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Calibrating the Reservoir Model of the Garraf Oil Field

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Abstract

History matching is a significant stage in reservoir modeling for evaluating past reservoir performance and predicting future behavior. This paper is primarily focused on the calibration of the dynamic reservoir model for the Meshrif formation, which is the main reservoir in the Garraf oilfield. A full-field reservoir model with 110 producing wells is constructed using a comprehensive dataset that includes geological, pressure-volume-temperature (PVT), and rock property information. The resulting 3D geologic model provides detailed information on water saturation, permeability, porosity, and net thickness to gross thickness for each grid cell, and forms the basis for constructing the dynamic reservoir model. The dynamic reservoir model integrates a variety of inputs, including well position and trajectory, well completion data, initial reservoir condition, and daily production/injection rates. The validation process involves comparing the original oil reserve derived from the geological model with the one obtained from the dynamic reservoir model. To achieve an accurate history matching, the calibration process has been performed by aligning observed data with simulation results. This involves focusing on production/injection data for each well and pressure measurements for selected wells. Notably, horizontal permeability is identified as a critical parameter in this study, which is adjusted iteratively to achieve a robust match for individual wells and the entire field. Thus, Successful calibration facilitates the subsequent stage and future scenarios allowing for the exploration of different conditions to predict the performance of the Garraf oilfield. This comprehensive approach improves the reliability of reservoir predictions, facilitating well-informed decision-making in reservoir management.

Keywords: History matching, reservoir model, Garraf oil field, Mishrif reservoir, dynamic model.

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1- Introduction

Constructing the reservoir model is crucial in the petroleum industry; it is considered the essential step for introducing development strategies in the field [1]. To meet the demand for evaluating and developing reservoirs, it may be possible to predict their performance more precisely by using comprehensive and complicated full-field reservoir models, which have become essential. In contrast to the substantial capital expenditures necessary for reservoir development, the increased knowledge and confidence in the information produced from sophisticated field-scale simulation helps the decision-making process be more reliable [2]. The reservoir model validation is the most difficult step since it requires an understanding of geoscience and reservoir engineering [3]. Reservoir history matching is a difficult inverse issue that arises in the petroleum industry to create a model that minimizes the discrepancy between the model's performance and reservoir history [4].

A numerical simulation analysis must provide the mathematical model with production/injection data (oil, water, and gas flow rates). Successful simulation research requires good-quality data in terms of direct input and reference data to assess the validity of the history match phase [5].

There is a lot of uncertainty in the initial geological model and the reservoir characterization. Therefore, the initial simulation model must be modified to match the current historical production data and forecast the reservoir's future performance. This tuning procedure is performed during the history-matching operation. So, history matching is a process for calibration that involves adjusting the uncertain parameters of a reservoir model until the model most closely matches the historical field performance [6, 7]. Furthermore, the tuned model can predict the reservoir performance under various operating scenarios after the most uncertain reservoir properties have been identified by matching actual reservoir behavior [8, 9]. An iterative process should be used to carefully modify the original simulation data to increase the match's quality. The reservoir data may be adjusted manually during the history-matching process or automatically using computer logic. Fig. 1 illustrates the history-match workflow [10].

The main objective of this research is to validate the reservoir model to use it as a basis for future reservoir development plans. The oil production rates, water injection rates, and flowing /static bottom hole pressure were used as observed data to be compared with the simulator results and to achieve the matching process.

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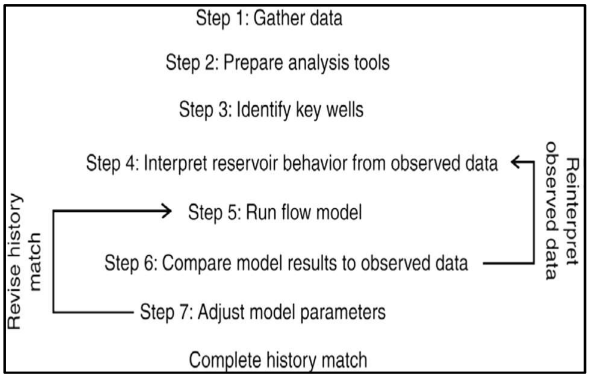

Fig. 1. History Matching Workflow

2- Methodology

2.1. Grid System

The Mishrif formation was constructed with a three-dimensional grid model (134 × 93 × 53) in I, J, and K directions with irregular grid sizes by using the tartan gridding to minimize simulation time by lowering the number of cells and concentrating them on essential locations to manage numerical calculation requirements better [11, 12].

The Mishrif units were divided into sub-layers. The interested units (M1.2, L1, L1.2, and L2) are given more layers to reflect the geological characteristics adequately. At the same time, Barriers (M1, M2) and water zones (L2.2, L2.3, and L2.4) were provided with a single layer to avoid a large cell number.

2.2. Initial Reservoir Conditions

The initial reservoir pressure is defined based on the modular formation dynamics tester (MDT) results for wells: Ga-1, Ga-2, Ga-3, Ga-4, Ga-5, Ga-A1P, and Ga-B5P. The initial reservoir pressure was set to 4017 psi at a datum and a free water level of 2394 m TVDSS [13].

2.3. Formation water properties

The average properties of formation water samples for well Ga-4 as detailed in Table 1 [13].

Table 1. Average Properties of Formation Water Sample for Well Ga-4

Property	value
Formation Water Density, Kg/m3	1127.5
μ_w , cp	0.57
Formation Water Salinity, ppm	177,000
B_w , rb/stb	1.018
C_w , 1/psi	$2.17*10^{-6}$

2.4. PVT data

The best sample representing the physical and thermodynamic properties of the Mishrif reservoir for the Garraf oil field was the bottom hole sample from the modular formation dynamics tester (MDT) result of well Ga-4 [14]. Oil formation volume factor (B_o), oil viscosity, Solution gas-oil ratio, and oil density are shown respectively in Fig. 2 to Fig. 5. All these properties are a function of pressure. Table 2 shows the properties of the fluid sample from well Ga-4.

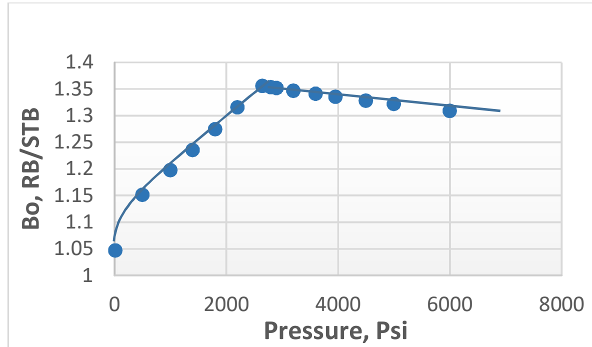

Fig. 2. Oil Formation Volume Factor Vs Pressure for Well Ga-4

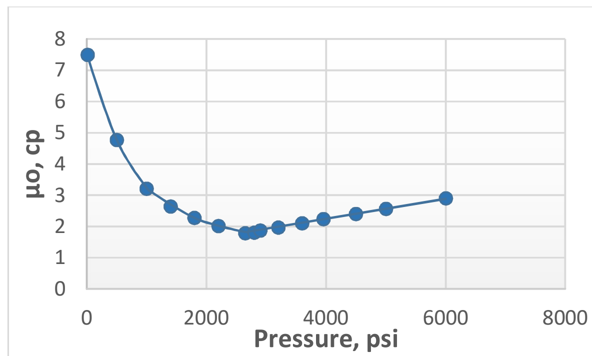

Fig. 3. Oil Viscosity Vs Pressure for Well Ga-4

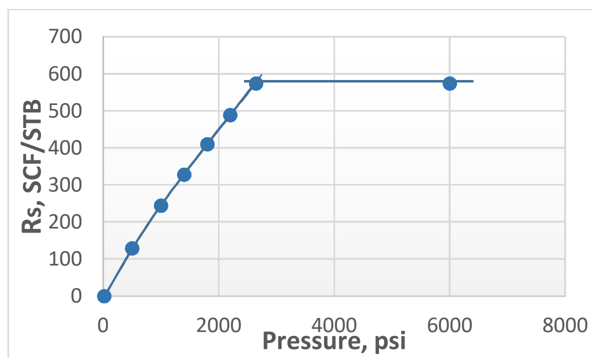

Fig. 4. Gas Solubility Vs Pressure for Well Ga-4

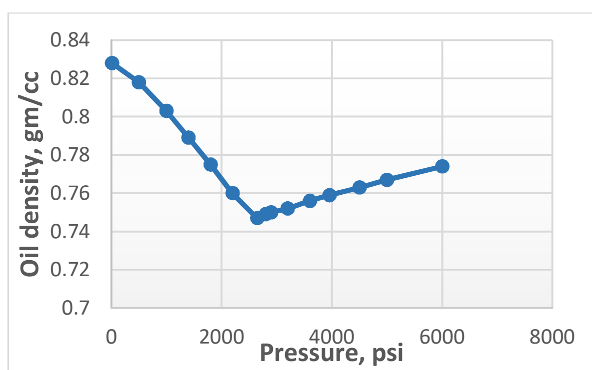

Fig. 5. Oil Density Vs Pressure for Well Ga-4

Table 2. Properties of the Fluid Sample of Well Ga-4

Sampling depth,m	2445.6
Bubble point pressure (Pb),psi	2646
Bo at Pb ,(RB/STB)	1.356
Rsi at Pb (SCF/STB)	574
Oil Viscosity at Pb ,cp	1.78
Oil Gravity,°API	25
Fluid density at Pb, gm/cc	0.747

2.5. Rock compressibility

The compressibility of Mishrif formation is about $30 * 10^{-6}\ psi^{-1}$ at a reference pressure of 3991 psi [13].

2.6. Relative Permeability

The core plugs for intriguing formations can be used as the basis for laboratory measurements to determine the relative permeability curves. The wettability influence can also be observed in the relative permeability curve changes [15].

Rock properties were based on core data of well Ga-4. The relative permeability curves for Mishrif formation in the Garraf oil field are shown in Fig. 6 [16]. It is obvious from the relative permeability curves that the system is slightly oil-wet.

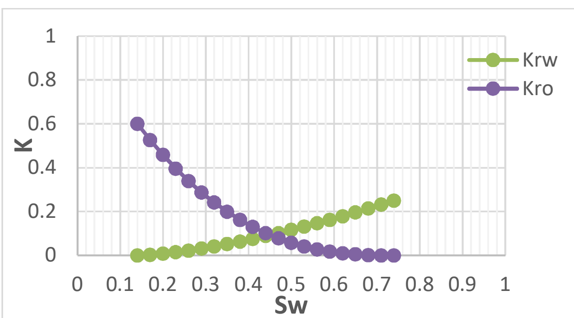

Fig. 6. Relative Permeability Curves for Mishrif Formation

2.7. Capillary pressure

Leverett (1941) defined the capillary pressure term as the pressure difference created across the interface between any two immiscible fluids when they exist adjacent to each other [17].

Usually, the initialization of simulation models is necessary to introduce the capillary pressure data measurement [18]. Typically, the capillary pressure measurement is done in a laboratory on the core samples cored from a specific depth of formation by using different methods. These measurements are done on laboratory conditions required to convert them to reservoir conditions using a particular correlation [19]. Capillary pressure analysis data for Mishrif formation in the Garraf oil field was obtained from core data of well Ga-4 [16]. Fig. 7 shows the capillary pressure curve as a function of water saturation.

2.8. Well Modeling

Until the end of 2021, 111 wells have been drilled and put into production from the Mishrif reservoir of the Garraf oil field [20]. There were 102 directional wells, seven vertical wells, and two horizontal wells. The survey data and the completion details of 111 wells have been prepared to use in the dynamic model from final well reports (FWR) and completion reports [21, 22]. The survey data included the well locations on the surface and the trajectory for each well type. Fig. 8 depicts the trajectory for the wells; each color represents a different well pad, where there are (11) well pads.

Fig. 9 shows the location of all wells on unit M1 from the Mishrif reservoir in the Garraf oil field. In this reservoir model, several completion configurations have been used to create a comparable link to reality between the wellbore and the reservoir. For the horizontal wells, the completion was represented using a casing with a perforated liner along the horizontal section, which is extended within unit L1.2. For vertical and deviated wells, a perforated casing at several intervals in units M1.2 and L units (L1, L1.2, and L2) was used depending on the information from the completion reports [22]. Fig. 10 to Fig. 12 show the completion schematic for the horizontal, directional, and vertical wells, respectively.

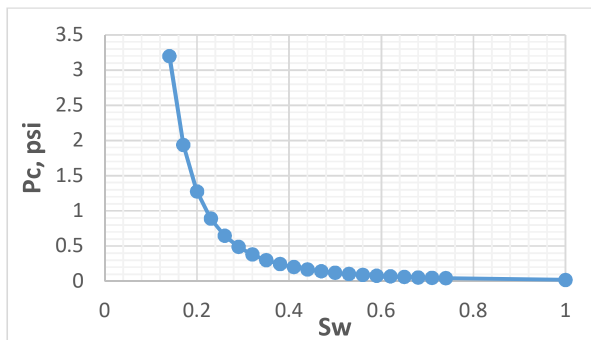

Fig. 7. Capillary Pressure Vs. Water Saturation for Mishrif Formation

3- Results and Discussions

3.1. Model Initialization

Once the reservoir model has been created, the simulator is run by using the initial conditions mentioned previously to complete the first stage of simulation in which the simulator calculates the OOIP. The estimated OOIP by the dynamic model is (5980 MMSTB), while the estimated OOIP using the geological model was 5666 MMSTB.

3.2. History Matching

History matching is a crucial step in reservoir modeling since it represents the validation of the reservoir model and serves as a guide in predicting future reservoir performances. History matching is one of the main challenging parts of this reservoir study, especially with 110 producing wells in the Garraf oil field. The matching process has been applied for all the producing and injecting wells in the Garraf oil field using daily oil production rates, daily water injection rates, and monthly flowing bottom hole pressure data. Two strategies with the same rules have been used to guide the history matching process; one to mimic the daily production/ injection data, and the other to represent the monthly bottom hole pressure data for the wells.

a. Oil Production Rates Matching

The daily oil production rates data for 110 producing well during eight years were fed into the simulator, beginning with the first production year of the Garraf oil field in 2013 and finishing at the end of 2021. A good match was obtained between the calculated production rates by the simulator and the observed production data.

b. Water Injection Rates Matching

In the fourth quarter of 2019, some production wells were gradually converted to water injectors in the oil leg of the Mishrif formation in the Garraf oil field according to the inverted nine-spot pattern with a total number of 15 wells by the end of 2021. The water injection data of 15 wells were fed into the simulator to confirm the history-matching process of every barrel injected into the reservoir. The computed water injection rates by the simulator and the observed injection data had a good match.

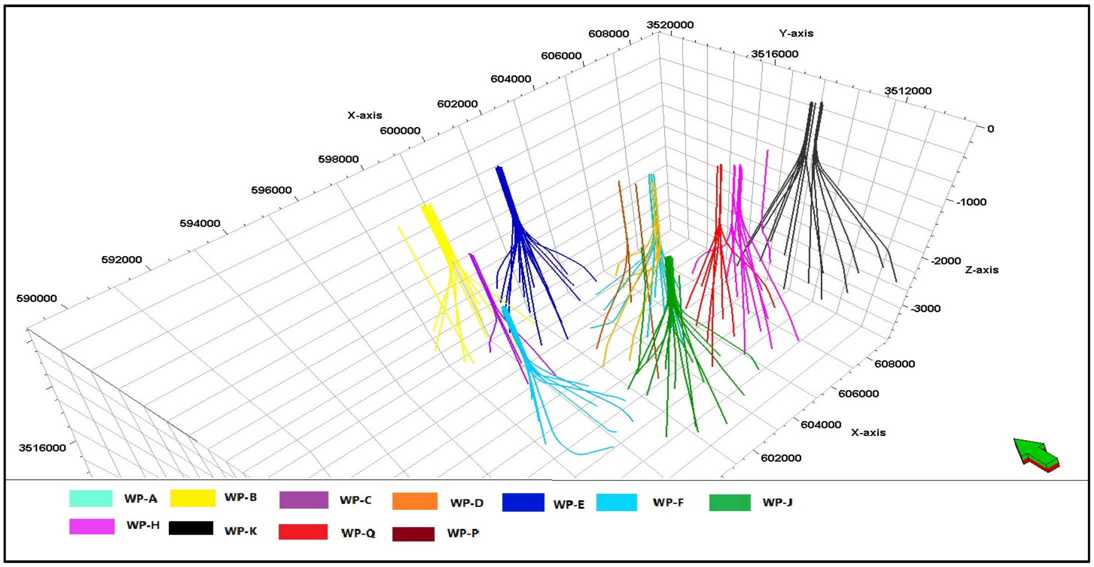

Fig. 8. Trajectory of Garraf Wells (each color represent a different well pad)

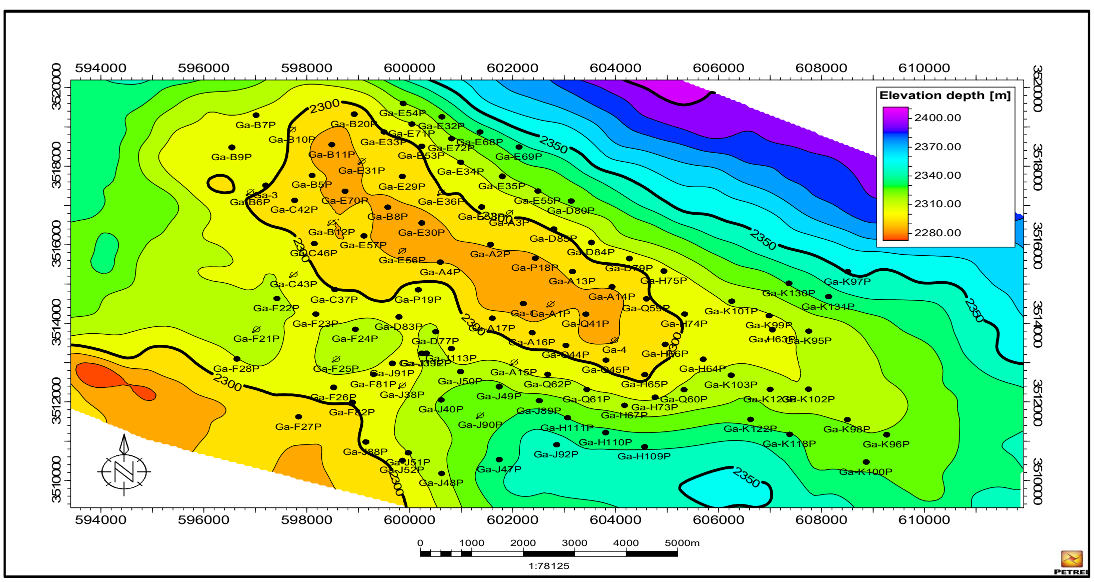

Fig. 9. Wells Locations on the Surface Map of Unit M1 for Mishrif Reservoir

c. Water Cut Matching

The daily production reports of the Garraf oil field didn't record any water production, and this was verified through the history matching process.

d. Bottom Hole Pressure Matching

The flowing bottom hole pressure data was used in the pressure matching process for some wells selected based on the pressure measurements' availability; the pressure data is used only for verification and is not used as input in the simulator calculations. The simulator was run several times to achieve the matching process by altering some parameters, such as horizontal permeability. The horizontal permeability was multiplied by a factor of (3.8) to confirm the pressure matching.

Fig. 13 to Fig. 15 show the result of the history-matching process of oil production rates, water injection rates, and water cuts for some producers that have been converted to injectors. Fig. 16 to Fig. 18 depict the result of the pressure history matching in some wells. Fig. 19 shows the history matching for the field.

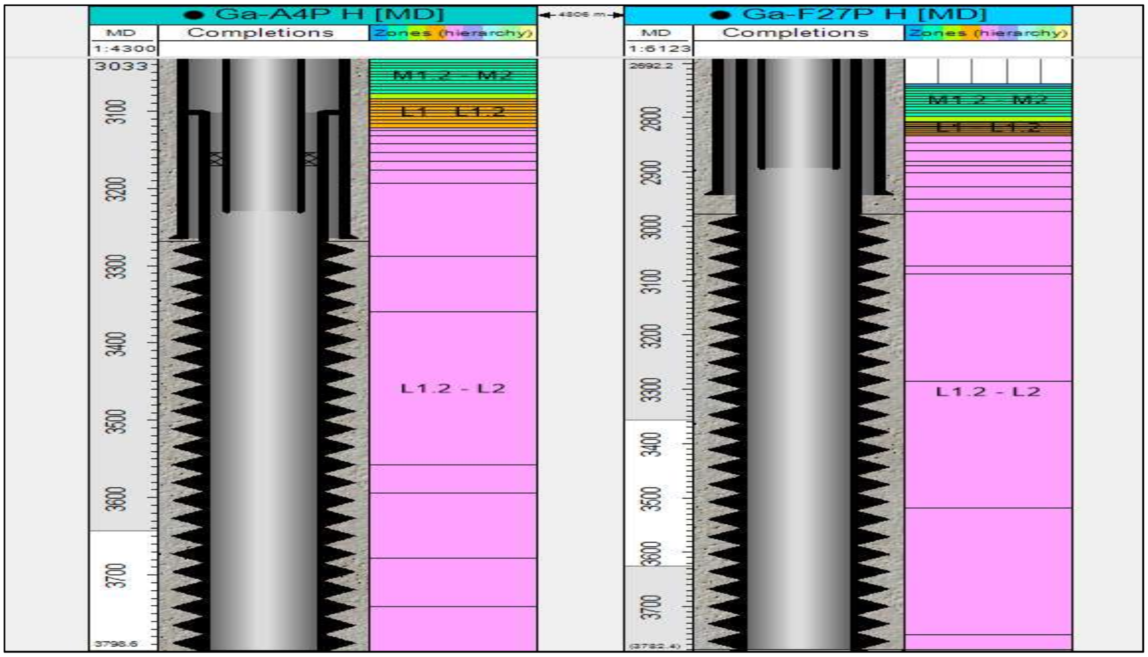

Fig. 10. Completion Schematic for Horizontal Wells

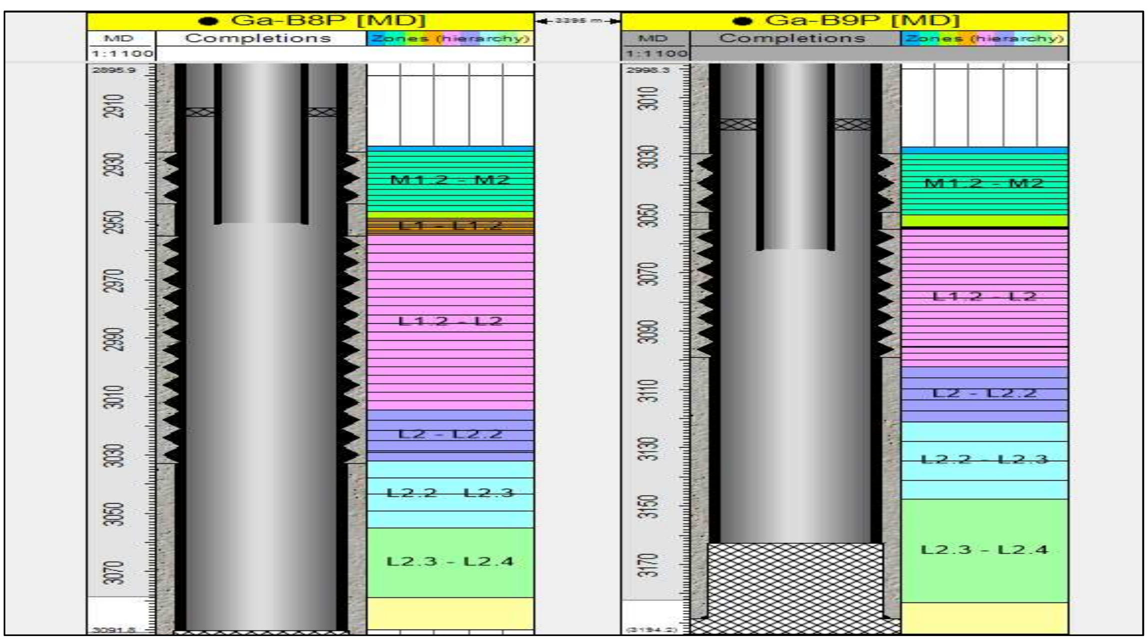

Fig. 11. Completion Schematic for Directional Wells

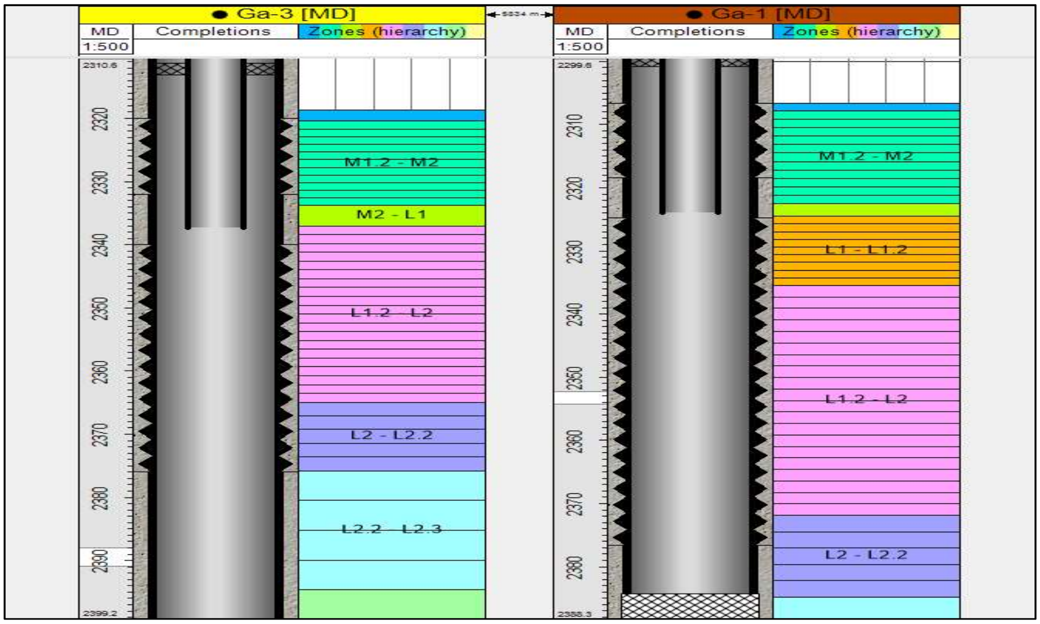

Fig. 12. Completion Schematic for Vertical Wells

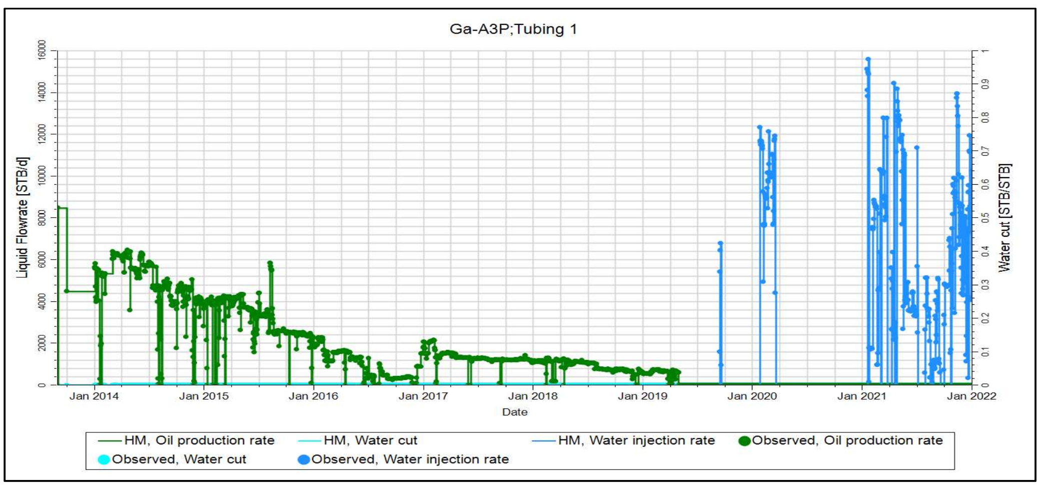

Fig. 13. History Matching of Well Ga-A3P

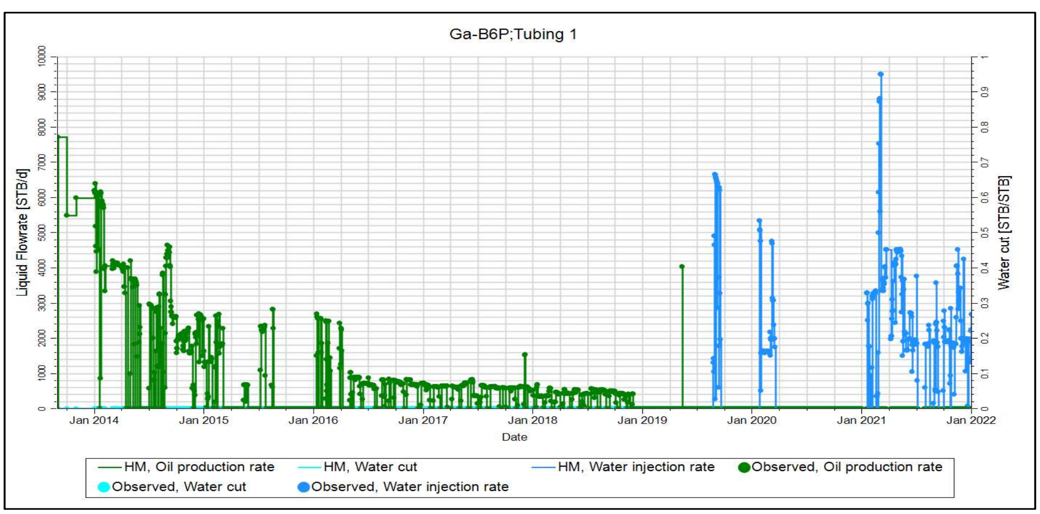

Fig. 14. History Matching of Well Ga-B6P

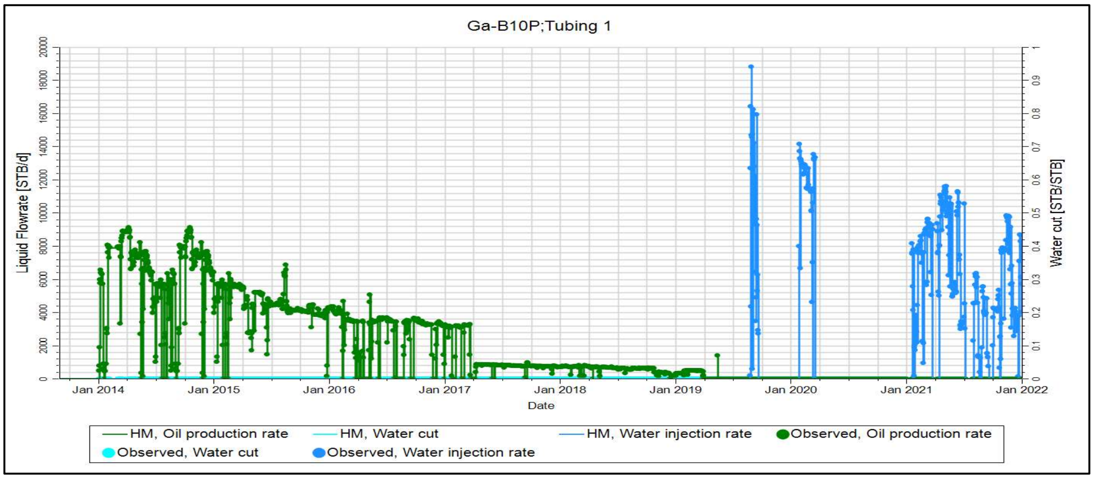

Fig. 15. History Matching of Well Ga-B10P

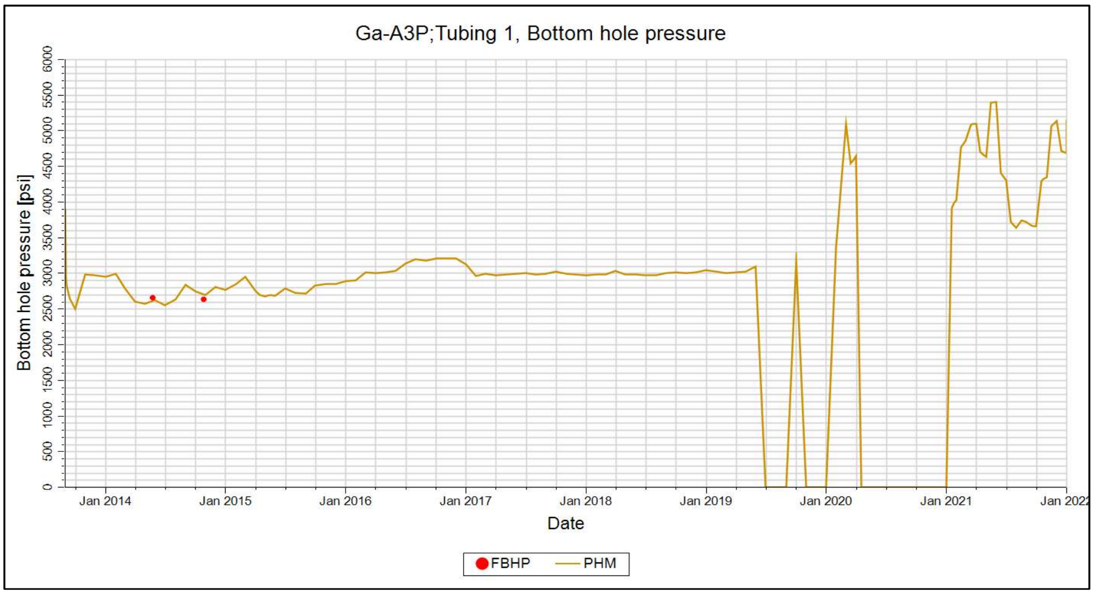

Fig. 16. History Matching of Well Ga-A3P

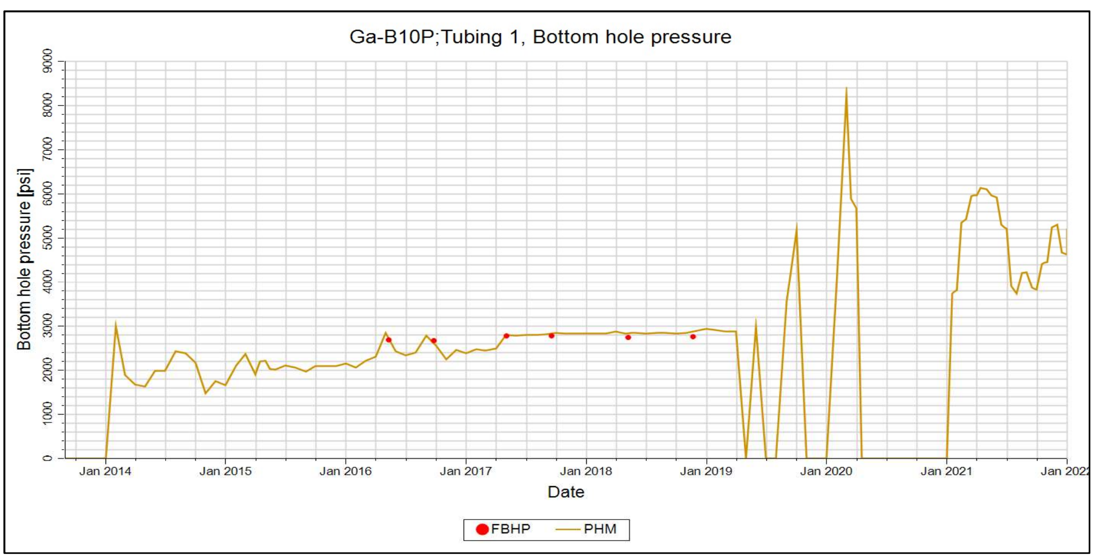

Fig. 17. History Matching of Well Ga-B10P

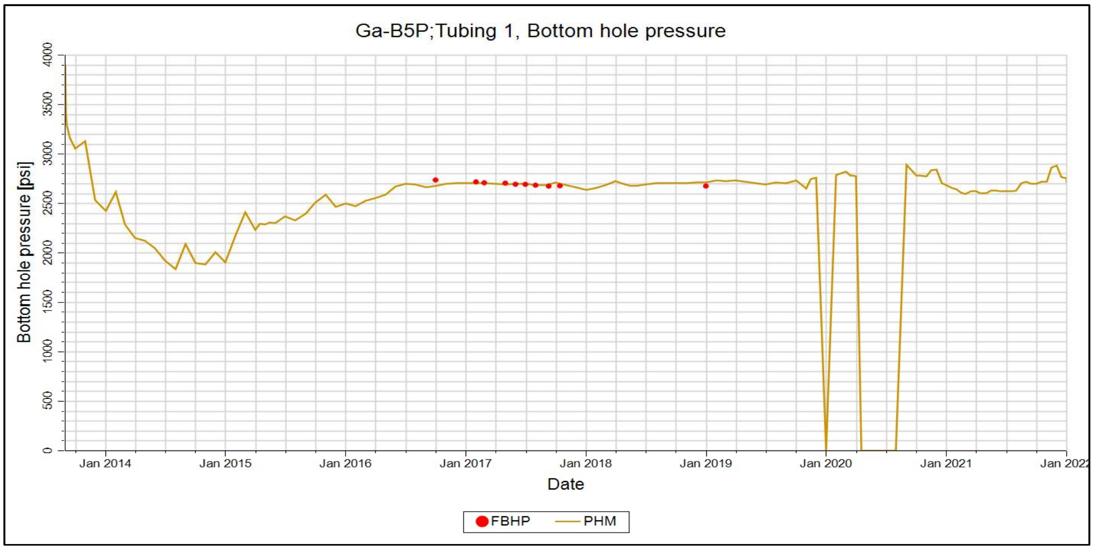

Fig. 18. History Matching of Well Ga-B5P

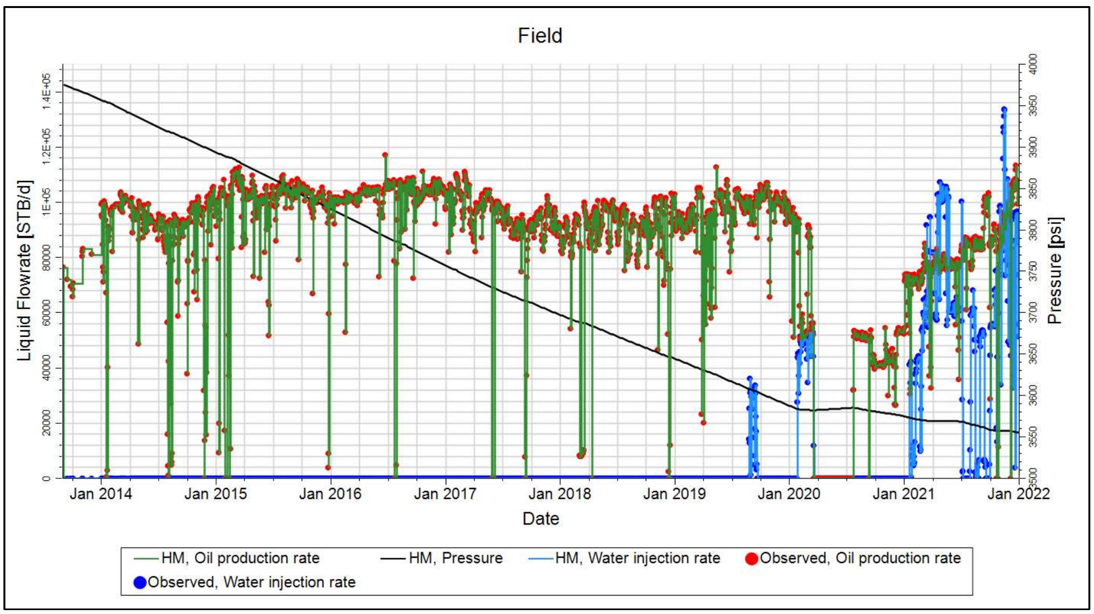

Fig. 19. History Matching of the Field

4- Conclusion

A full-field reservoir model for the Meshrif formation in the Garraf Oil Field was constructed. It was calibrated focusing on production/injection data and pressure measurements for the wells. Based on the results, horizontal permeability was identified as the most influential parameter in achieving a robust history match. A good history match of the oil production and water injection rates data has been achieved for all tested wells. However, the matching process for the bottom hole pressure illustrates a reasonable match. This was achieved via an iterative improvement process which included a notable multiplication of horizontal permeability by a factor of 3.8, and efficiently aligned observed data with simulation results. The well-calibrated reservoir model resulting from this comprehensive calibration process can be a reliable tool for predicting the future performance of the Garraf oil field. Its validity, established through the history matching process, indicates its effectiveness in formulating a variety of development strategies.

Nomenclature

OOIP: Original oil in place, STB
μ_w: formation water viscosity, cp
C_w: formation water compressibility, 1/psi
B_w: water formation volume factor, rb/stb
B_o: oil formation volume factor, rb/stb
R_{si}: initial gas solubility, SCF/STB

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معايرة الموديل المكمني لحقل الغراف النفطي

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الخلاصة

معايرة الموديل المكمني هي الطريقة الأكثر عملية لتقييم صلاحية الموديل المكمني . من الضروري إنشاء موديل يصور بدقة جريان الموائع في المكمن في الماضي لأستخدامه كأداة للتنبؤ بأدائية المكمن في المستقبل. مكمن المشرف من المكامن الرئيسية في حقل الغراف النفطي. تم استخدامه في هذه الدراسة لبناء موديل مكمني متكامل ب ١١٠ بئر منتج. الموديل الجيولوجي المفصل الذي يعكس توزيع النفاذية و تشبع الماء والمسامية و نسبة صافي السمك الى السمك الكلي كان هو الاساس لبناء الموديل المكمني. بيانات الحجم والضغط والحرارة وخصائص الصخرة (النفاذية النسبية و الضغط الشعري وانضغاطية الصخرة) وموقع ومسار كل بئر وبيانات اكمال الابار و الظروف الابتدائية ومعدلات الإنتاج والحقن اليومية وقياسات الضغط الشهرية لكل بئر، كل هذه البيانات تم استخدامها معآ من اجل تشغيل الموديل المكمني. تم التحقق من صحة نتائج التهيئة (initialization results) من خلال مقارنة قيم المخزون الابتدائية المحسوبة من الموديل الجيلوجي مع قيم المخزون الابتدائية المحسوبة من الموديل المكمني. تمت معايرة الموديل المكمني من خلال عملية تطابق لبيانات سابقة (History matching) حيث تتضمن مقارنة القيم المقاسة المدخلة لبرنامج المحاكاة مع نتائج برنامج المحاكاة والتي تشمل بيانات الإنتاج والحقن لكل بئر والقياسات المتوفرة للضغط لبعض الابار. تم تحديد النفاذية الافقية على انها اكثر عامل مؤثر في عملية (history matching) في هذه الدراسة. تم تعديلها مرات عدية من اجل الحصول على تطابق لكل بئر على حدا وللمكمن. ان معايرة الموديل المكمني سوف تسمح للخطوة اللاحقة وهي عمل عدة سيناريوهات من اجل التنبؤ بأدائية حقل الغراف في المستقبل.

الكلمات الدالة: تطابق التاريخ, الموديل المكمني، حقل الغراف النفطي، مكمن المشرف، موديل ديناميكي.