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Integrated Reservoir Evaluation: Oil in Place Estimation, Aquifer Characterization, and Future Production Prediction, a Case Study of Zenad-Farrud Reservoir

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ABSTRACT: The accurate estimation of original oil in place (OOIP) and the optimization of reservoir production performance are critical tasks in petroleum engineering, the material balance MB method is a powerful technique used to study reservoir performance and describing the important properties of the reservoir, including the estimates of original oil in place, and the strength of aquifer. It also provides the understanding of drive mechanisms at work.This paper aims to determine the OOIPof the Zenad oil field using both volumetric Method, Material Balance method identified by MBAL software. Additionally,it seeks to detect the presence of an aquifer in the field, characterize its strength, and predict future reservoir performance. In this study energy plot are used as diagnostic tools to identify the aquifer type based on the signature of production and pressure behavior. Two scenarios involved in MBAL software; the first isbuilding a reservoir model without aquifer connecting, and the other tested different aquifer models to matching observed reservoir and simulation data. The findings of this work showed that, Schilthuis Steady State model best describes the Zenad aquifer with a minimum standard deviation of 0.17365. Results also indicated that the Zenad oil field has a weak aquifer. The OOIP value estimated by the volumetric method is 405 MMSTB, while MBAL software estimates it at 465 MMSTB, a difference of about 12% due to early data collection issues and heterogeneities in reservoir parameter calculations. Future production show that injecting 5400 STB/D of water with a flow rate of 3000 STB/D will yield 69.6 MMSTB of cumulative oil and a recovery factor of 14.9% by 2032. With a flow rate of 4000 STB/D, injecting 7500 STB/D of water will sustain pressure, increasing cumulative oil to 72.98 MMSTB and the recovery factor to 15.67%.

Keywords: MBAL Software, Aquifer, Original oil in place, PerformancePrediction.

الملخص: يُعدّ التقدير الدقيق لكمية النفط الأصلية الموجودة في المكمن (OOIP) وتحسين أداء إنتاج المكمن من المهام الحاسمة في هندسة البترول. وتُعتبر طريقة موازنة المواد (MB) تقنية فعّالة لدراسة أداء المكمن ووصف خصائصه المهمة، بما في ذلك تقديرات كمية النفط الأصلية الموجودة في المكمن، وقوة الخزان الجوفي. كما تُسهم هذه الطريقة في فهم آليات الدفع العاملة. تهدف هذه الورقة البحثية إلى تحديد كمية النفط الأصلية الموجودة في المكمن لحقل زيناد النفطي باستخدام كلٍ من الطريقة الحجمية وطريقة موازنة المواد التي يُحددها برنامج MBAL. بالإضافة إلى ذلك، تسعى الدراسة إلى الكشف عن وجود خزان جوفي في الحقل، وتحديد خصائصه، والتنبؤ بأداء المكمن في المستقبل. في هذه الدراسة، تُستخدم مخططات الطاقة كأدوات تشخيصية لتحديد نوع الخزان الجوفي بناءً على خصائص الإنتاج وسلوك الضغط. يتضمن برنامج MBAL سيناريوهين: الأول هو بناء نموذج للمكمن دون ربطه بخزان جوفي، والآخر هو اختبار نماذج مختلفة للخزانات الجوفية لمطابقة بيانات المكمن المرصودة وبيانات المحاكاة. أظهرت نتائج هذه الدراسة أن نموذج Schilthuis للحالة المستقرة يصف طبقة المياه الجوفية في حقل زيناد على أفضل وجه، بانحراف معياري أدنى قدره 0.17365. كما أشارت النتائج إلى أن حقل زيناد النفطي يتميز بطبقة مياه جوفية ضعيفة. وقد بلغت قيمة المخزون الأصلي في المكان (OOIP) المقدرة بالطريقة

الحجمية 405 مليون برميل، بينما يقدرها برنامج MBAL بـ 465 مليون برميل، وهو فرق بنسبة 12% تقريبًا، ويعزى ذلك إلى مشاكل في جمع البيانات الأولية وعدم تجانس حسابات معلمات المكمن. تشير التوقعات المستقبلية للإنتاج إلى أن حقن 5400 برميل قياسي يوميًا من الماء بمعدل تدفق 3000 برميل قياسي يوميًا سيؤدي إلى إنتاج 69.6 مليون برميل قياسي من النفط التراكمي وعامل استخلاص بنسبة 14.9% بحلول عام 2032. ومع معدل تدفق 4000 برميل قياسي يوميًا، فإن حقن 7500 برميل قياسي يوميًا من الماء سيحافظ على الضغط، مما يزيد من النفط التراكمي إلى 72.98 مليون برميل قياسي وعامل الاستخلاص إلى 15.67%..

الكلمات المفتاحية :برنامج MBAL، طبقة المياه الجوفية، النفط الأصلي الموجود في مكانه، توقعات الأداء.

I. Introduction

The activities of reservoir engineering fall into three general categories like Reserve estimation, development planning and production operation optimization Sapale et al. (2019).A reservoir engineer roles to continuously monitor the reservoir, data acquisition, data analysis to validate and interpretation of these data which is able to characterize the corresponding reservoir system, evaluate past, present and forecast future reservoir performance to control the flow of fluids inside the reservoir with aimed to increase cumulative oil production, ultimate oil recovery and accelerate oil recovery under various types of natural driving mechanism Sapale et al. (2019). Water drive is usually the most efficient reservoir driving force in oil reservoirs. Recovery efficiencies may vary from 30% to 80%, depending upon the size and strength of the aquifer Ahmed. (2001). Formation of any hydrocarbon reservoir requires aquifers, porous rocks, which basically let the oil or gas flow through them and get accumulated in a porous and permeable layer bounded by an impermeable soil. These aquifers may be substantially larger than the oil or gas reservoir they adjoin as to appear infinite in size, and/or they may be as small in sizeAs to be negligible in their effect on reservoir performance. To determine the effect that an aquifer has on oil and gas production, it is important to estimate the amount of water that has entered into the reservoir from the aquifer. So, water influx that is water that enters the reservoir and it is responsible for primary recovery of hydrocarbons. Its sources are the aquifer beneath the reservoir, surface water from outcrops and water injection from the surface to supplement a weak aquifer Belomo. (2022) et al..Estimating reservoir water influx amounts isimportant for various applications, including material balance for reserve estimation, reservoir simulation studies for model calibration, production scheduling, and development strategies to maximize hydrocarbon recovery. With the help of an efficiency aquifer model that can reflect the genuine dynamics of the petroleum subsurface system, an accurate calculation of water influx into the reservoir is required . Ahmed. (2001).

The role of reserves estimates in operational, financial, and policy decisions emphasizes the need for the estimates to be as accurate and current as possible. The methods used to estimate reserves and the accuracy of the result depend on the type, amount and the quality of geologic and engineering data available The different methods used to estimate reserves may be applied to be connected or to be compared together to provide a possible reliable estimation of the property Metsebo. (2022)..In the field of integrated reservoir evaluation, a significant challenge lies in accurately estimation oil in place while ensuring reliable aquifer characterization and precise production prediction. This study aims to address this challenge effectively by conducting a comparative analysis between two prominent methods: volumetric analysis and Material Balance Equation. Additionally, for MBE analysis will using one of the advanced software tools called MBAL software to enhance the accuracy of OOIP estimation, refine aquifer characterization, and improve production performance prediction where various data sets and employing simulation models to forecast the reservoir′s behavior under different production scenarios.

II. Case Study – Zenad Oil Filed

The Zenad Field is located in the concession 11 south-western part of Haroug′s Area 87/88/103 in the western Sirte Basin. The Zenad-Farrud reservoir is a structural high, covering 3100 acres, between the Maamir trough and the Ramla syncline, and is bounded by the NW-SE trending faults and water table.The Field was discovered in February 1980 by completing wildcat VVV1-11 in the Farrud formation. Wells with initial production test rates of more than 3000 BOPD were common. Peak production, of 12,000 BOPD occurred in June 1987.

The ZenadFarrud reservoir was discovered undersaturated, at the initial pressure of 2399 psia, and the solution GOR of 465 SCF/STB. Reservoir fluid bubble point pressure was determined to be 1728 psia. Crude is of 38º API gravity and is sweet. The reservoir has been undergoing development in the recent years and to date, 18 wells have been completed in this reservoir.In order to arrest the decline in the reservoir pressure, two wells (VVV8 & AAAA3) were converted to water injectors in November 1989, and 4 wells were converted to injector later, namely; VVV2. VVV10, VVV11 and VVV13. Current water injection scheme comprises of 6 injectors and is supporting approximately 4591 BOPD of production.The last pressure surveys run in May 2014 shows average reservoir pressure without injectors to be 2116 psi at a datum depth of 5260 ft Craft et al. (1991). The cumulative production performance of the Zenad oil field is shown in figure 1. Average fluid properties and average Rock Properties of the field are shown in Table 1.

Table 1: Average rock and fluid properties of Zenad oil field[5].

Properties	Symbol	Value
Area	A	3100 (acres)
Average net pay thickness	H	126ft
Original reservoir pressure	P_i	2415 (psia)
Oil gravity	API^O	40.64
Oil formation factor	B_o	1.334 (bbl/STB)
Oil viscosity	μ_o	0.61
Porosity	Ø	22%
Solution gas oil ratio	GOR	713 (SCF/STB)
Saturation pressure	P_b	1732 (psia)
Temperature	T	180º F

III. Volumetric Methods

The oil in place was determined by the volumetric method by using data generated from geological and petro physical evaluation (areal extent, formation sand thickness, porosity and the saturation etc.) and computing the initial oil in place from the general formula [Metsebo. (2022).].

The governing equation for the volumetric estimation of oil in place is given as:

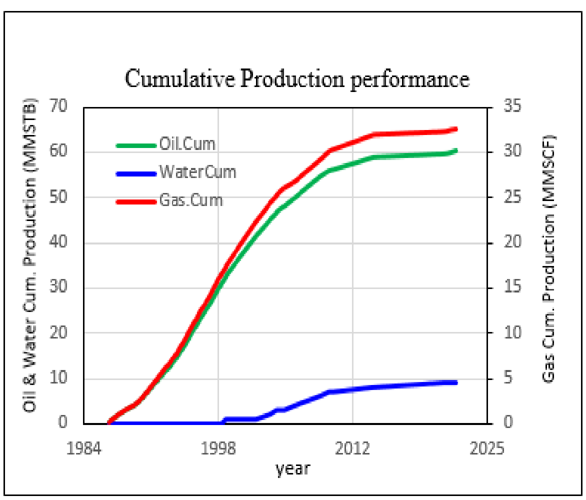
$$N = \frac{7758 \times A \times h \times \emptyset \times (1 - S_{wi})}{\beta_{oi}}, (STB) \quad (1)$$

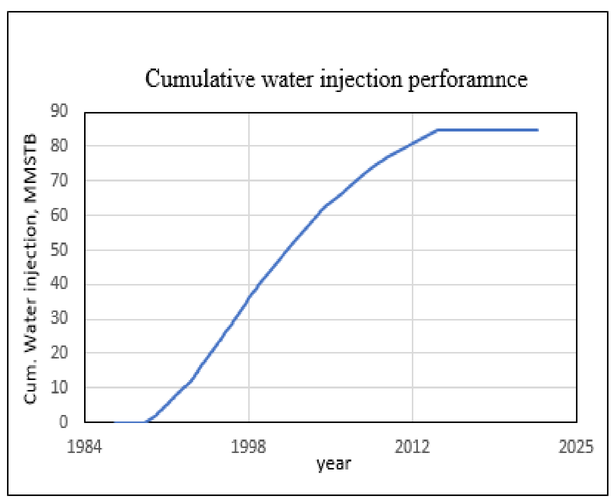
IV. Material Balance Method

The material balance equation (MBE) has long been recognized as one of the basic tools of reservoir engineers for interpreting and predicting reservoir performance[AAPG.]. Schilthuis in 1941 was the first to present the general form of the material balance equation. The equation is derived as a volume balance which equates the cumulative observed production, expressed as an underground withdrawal, to the expansion of the fluids in the reservoir resulting from a finite pressure drop. There was certain assumption made in this technique where reservoir considered as a homogenous tank model [Ahmed. (2001)].By using the material balance method, the Volume of oil in place is given by:

$$N = \frac{N_P\left(B_t + (R_s - R_{si})B_g\right) - \left(W_e - W_p B_w\right)}{B_t - B_{ti} + mB_{ti}\left(\frac{B_g}{B_{gi}} - 1\right) + B_{ti}(1+m)\left[\frac{S_{wi}C_w + C_f}{1 - S_{wi}}\right]\Delta p} \quad (2)$$

MBAL software based on this concept while using minimum data the reservoir engineer can be used this tool for reservoir analysis throughout the life of the field. Basic equation used in MBAL software i.e.





$$F = N\left[E_o + mE_g + E_{f,w}\right] + W_e \qquad (3)$$

V. Water Influx Models

Natural influx of water in oil reservoir surrounded by water aquifers play a very important role in increasing oil recovery. The calculation of water influx is very difficult as it involves many uncertainty such as aquifer size, shape, and structure and aquifer rock properties [Craft et al. (1991)]. To the determination of water influx required a mathematical model which relies on aquifer properties. The material balance equation can be used to determine historical water influx provided original oil-in-place is known from pore volume estimates. The mathematical water influx models that are commonly used in the petroleum industry include [Craft et al. (1991)]:

- Pot aquifer model
- Schilthuis' steady-state model
- Hurst's modified steady-state model
- The Van Everdingen-Hurst unsteady-state model
    - **a.** Edge-water drive.
    - **b.** Bottom-water drive.
- The Carter-Tracy model.
- Fetkovich's method.
    - **a.** Radial aquifer.
    - **b.** Linear aquifer.

In MBAL software to build a correct aquifer model required 'try and see it' for correct matched with field history data. Different Aquifer influx modeled were checked from which a suitable match of reservoir trend was selected by used a sensitivity analysis and agreement between OIIP value estimated by Volumetric and MBE method.

VI. Method/Procedure

The figure below shows the flow chart of study when work on MBAL:

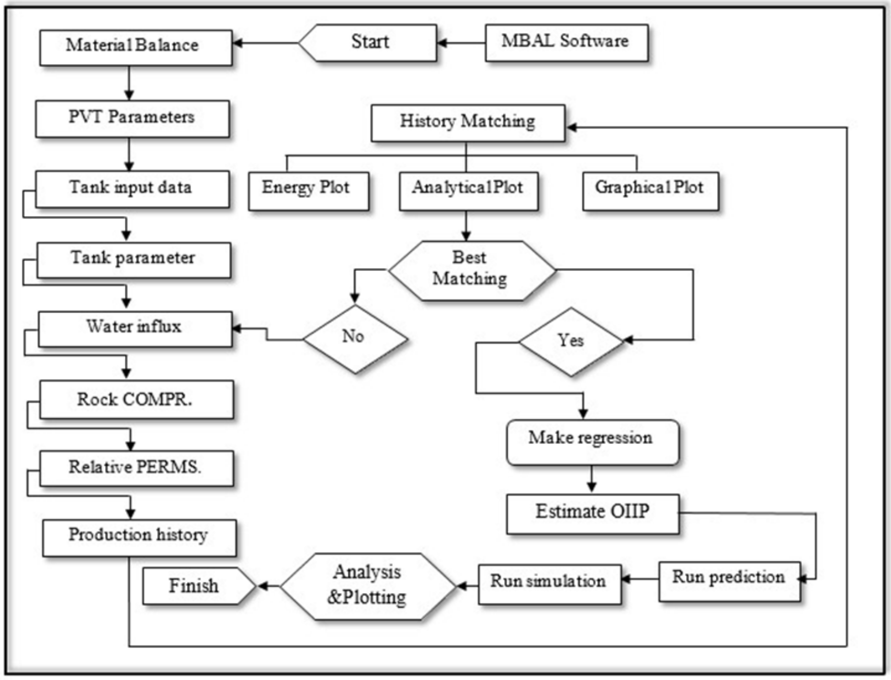


Figure 3: Flow chart explain the steps of methodology of MBAL used in this study.

VII. Results and Discussion

The results obtained from the volumetric method calculations by using Excel software and simulations by using MBAL software are presented and discussed in this section.Where the PVT data, initial reservoir pressure, reservoir average pressure history, production history and all available reservoir and aquifer parameterswere needed for the estimation of in place volume by using the material balance method.

1. Volumetric Method

For estimating reserves through the volumetric methods, the formula (1) is integrated in Excel software following by data available. Table 1 showing the results obtained:

Table 2: Volumetric method calculations on Excel software.

Petrophysical data	Value	Units
Oil FVF	1.334	Bbl/STB
Water saturation	0.19	Frac.
Porosity	0.22	Frac.
Thickness	126	ft
Area	3100	Acre
Result (OIIP)	405	MMSTB

2. Material balance (MBAL software)

The history matching is used to determine and identify sources of reservoir energy and their magnitude, the value of original oil in place, original gas in place, aquifer type and strength etc. [Metsebo. (2022).].The idea behind history matching was that the model input is adjusted to match the field pressure and production history data[Sapale et al. (2019)].Two different types of histories matching are used: Analytical and graphical methods, and there are Two assumptions supposed in this study, the first one isbuild the reservoir model without aquifer influxto distinguish if the reservoir is in contact with aquifer influx or the reservoir layer isolated, and the second is aquifer model is involved with the model.

i. Analytical plot without aquifer

The Analytical plot represents the cumulative oil production as a function of reservoir pressure decline in figure 4. As seen the Plot shows considerable deviation between history matching data and history matched simulation model result.

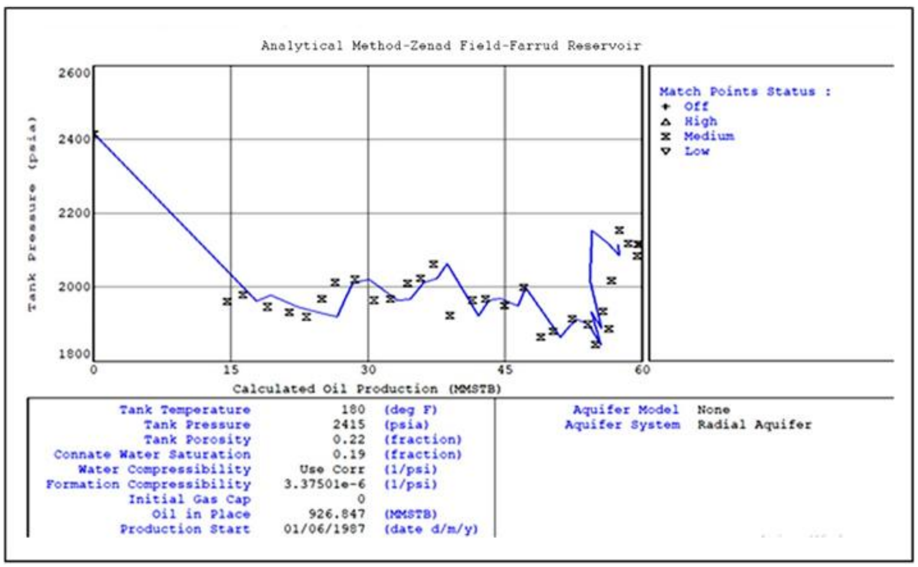


Figure4: Analytical plot of reservoir pressure versus cumulative oil production without aquifer.

As a result of inaccuracy of the first assumption, the second assumption must be applied to improve the quality of the matching by including the aquifer into reservoir model.

ii. Analytical plot with aquifer

After it had performed different water influx models, the results found that the most representing water influx model for the reservoirbased on the standard deviation and agreement between OIIP value estimated by Volumetric and MBE method is a schilthuis steady state model with standard deviation about 0.17365 and diffusivity about 2.0088 (RB/Psia/Day),as seen in figure 5 there is good matching between observed data and simulation.

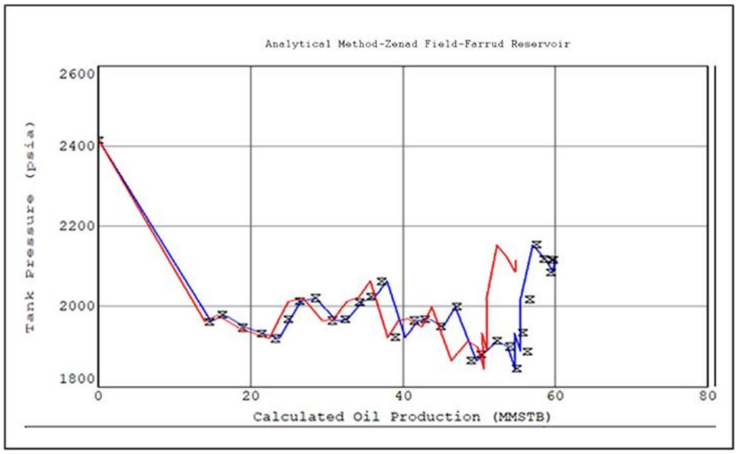


Figure5: Analytical plot with aquifer (Schilthuis' steady-state model).

Graphical method

In this study the graphical method was used to evaluate model results of Zenad Field is F/E_t versus We/E_t in order to estimate the value of the oil initial in place, which turned out to be an acceptable results and good straight line as seen in figure below:

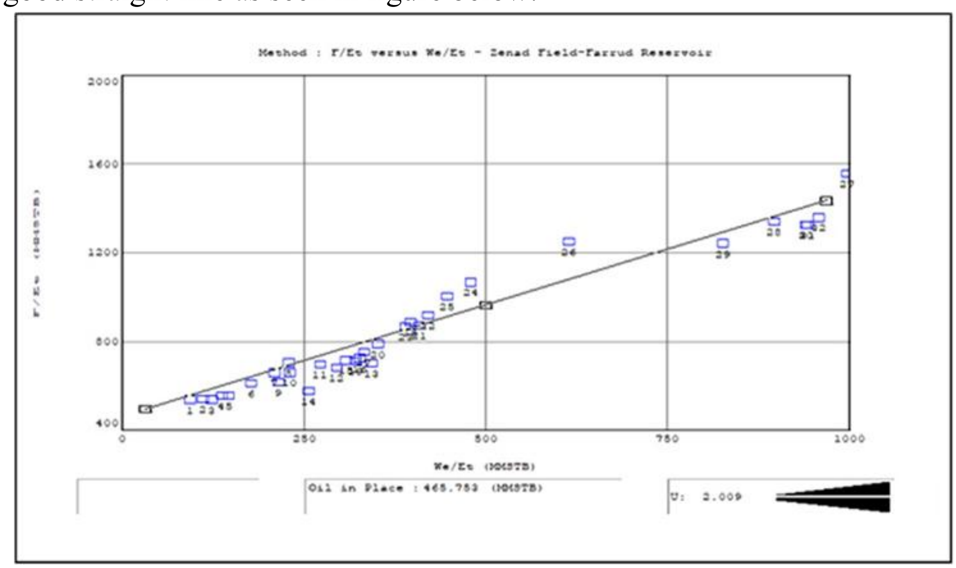


Figure 6:OIIP Calculation Using Schilthuis' steady-state model.

iii. The Energy of the system

Different driving mechanism plays a role into reservoir for providing enough energy for the system.In the case of drive indices plot (Energy plot) in MBAL software, various sources of energy available in the (Zenad-Farrud) reservoir are drawn in a single plot as a function time.The result showed that three drives affecting the recovery of oil which are Pore Volume Compressibility, Fluid Expansion, and water influx. Fluid expansion identified as a dominated energy in the system until the end of year 1989, because there is a less support from aquifer (weak water drive) which leading to use secondary recovery techniques at the early life of the reservoir to provided pressure maintenance, then water injection become a dominated energy source in the system.

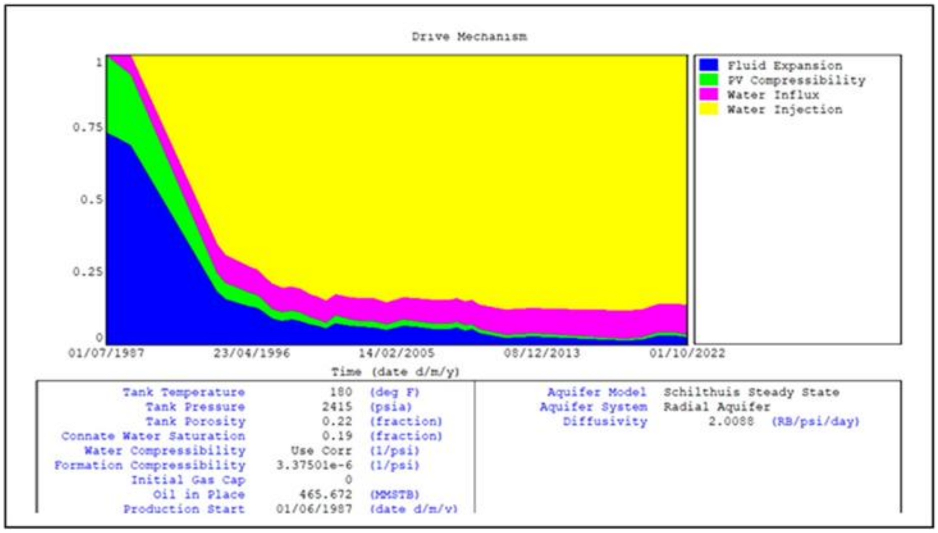


Figure 7: Energy plot.

iv. Performance Prediction/Forecasting

After acceptable history matched obtained, where found that schilthuis model is the optimum water influx model match with the Zenad Field. The prediction of the future performance in the studied reservoir is the final step on the MBAL software. In this study two scenarios has been performed to predict the reservoir performance for ten years,<u>First Case: constant rate of oil producing 3000STB/day, and injection water rate 5400STB/day.</u>

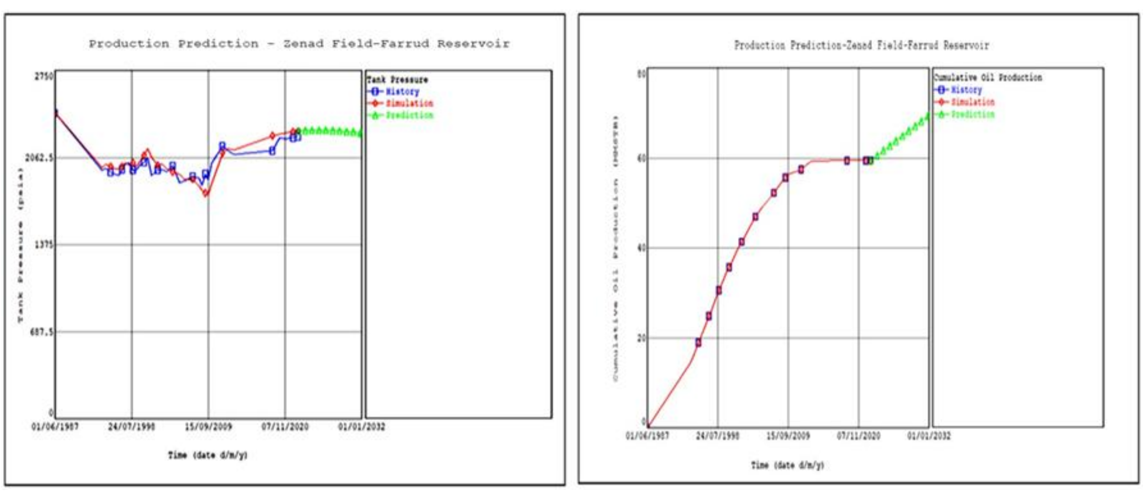


Figure 8: Performance prediction of reservoir and History match data plotted (first case).

Second Case: constant rate of oil producing 4000STB/day, and injection water rate 7500STB/day.

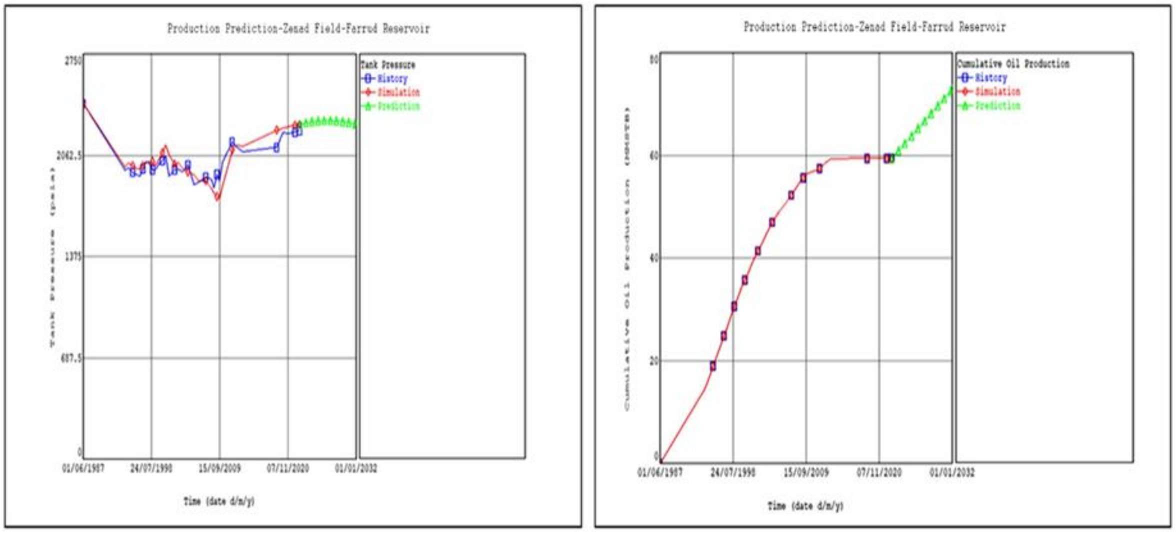


Figure 9: Performance prediction of reservoir and History match data plotted (second case).

As shown by the prediction results through the two scenarios, it is possible to know which the flow rate gives the best oil recovery factor and cumulative oil producing, and this will provide the information regarding water injection requirement to sustain the reservoir pressure and economic limit of the reservoir. The following table illustrates the different between results:

Table 3: prediction performance results.

The cases (Oil producing rate)	Water inj. Rate (STB/day)	Pressure (Psia)	Cum.oil production (MMSTB)	Recovery factor (%)
3000 STB/day	5400	2257.07	69.6	14.9
4000 STB/day	7500	2274.7	72.98	15.67

VIII. Conclusion

From this study, the following summarizes the major conclusions:

1. The volumetric and material balance methods are independent ways to estimate fluid initially in place. Since the basic assumptions for each method are different, the two methods may not account for the same volume of hydrocarbons, which might lead to significant differences between estimates.
2. It was found that the volumetric method gave estimated oil in place of about405MMSTB, while the oil in place generated from MBAL software was 465MMSTB. The absolute error between the two values was about 12%.
3. The OIIP estimated by volumetric method is less than the value estimated by MBE, this is might been due to inconsistency in the petro physical data used for the analysis.For further analysis of the reservoir a dynamic model like Eclipse Software is recommended.

4. In reservoir engineering material balance equation has proven to be a very useful tool to detect the presence of aquifer. The energy plot is one such graphical technique. It's very useful as diagnostic tools for detecting and characterizing aquifer and water drive strength.
5. Energy plot showed a weakwater drive for the reservoir.The main source of energy maintained the reservoir pressure is the water injection and become an early assistance in its production lifespan.
6. The schilthuis steady state model is considered to be the best water flow model for the Zenad oil field, with a lower error value about 0.17365 and diffusivity about 2.0088 (RB/Psia/Day).
7. The history reservoir pressure curve is matching to the stimulation curve, this gives a good allusion of the input data that has been entered to the model.
8. In evaluating the two scenarios for predicting reservoir performance, the second scenario demonstrated slightly better technical performance by producing more oil and achieving a higher recovery factor. The enhanced recovery and sustained reservoir pressure indicate a more efficient extraction process, suggesting being long-term reservoir management.
9. From an economic perspective, the first scenario typically has lower operating costs compared to the second scenario where there is an increase in water injection rate, although this can vary based on numerous factors such as efficiency, technology, and scale.

IX. Acknowledgment

The authors would like to thankthose who provided guidance and support during this research.

Nomenclature

B_g	Gas formation volume factor, bbl/scf
B_{gi}	Gas formation volume factor at initial reservoir pressure, bbl/scf
B_o	Oil Formation Volume Factor, bbl/STBs
B_{oi}	Oil Formation Volume Factor at initial reservoir pressure, bbl/STB
B_w	Water Formation Volume Factor, bbl/STB
c_f	Formation compressibility, psi^{-1}
c_w	Water compressibility, psi^{-1}
E_g	Cumulative gas expansion, bbl/STB
$E_{f,w}$	Cumulative formation and water expansion, bbl/STB
E_o	Cumulative oil expansion, bbl/STB
Et	Cumulative total expansion, bbl/STB
F	Cumulative reservoir voidage, bbl
M	ratio of initial gas cap volume to initial oil zone volume at reservoir conditions, dimensionless
N	Stock tank oil initially in place, STB

N_p	Cumulative Oil Production, STB
R_s	Gas Solubility, scf/ STB
R_{si}	Gas solubility at initial reservoir pressure, scf/STB
S_{wi}	Initial water saturation, fraction
W_e	Cumulative water influx, bbl or STB
W_p	Cumulative water production, STB
μ_o	Oil viscosity, cp
ΔP	Average change in reservoir pressure, (pi − p), psia
P_i	Initial reservoir pressure, psia

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