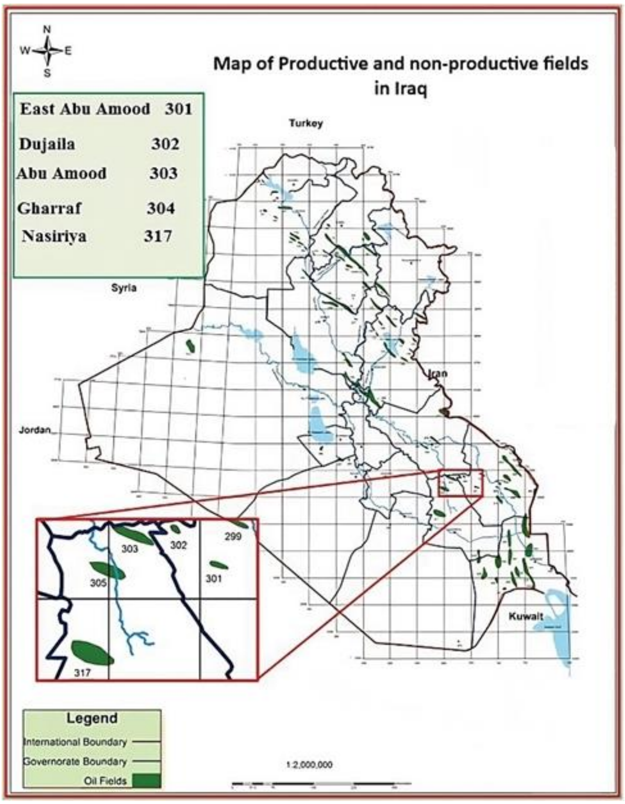


Fig. 1. Abu-Ammod oil field location [3]

2- Methodology

2.1. Nahr Umr geological model

Nahr Umr formation is subdivided into five units [8]: unit-1 is a caprock unit, unit-2 consists of shale rocks, and unit-3 is the most promising unit due to its high porosity, permeability, and oil saturation. Where it consists of sandstone rocks, unit-4 is a thin water-filled shaly sandstone unit, and finally, unit-5 is a water-filled sandstone unit. Table 1. shows the porosity and permeability statistical description for each unit.

Table 1. Statistical description of the distributed petrophysical properties

Unit	Porosity (%)			Permeability (mD)		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
Unit 1	0.83	5.53	2.53	0.0012	0.0184	0.0048
Unit 2	0.42	13.08	6.07	0.0009	1.5546	0.0795
Unit 3	16.97	27.74	22.86	15.3149	5986.92	1616.144
Unit 4	17.43	26.66	21.72	0.6417	739.1732	78.5432
Unit 5	17.61	25.74	23.52	0.7248	207.1128	92.6912

2.2. Dynamic model grid and grid properties

The geological model that was made using Petrel software [8] was exported to CMG Builder software. Porosity, horizontal permeability, and the grid were exported from Petrel. Vertical permeability was taken as 0.25 of the horizontal permeability (the 0.25 value was taken from two measured points from well AAM-1).

Layers 1 to 6 were marked as null in the model for many reasons. One, layers 1 through 6 represent unit-1 and unit-2, where unit-1 is assumed to be a cap rock while unit-2 is predominantly shale, and most of its information has a high degree of uncertainty. Two, the fact that the saturation distribution is initialized by the vertical-equilibrium method means that these layers will be treated as oil-saturated layers, which will give the wrong estimation of the original oil in place. Three, marking these layers as null will help the case run faster due to the fact that these layers don't enter the solution matrix when the case is running.

2.3. Fluid model

Compositional simulators require the pressure-volume-temperature (PVT) fluid data to be entered as components, given that compositional simulators utilize an equation of state (EOS) to get the required fluid property during the simulation process.

The fluid PVT data was modeled using the CMG Winprop software and then exported to the model. Table 2 and Table 3, present general information about Nahr Umr fluid and the composition of the selected fluid for modeling.

Table 2. General information about Nahr Umr fluid data

Parameter	Value
Reservoir temperature, °F	202
Reservoir pressure, psi	5012
Saturation pressure, psi	1112.265
B_o at saturation pressure, v/v	1.241
Solution gas-oil ratio, SCF/STB	315.563
API	26.3

Table 3. Nahr Umr fluid composition

Component	Composition, %
N2	0.7
CO_2	1.57
CH4	12.58
C2H6	7.01
C3H8	7.14
IC4	1.19
NC4	4.95
IC5	1.94
NC5	2.98
C6+	59.94
Sum	100

The procedure to model a fluid starts with choosing an EOS, then uploading the experimental results (i.e., differential liberation and constant composition expansion experiments), and finally selecting a regression parameter that requires tunning. Hence, the EOS gives a better match with the experimental results.

The available Peng-Robinson 1978 was chosen as the EOS for use, and critical pressure, critical temperature, and volume shift parameters for the C6+ component were selected as the regression parameter for tunning to get a match with differential liberation and constant composition expansion (CCE) data [9-11].

The matching was done in steps where the first match was done for saturation pressure; then the next match was for CCE; as for the last match, which is differential liberation matching, there was no need to do the last matching step as the EOS after CCE matching gave a good match with the experimental data. Fig. 2 and Fig. 3 illustrate the matching between the EOS and the experimental data presented in the PVT report.

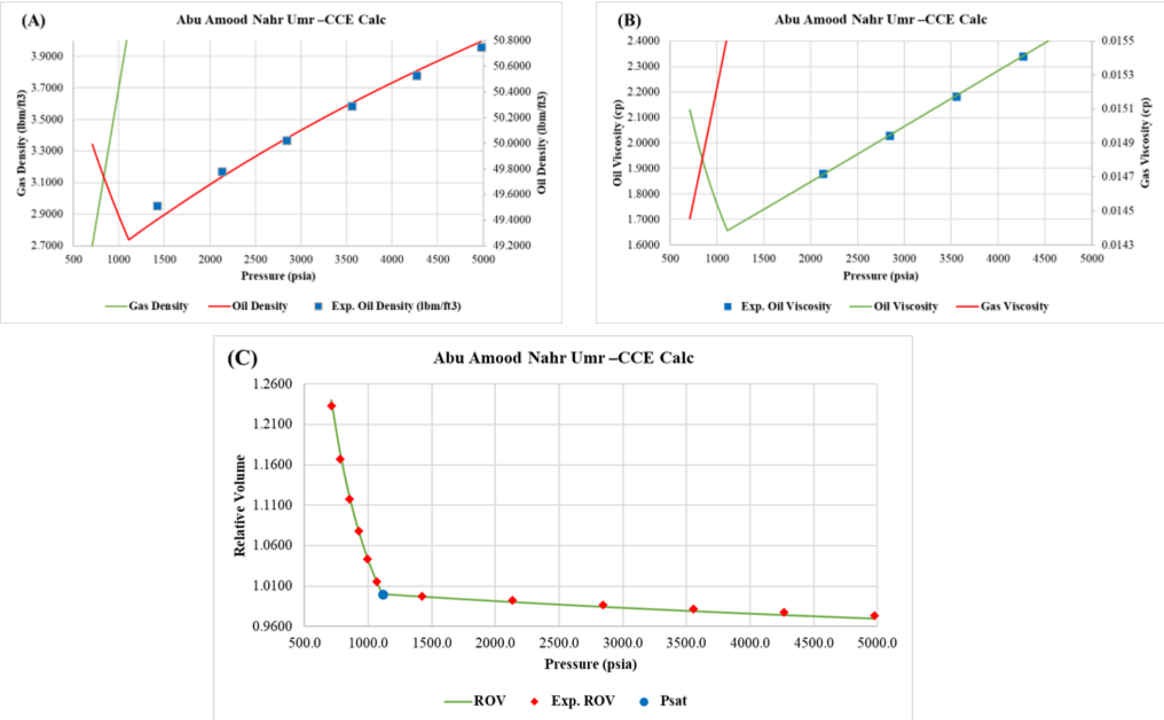


Fig. 2. Constant composition expansion data. (A) oil density, (B) oil viscosity, (C) oil ROV

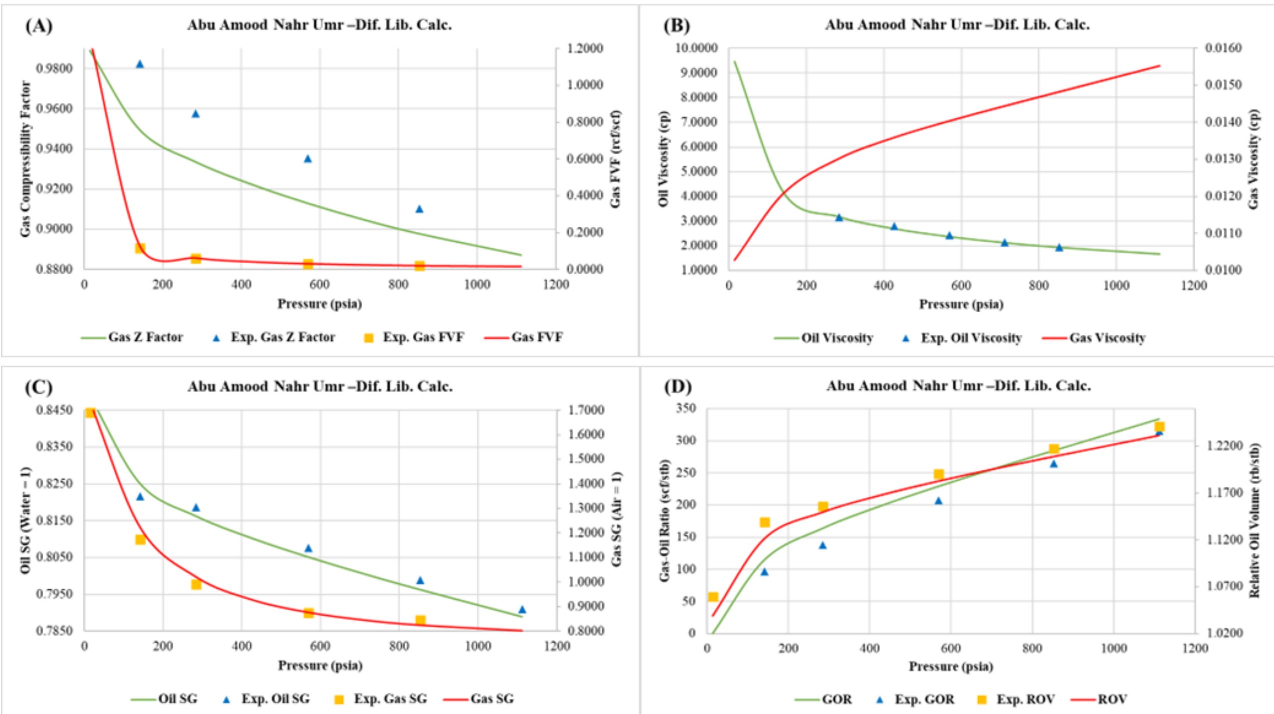


Fig. 3. Differential liberation data. (A) gas z-factor and gas formation volume factor, (B) oil and gas viscosity, (C) oil and gas specific gravity, (D) Rs and Bo

2.4. Rock-fluid data

Rock-fluid data is one of the important sections when building a dynamic model, as this section deals with relative permeability data of the fluid, which directly affects the fluid movement in the reservoir, and capillary pressure data, which contributes to the thickness of the transition zone [12].

No special core analysis was conducted on the Nahr Umr Formation in the Abu-Amood oil field except for the capillary pressure test from AAM-5 well. As a result, the necessary data were gathered from nearby fields (i.e., Nahr Umr formation at Luhais oil field).

Table 4 shows the capillary pressure data obtained from the AAM-5 well in Abu-Amood, while Table 5, along with Fig. 4, shows the oil-water relative permeability and gas-oil relative permeability data from the Nahr Umr Formation at Luhais field.

Because of the data collected from different sources and software constraints on input data, a change must be made so that the model can work well. To satisfy Eq. 1 the endpoint of the gas saturation (Sg) must be changed to (54%), the maximum value of oil relative permeability (Kro) in the oil-water relative permeability data must be changed to (0.88) to match the (Kro) value in the gas-oil data due to software input constrain, as for capillary pressure (Pc) data, each entered saturation must have the Pc value with it and because the Pc data doesn't have the required saturation, a linear interpolation between the first and the second data point was made to obtain the necessary Pc value with it corresponding saturation, Eq. 2 shows the used equation. Table 6 shows the rock-fluid data that was entered into the dynamic model.

$$Sw_{connet} + So_{residual} = 1 - Sg_{max} \quad (1)$$

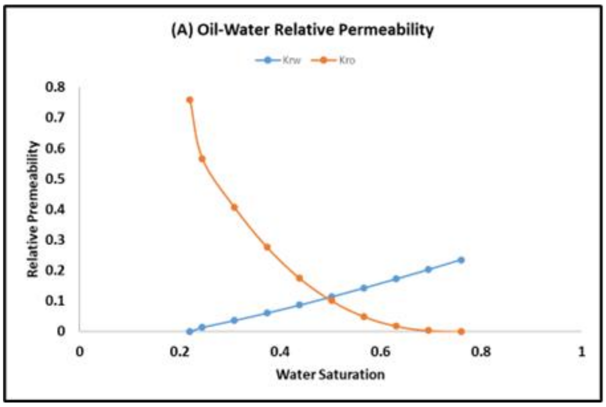
$$P_c = -0.0126 \times S_w + 1.2553 \quad (2)$$

Table 4. Capillary pressure data

Pc, psi	Water saturation
0	100
1	20.34
2	18.65
4	14.39
8	9.45
15	9.44
30	9
45	8.31

Table 5. Oil-water, gas-oil relative permeability data

Sw	Krw	Kro	Sg	Krg	Kro
22	0	0.76	4	0.00	0.88
24.444	0.014	0.56682	5	0.01	0.83
30.889	0.03695	0.40648	10	0.04	0.60
37.333	0.060843	0.27691	15	0.07	0.43
43.778	0.086673	0.17587	20	0.10	0.31
50.222	0.11405	0.1009	25	0.14	0.23
56.667	0.14272	0.049293	30	0.18	0.16
63.111	0.17251	0.01796	35	0.22	0.10
69.556	0.20331	0.0031971	40	0.26	0.06
76	0.235	0	45	0.30	0.03
			50	0.37	0.01
			55	0.49	0.00



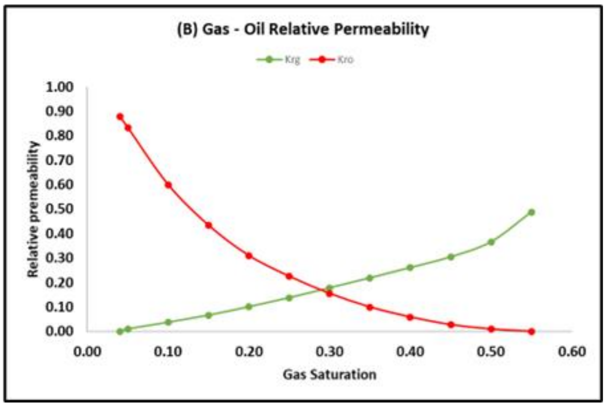


Fig. 4. Relative permeability data. (A) oil-water data, (B) gas-oil data

Table 6. Rock-fluid data that was used in the model

Sw	Krw	Kro	Pc, psi	Sg	Krg	Kro
22	0	0.88	0.979161	4	0.00	0.88
24.444	0.014	0.56682	0.948481	5	0.01	0.83
30.889	0.03695	0.40648	0.867575	10	0.04	0.60
37.333	0.060843	0.27691	0.786681	15	0.07	0.43
43.778	0.086673	0.17587	0.705775	20	0.10	0.31
50.222	0.11405	0.1009	0.624881	25	0.14	0.23
56.667	0.14272	0.049293	0.543974	30	0.18	0.16
63.111	0.17251	0.01796	0.463081	35	0.22	0.10
69.556	0.20331	0.0031971	0.382174	40	0.26	0.06
76	0.235	0	0.301280	45	0.30	0.03
				50	0.37	0.01
				54	0.49	0.00

The transition zone was calculated from the capillary pressure data in Table.6 by converting the Pc value to heights using Eq. 3. Fig. 5 depicts the fluid height distribution where the transition zone thickness is about (2.5 m). It should be noted that the free water level (FWL) depth is the same as the end depth of the transition zone, which is evident by **Error! Reference source not found.** where at water saturation equal to 100, the capillary pressure is zero, and this is attributed to the formation high permeability.

$$h = \frac{P_c}{\gamma_{water} - \gamma_{oil}} \quad (3)$$

Where: h: Height, ft. P_c: Capillary pressure, psi. γ_{water}: Water gradient (0.4730), psi/ft. γ_{oil}: Oil gradient (0.3515), psi/ft.

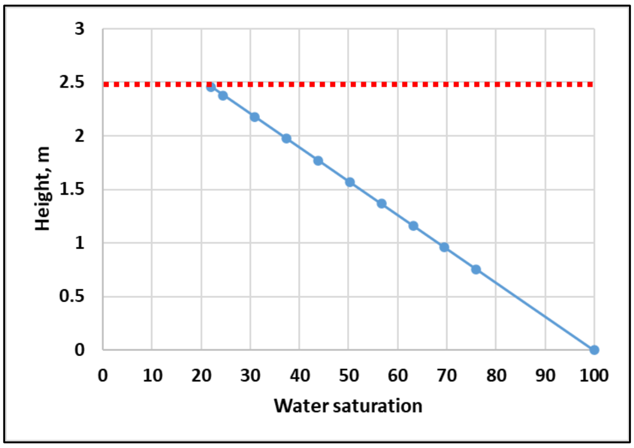


Fig. 5. The fluid distribution and oil/water transition zone

2.5. Model initialization

To initialize the model in CMG-GEM software, depth of OWC, pressure at reference depth, and fluid composition must be provided. For OWC depth, 3120 M was used. For the reference pressure, the information was taken from the AAM-5 FGR report, where a Drill stem test (DST) was written with both depth and pressure; the depth interval of the test was (3098 – 3111 m), and the pressure value is 5040 psi, the mean depth (i.e., 3104.5 M) was entered with the pressure value in the model. For the fluid composition, the values in Table 3 were used.

2.6. Model and wells specifications

This section focuses on determining the optimal number of wells required effectively drain the Nahr Umr reservoir. Fig. 6 illustrates a schematic map of the Nahr Umr reservoir, highlighting the most suitable areas for drilling new wells. To determine the ideal number of wells, the total area of the reservoir region was first calculated and then calculated the drainage area of a single vertical well. Afterward, by dividing the total area by the drainage area of a single well, the optimum number of vertical wells can be calculated. The area of the reservoir region was calculated using ellipse Eq. 4, as the shape of the Nahr Umr reservoir closely resembles that of an ellipse, as illustrated in Fig. 6. The lengths of semi-major and semi-minor axes of the ellipse are 2000 and700 meters, respectively.

Vertical well drainage area was calculated by generally using the distance taken between vertical wells in southern Iraq oil fields, which is about 800-1000 M as a reference. The drainage radius of a vertical well is about 400-500 M. The area was then calculated using Eq. 5. Table 7 shows the reservoir and well areas as well as the optimum number of wells.

$$A_{Res} = a \times b \times \pi \quad (4)$$

$$A_{well} = \pi\, r_e^2 \quad (5)$$

Where: A_{Res}: Reservoir area, m^2. A_{well}: Vertical well area, m^2. a: Length of the semi-major axis of the ellipse, m. b: Length of semi-minor axis of the ellipse, m. r_e: Drainage radius of the vertical well, m.

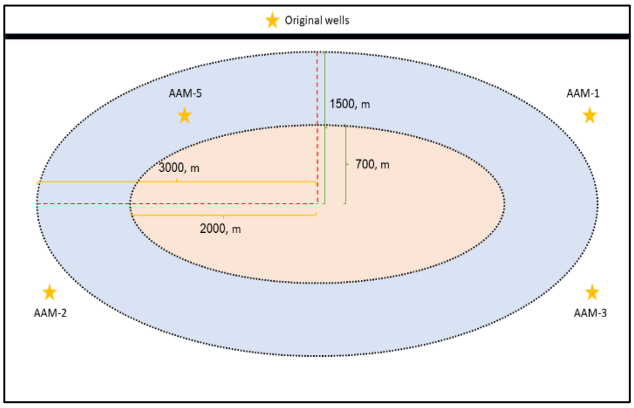


Fig. 6. Nahr Umr reservoir schematic map. The blue region represents a bad area to drill new wells, while the beige region represents a good area to drill new wells

Table 7. Reservoir and vertical well areas calculations

Parameter	Value	
Reservoir area, M^2	4,398,230	
Vertical well area, M^2	$r_e = 400\ M$ 502,655	$r_e = 500\ M$ 785,398
Number of wells	$r_e = 400\ M$ 9	$r_e = 500\ M$ 6

It was recommended that six new producers be drilled, with spacing of 500 meters, in addition to the five original production wells, to effectively drain the reservoir. Table 8 shows the northing and easting coordinates as well as the depth of both the original and the suggested production wells. Typically, the time required to complete drilling and start production from a new well is approximately 2 months. Consequently, the new suggested producers were scheduled to begin production two months from after the previous well's opening time. Fig. 7 illustrates the production start time for the suggested production wells.

3- Result and discussion

The calculated original oil in place (OOIP) in the dynamic model is approximately 500 MMSTB, which is different from the obtained value using the geological model (i.e., 748 MMSTB) [8]. This is because the resultant OOIP value is calculated under the following considerations.

The OOIP calculation method is different between the static and dynamic models and for the following reasons: a single value of oil formation volume factor (B_o) is used during the calculation of OOIP in a static model, while the B_o value in the dynamic model is calculated for each block using the equation of state, where the blocks have different pressure values. In contrast to the dynamic model, the geological model doesn't include rock compressibility in the calculation process. The difference in the water saturation values is that the geological model uses water saturation obtained from well-log interpretation. In contrast, the dynamic model uses the capillary gravity equilibrium method [13-16] to get the water saturation distribution [17]. It is important to note that no history marching was conducted on the model due to the missing of production data for Abu-Amood oil field.

Additionally, fluid distribution as a function of height in transition zones is highly complex and dependent on the heterogeneities of the rock fabrics within the formation. Fig. 5 reveals that the transition zone thickness is approximately 4.6 ft, whereas the oil-saturated zone (the green-colored zone) has a larger volume. This result is consistent with the findings reviewed in the literature [18].

Table 8. Wells origin, type, coordinates, and perforation depth

Well name	Origin	Type	Easting, m	Northing, m	Perforation Depth, m
5-spot-p1-w1	Suggested	Producer	612240	3534186	3088
5-spot-p2-w1	Suggested	Producer	613242	3534186	3089
5-spot-p3-w1	Suggested	Producer	610240	3535101	3088
5-spot-p4-w1	Suggested	Producer	611240	3535101	3079
5-spot-p5-w1	Suggested	Producer	612240	3535101	3081
5-spot-p6-w1	Suggested	Producer	610240	3536076	3087
AAM-1	Original	Producer	614800	3533800	3110
AAM-2	Original	Producer	608000	3536550	3115
AAM-3	Original	Producer	613650	3532700	3116
AAM-4	Original	Producer	620600	3531050	3153
AAM-5	Original	Producer	611100	3536500	3098

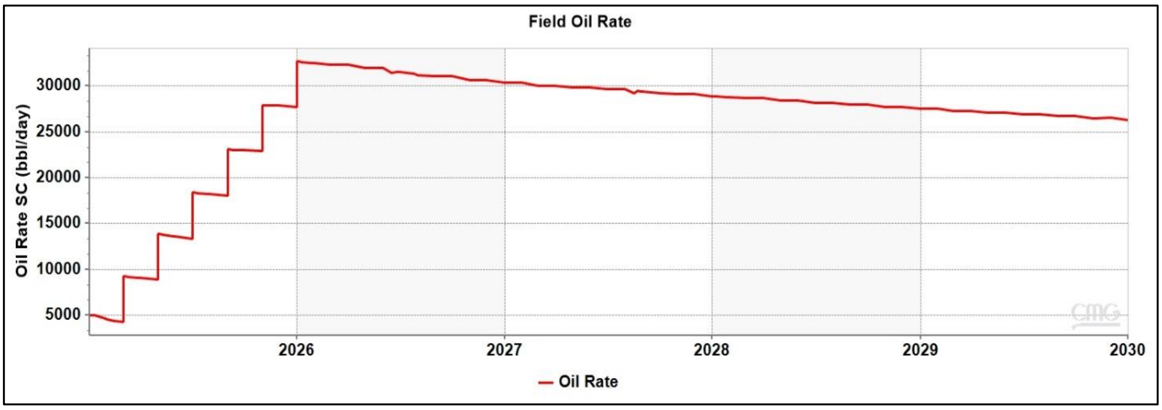


Fig. 7. Showcases suggested producers' opening time

4- Conclusion

This research yields several important insights. The estimated original oil in place (OOIP) for the Nahr Umr Formation in the Abu-Amood oil field is approximately 500 million stock tank barrels (MMSTB). The developed compositional dynamic model offers more versatility than the traditional black-oil model. It can be utilized to simulate a relatively wide range of scenarios, including enhanced oil recovery (EOR) processes such as miscible gas injection and chemical reactions within the reservoir between the fluids and the reservoir rock. This advanced modeling capability is crucial for designing and implementing more effective production strategies, ultimately enhancing oil recovery from the Nahr Umr Formation. Additionally, this study shows that the Nahr Umr Formation can be effectively drained utilizing only six producers, as determined through calculations of the reservoir and well areas.

Nomenclature

Symbol	Description	Unit
Bo	Oil formation volume factor	BBL/STB
Rs	Solution gas oil ratio	SCF/STB
Pc	Capillary pressure	Psia

Abbreviations

Abbreviation	Description
API	American Petroleum Institute
CMG	Computer modeling group
Krg	Relative gas permeability
Kro	Relative oil permeability
Krw	Relative water permeability
OOIP	Original oil in place
ROV	Oil volume to oil volume at saturation pressure
Sg	Gas saturation
STB	Stock tank barrel
Sw	Water saturation

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تطوير نموذج مكمن تركيبي ديناميكي لتعزيز استخلاص النفط في تكوين نهر عمر لحقل أبو عامود النفطي

محمد قاسم عبد طالب [١، *]، محمد صالح الجواد [١، *]

١ قسم هندسة النفط، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

نظرًا لوجود فجوة بحثية في الأدبيات العلمية فيما يتعلق بالدراسات حول تكوين نهر عمر في حقل أبو عمود النفطي، تقدم هذه الدراسة تطوير نموذج ديناميكي تركيبي لمكمن نهر عمر في حقل أبو عمود النفطي، الواقع في محافظة ذي قار بالعراق. تهدف هذه الدراسة إلى بناء نموذج تركيبي يتنبأ بسلوك الخزان تحت استراتيجيات إنتاج مختلفة لزيادة انتاج النفط إلى أقصى حد. يتكون تكوين نهر عمر بشكل رئيسي من الحجر الرملي، ويقع على عمق ٣٠٢٥ مترًا تحت مستوى سطح البحر، مع إمكانية كبيرة لوجود الهيدروكربونات. تم بناء النموذج باستخدام بيانات من التقارير جيولوجية، وتم تطبيقه باستخدام برمجيات Peterl و CMG. تم تطوير نموذج السوائل باستخدام بيانات الضغط والحجم ودرجة الحرارة (PVT) ومعادلة الحالة لبنغ-روبنسون (EOS) للحصول على نمذجة دقيقة لخصائص السوائل. بالإضافة إلى ذلك، تُظهر هذه الدراسة من خلال حسابات مساحات المكمن والآبار، أن مكمن نهر عمر يمكن استنزافه بفعالية باستخدام ستة آبار إنتاج فقط. يعد هذا النموذج الشامل أداة حيوية لتصميم استراتيجيات إنتاج فعالة، مما يساهم في تحسين انتاج النفط من تكوين نهر عمر.

الكلمات الدالة: المخزون الأصلي للنفط، تكوين نهر عمر، أبو عامود، النموذج التركيبي.