NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

Analysis of a Saturated Oil Reservoir using Material Balance Tool : A Case Study in an Onshore Niger Delta Field.

Paul Osaze Ogbeide and *James Ojo Alleh
Department of Petroleum Engineering, University of Benin, Edo State, Nigeria.
*Corresponding Author Email: jamesalleh@gmail.com

Article information

Article History
Received 20 May 2023
Revised 27 May 2023
Accepted 30 May 2023
Available online 12 June 2023

Keywords:
Aquifer , Drive mechanism , Operational production scheme , Well positioning, Reservoir geometry, Tank model, Gas-to-water injection

OpenAIRE

https://doi.org/ 10.5281/zenodo.8025454

https://nipes.org

Abstract

The continual necessity in the oil and gas industry to establish the exact amount of oil and gas initially in place in the reservoir is of great relevance. This research work is primarily aimed at studying the performance of a saturated oil reservoir in an onshore Niger Delta field using Material Balance Analysis, with specific goals of estimating the initial oil in place, determining the presence of an aquifer and its strength, estimating a suitable drive mechanism, and determining the best operational production scheme that would maximize recovery. The majority of the data used in this study was obtained from Integrated Data Services Limited (IDSL). IDSL also provided the software used in this study. The Material Balance (MBAL) tool, which is a simplified analytical tool used to discover reservoir features utilizing the principle of material balance(conservation of mass), is the simulation software that was employed for the case of this study. The material balance software predicts reservoir behavior using a conceptual model based on its effect on reservoir fluid production and gas-to-water injection. From the MBAL software, the reservoir was seen to have 104.06 MMSTB of oil initially in place and the predicted volume of water in place to be 81706.1 MMft^3*. Furthermore, the effect of the aquifer on reservoir pressure demonstrates that water drive is the most predominant driving mechanism responsible for production.*

1. Introduction

Water The distinct temperature and pressure regimes of reservoirs and their hydrocarbon-containing power has encouraged the use of scientific and technological tools in estimating oil and gas reserves. The fundamental theories used to evaluate reservoir dynamics is the material balance equation. Material balance analysis is an analytical method that assesses reservoir behavior by measuring physical parameters such as specific gravity, viscosity, or using empirical tests. The determination of the oil and gas initially in place, as well as the prediction of future reservoir performance, is critical in the oil and gas sector, which has led to the development of several material balance equations and modifications by various scientists.[1]

The earliest useful oil and gas reservoir Material Balance equations was derived by Schilthius (1936) [2] . The use of the Schilthius equation in estimating future reservoir performance has proven time-consuming, with numerous estimates required at each phase of the trial-and-error computation before arriving at a check of the oil in situ. It essentially states that "conservation of mass and is a method of accounting for the volumes and quantities of fluids produced from injected fluids and remaining oil in the reservoir at any state of depletion." [3] Tarner (1944) and [4] Muskat (1945) provided methods for predicting the performance of depleted (solution-gas)-drive reservoirs utilizing rock and fluid parameters under internal gas drive methods. Both approaches make the premise of negligible gravity segregation forces. As a result, these authors exclusively considered thin, horizontal reservoirs. Both methods forecast reservoir performance at pressures where gas saturation exceeds the critical value using the material balance principle (static) and a producing gas-oil ratio equation (dynamic). A more extensive explanation of both strategies may be found in (Craft and Hawkins 1991) [5].

The Tarner, Muskat, and Tracy technique improved the material balance equation through several adjustments for predicting reservoir performance by employing time functions. These allow the reservoir engineer to history match and predict the reservoir's performance. The following assumptions were typically used in various prediction methods:

- Uniform porosity, fluid saturation, and relative permeability at all times.
- Uniform pressure throughout the reservoir in both the gas and oil zones.
- Negligible gravity segregation forces.
- Equilibrium at all times between the gas and the oil phases.
- No water encroachment , Negligible water production.

[6] Duffaut and Torsaeter (2019) conducted a study on material balance methods for oil reservoir simulation. They reviewed various approaches to material balance, including analytical, numerical, and statistical techniques, and assessed their strengths and weaknesses. The study emphasized the significance of accurate initial oil in place and recovery factor estimates for effective reservoir management. The authors also emphasized the need to combine material balance methods with other reservoir characterization methods, such as well log analysis and fluid sampling, to increase accuracy. Additionally, they identified challenges, such as uncertainties in data quality and modeling assumptions, and suggested that incorporating uncertainty analysis and sensitivity analysis would provide valuable insights. Overall, the study provided a thorough overview of material balance methods and their potential for enhancing oil reservoir management and production optimization.

A study by [7] Olajumoke et al. (2017) applied material balance methods to analyze four wells in the Niger Delta region. The researchers used both numerical and analytical methods in their analysis, and findings showed that the four wells had declining reservoir pressure and varying quantities of remaining oil. They also identified that the reservoirs had been invaded by water, which affected oil production rates. The study's findings showed that material balance techniques could provide crucial insights into oil reservoir behavior and aid proper reservoir management and production optimization in the region.

[8] Oseni et al. (2019) applied a numerical material balance method to analyze an oil reservoir in the Niger Delta region. The researchers used production data from six wells in the field and found that the reservoir was initially overestimated, but the updated reserve was sufficient to sustain production for an extended period. They also noted that pressure data were critical in estimating

the remaining oil in the reservoir, and recommended pressure build-up tests to obtain accurate pressure data.

In 2021, [9] Oyekoya et al. conducted a material balance analysis of an oil reservoir in the Niger Delta, using production data from seven wells. They employed both analytical and numerical methods and found that water influx was the primary cause of pressure decline and that the remaining oil in the reservoir was less than initially predicted. They also proposed a new methodology that combined both analytical and numerical techniques for more accurate estimates of reservoir parameters.

In a study by [10] Daramola, et al. (2019) on a depleted sandstone reservoir in offshore Niger Delta, material balance calculations were used to estimate the initial oil in place and the remaining oil. The authors used data from well logs, fluid samples, and production history to carry out the analysis. The study revealed that the reservoir initially had 300 million barrels of oil in place, and the current recovery factor was 25%. The researchers recommended the use of gas injection and water flooding to increase the recovery factor.

A study by [11] Olotu, et al. (2018) presents a material balance analysis of an onshore Niger Delta field's oil reservoir. The authors used well log and production data to estimate the original oil in place and the remaining oil in the reservoir. The study revealed that the reservoir initially contained 40 million barrels of oil, and the current recovery factor was 20%. The authors recommended the use of gas injection and water flooding to improve the recovery factor and increase the reservoir's production.

A study by [12] Adenuga, et al. (2018) analyzed an onshore Niger Delta field's oil reservoir using material balance calculations. The authors used production data and well log analysis to estimate the original oil in place and the remaining oil in the reservoir. The study revealed that the reservoir initially contained 15.8 million barrels of oil, and the current recovery factor was 25.6%. The authors recommended the use of enhanced oil recovery techniques such as water flooding and gas injection to improve the recovery factor.

This research seeks to address the following:

- To estimate the initial oil in place using the Material Balance Model in "MBAL" software
- To determine the presence of an aquifer and its strength
- To estimate a suitable drive mechanism
- To give the best operational production scheme that would maximize recovery.

The relevance of this study is to effectively use MBAL to predict the Onshore Niger Delta Field reservoir performance and recommend an economic recovery strategy as an implied production optimizer using data from an onshore Niger Delta Field Reservoir. Therefore, this research work utilizes Tarner's technique for predicting the performance of the reservoir , considering rock and fluid parameters, to forecast reservoir behavior.

2. Materials and Method

The methodology involved the utilization of a commercial software called Material Balance software (MBAL) for the evaluation and analysis of reservoir characteristics based on the material balance concept. MBAL is a widely used industry-standard software specifically designed for reservoir engineering applications. It offers a comprehensive set of features to assess and model the behavior of oil reservoirs. MBAL incorporates advanced algorithms that enable the software to perform history matching, a process of adjusting model parameters to match the observed production and pressure data from the reservoir. Through history matching, MBAL can calibrate the reservoir model to accurately represent the behavior of the actual reservoir. This calibration is essential for reliable prediction of future reservoir performance.

In this study, the Hurst-Van Everdingen model was selected as the radial flow model to characterize the reservoir behavior. This model is recognized in the industry for estimating radial flow and considering the presence of an aquifer in the reservoir system. The model assumes a uniform reservoir, isotropic permeability, and radial flow towards the wellbore. To apply the Hurst-Van Everdingen model, relevant equations and parameters were inputted into MBAL. These included reservoir permeability, thickness, and aquifer properties. The software's history matching options were used to adjust the model parameters and match observed production and pressure data from the reservoir, ensuring an accurate representation of the reservoir conditions.

Once the reservoir model was calibrated, MBAL's prediction capabilities were employed to forecast future reservoir performance based on the material balance principles and the Hurst-Van Everdingen model. This included predicting future production rates, pressure trends, and other key reservoir parameters. By incorporating the Hurst-Van Everdingen model, the analysis aimed to capture radial flow and aquifer effects, enhancing the accuracy and reliability of the reservoir evaluation. The inclusion of this model provided a comprehensive understanding of the reservoir's behavior and improved the reliability of predictions. Overall, the methodology involved the use of MBAL software for material balance analysis, with the specific inclusion of the Hurst-Van Everdingen model to characterize reservoir behavior and enhance the accuracy of the evaluation.

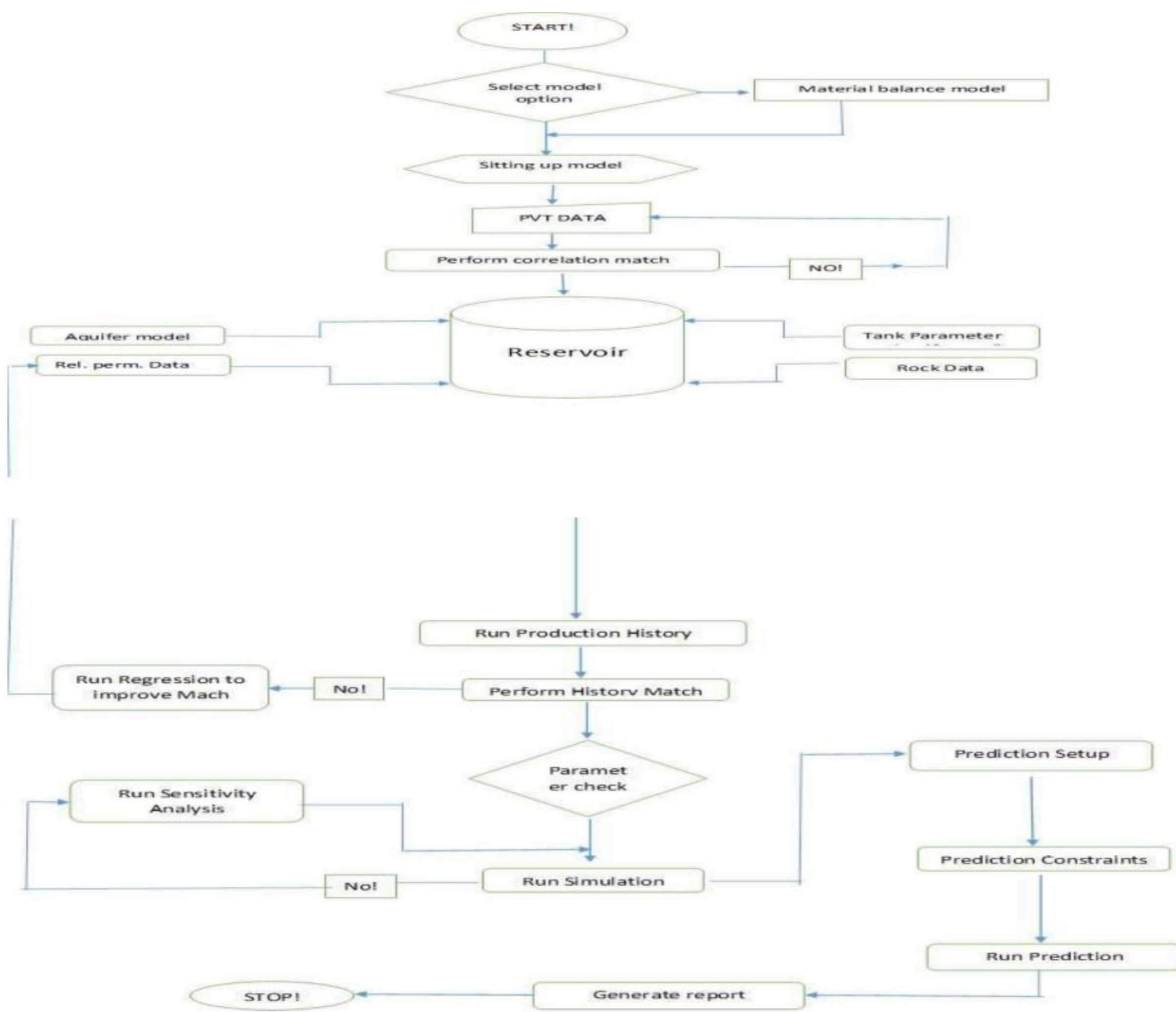

Figure 1: Work flow Diagram for Mbal

The flow chart illustrates the sequential steps involved in analyzing the saturated oil reservoir. Each stage of the flow chart has been elaborated to provide a clear understanding of its purpose and relevance to this study. Data Acquisition: The first step involves gathering essential reservoir data, including production rates, pressure data, fluid properties, and reservoir rock properties. These data serve as inputs for subsequent analysis.

1. Data Acquisition: The first step in the analysis process involves gathering essential reservoir data, including production rates, pressure data, fluid properties, and reservoir rock properties. These data serve as inputs for subsequent analysis.
2. Model Initialization: Once the data is acquired, the reservoir model is initialized within the MBAL software. This step involves incorporating the reservoir geometry, fluid properties, and rock properties based on available data and prior knowledge.
3. History Matching: The history matching process is a crucial step in reservoir analysis. It is performed using MBAL's advanced options and algorithms. During this stage, model parameters are adjusted to achieve a match between the observed production and pressure data and the behavior of the reservoir model. This ensures an accurate representation of the reservoir's characteristics.
4. Calibrated Model: After completing the history matching process, a calibrated reservoir model is obtained. This model accurately represents the behavior of the actual reservoir, taking into account the adjusted parameters from the history matching stage. The calibrated model serves as the foundation for further analysis.
5. Performance Prediction: Using the calibrated model, performance prediction is carried out to forecast the future behavior of the saturated oil reservoir. MBAL utilizes material balance equations and incorporates reservoir and fluid properties to generate predictions of production rates, pressure trends, and other key reservoir parameters. This step provides insights into the reservoir's performance under different conditions.
6. Analysis and Interpretation: The predicted results obtained from MBAL are thoroughly analyzed and interpreted. This analysis involves assessing factors such as reservoir depletion, fluid movement, and overall performance. The interpretation of the results provides valuable insights into the behavior and characteristics of the saturated oil reservoir.
7. Assessment and Decision Making: Based on the analysis and interpretation, informed decisions can be made regarding field development strategies, production optimization, and potential interventions. The assessment stage takes into account the analyzed data and predictions from MBAL to guide decision-making processes for effective reservoir management.

2.1 Mathematical Concept of Material Balance Equation (MBE) Programmed into MBAL

Material balance involves creating balance in their volumes (volume produced = fluid expansion). So, material balance is based on the principle of conservation of mass, which maintains that matter cannot be generated or destroyed but can only change form.

This means that:

Total underground withdrawal (rb) = Expansion of primary Gas cap Gas (rb) + Expansion of Oil + Originally Dissolved Gas (rb) + Expansion of Connate water (rb) + Decrease in (Rock) pore volume (rb).

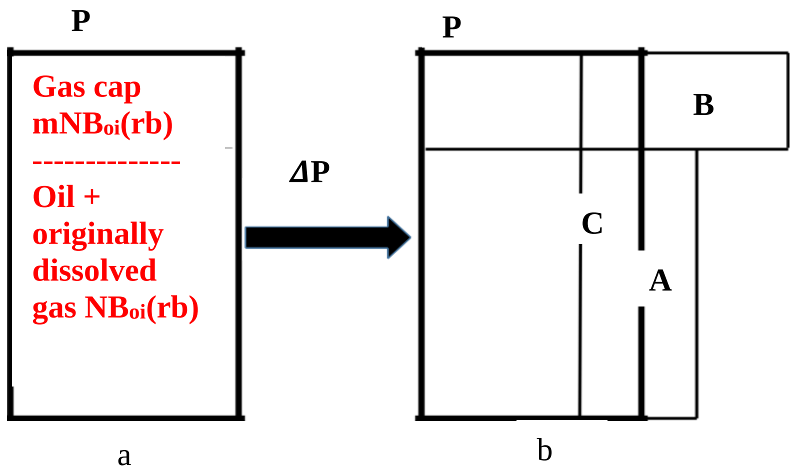

Figure 2: Volume changes in the reservoir associated with a finite pressure drop Δp; (a) volumes at initial pressure, (b) at the reduced pressure

Therefore, the following was noted :

Cumulative Production = Expansion = A + B + C 1

Where,
A = Expansion of the oil + originally dissolved gas (rb)
B = Expansion of the gas cap gas (rb)
C = Reduction in the Hydrocarbon Pore Volume due to connate water expansion and decrease in the pore volume (rb).

The underground withdrawal or surface production = $N_p[B_o + (R_p - R_s)]B_g$ 2

Equating 2 to the sum of the volume changes , a general expression becomes;

$$N_p[B_o + (R_p - R_s)]B_g = NB_{oi}\left[\frac{(B_o + (R_p - R_s)B_g}{B_{oi}} + m\left(\frac{B_g}{B_{gi}} - 1\right) + (1 + m)\left(\frac{C_w S_{wc} + C_f}{1 - S_{wc}}\right)\Delta P\right] + (W_e - W_p)B_w \quad \ldots 3$$

Equation 3 represent the material balance expression.
So, the material balance(MBAL) expression is presented as a straight line in the way presented by Halvena and Odeh,

Underground withdrawal ,

$$F = N_p[B_o + (R_p - R_s)]B_g + W_p B_w \quad \ldots 4$$

Where the Halvena and Odeh defined terms are stated below;

$$E_o = (B_o - B_{oi}) + (R_{si} - R_s)B_g \ldots\ldots\ldots\ldots\ldots\ldots \text{(oil and gas expansion)}$$

$$E_g = \left(\frac{B_g}{B_{gi}} - 1\right) B_{oi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(free gas expansion)}$$

$$E_{fw} = B_{oi}\,(C_w S_{wc} + C_f)\frac{\Delta P}{(1 - S_{wc})} \ldots\ldots\ldots\ldots\ldots \text{(connate water of rock)}$$

Using these terms by substitution,

$$F = N[E_o + mE_g + (1 + m)E_{fw}] + W_e B_w$$

The material balance equation(MBE) becomes ,

$$N = \frac{N_p[B_o + (R_p - R_s)]B_g + W_p B_w}{[E_o + mE_g + (1+m)E_{fw}] + W_e B_w}$$

Where:

N is Initial oil in place in stock tank barrels (stb) = $\frac{V\emptyset(1-S_{wc})}{B_{oi}}$

m is the ratio initial hydrocarbon volume of the gas cap to initial hydrocarbon volume of the oil
(and, being defined under initial conditions, as a constant)

Np is the cumulative oil production in stock tank barrels,

R_p is the cumulative gas oil ratio = Cumulative gas production (scf) to Cumulative oil production (stb)

We = Cumulative water influx from the aquifer into the reservoir, (stb.

W_p = Cumulative amount of aquifer water produced, (stb).

B_w = Water formation volume factor (rb/stb)

$(W_e - W_p)B_w$ = the net water influx in the reservoir

2.2 Analysis of Various Drive Mechanism Using MBE

Evaluating the reservoir drive index , the material balance equation(MBE) is then rearranged to obtain drive indexes; whose sum gives 1. Fractions such as the depletion drive index (DDI), the segregation gas cap index (SDI) , the water drive index (WDI), Compaction Drive Index (CDI), and sometimes injection drive (IDI).

$$\text{Reservoir Drive mechanism} = \frac{\textit{Individual Production Contribution}}{\textit{Total Underground HC Production}}$$

$$\text{Depletion Drive Index(DDI)} = \frac{N[(B_o - B_{oi}) + (R_{si} - R_s)B_g]}{N_p[B_o + (R_p - R_s)B_g]}$$

$$\text{Gas cap Drive Index(SDI)} = \frac{mNB_{oi}\frac{B_g}{B_{gi}} - 1}{N_p[B_o + (R_p - R_s)B_g]}$$

$$\text{Compaction Drive Index (CDRI)} = \frac{(1+m)NB_{oi}\frac{(C_w S_{wc} + C_f)}{(1 - S_{wc})}}{N_p[B_o + (R_p - R_s)B_g]}$$

$$\text{Water Drive Index(WDI)} = \frac{(W_e - W_p)B_w}{N_p[B_o + (R_p - R_s)B_g]}$$

$$\text{Injection Drive Index(IDI)} = \frac{(W_i B_w + G_g B_g)}{N_p[B_o + (R_p - R_s)B_g]}$$

Therefore,

$$DDI + SDI + WDI + IDI = 1 \quad \text{..........} \quad 5$$

The major fundamental driving mechanisms by which oil may be extracted from oil reservoirs are represented by the four terms on the left-hand side of equation 5.
Furthermore, the data used for this research is shown below,

Table 1 PVT Data for the field

Separator	Single Tank
Formation GOR (scf/stb)	410
Oil Gravity (API)	38.7
Gas Gravity	0.6
Water Salinity	20,000
Mole Percent of H_2S	0
Mole Percent of CO_2	0
Mole Percent of NO_2	0

Table 2 Tank Parameter Data

Tank type	Oil
Temperature(F)	149
Initial Pressure (psig)	3624
Porosity	0.24
Connate Water Saturation	0.2
Initial Gas Cap	1.08
Original Oil in place (MMSTB)	104.06
Start of Production	7/1/1969

Table 3 Water Influx Data

Model	Hurst-Van Everdingen Model
System	Radial Aquifer
Reservoir thickness(ft)	85
Reservoir Radius(ft)	3500
Outer/Inner Radius Ratio (ft)	90
Encroachment Angle(Deg)	360
Aquifer permeability(mD)	850

Table 4 Relative Permeability Data

Relative Permeability	Residual Saturation	Endpoint	Exponential
K_{rw}	0.1	0.6	4.1
K_{ro}	0.1	0.9	1.2
K_{rg}	0.3	0.2	6

3. Results and Discussion

3.1 Analysis of Results

The objective of the project, which was to estimate the initial oil in place, anticipate the future reservoir performance, and determine the drive mechanisms, has been met through the use of material balance analysis on the field . The results are shown below;

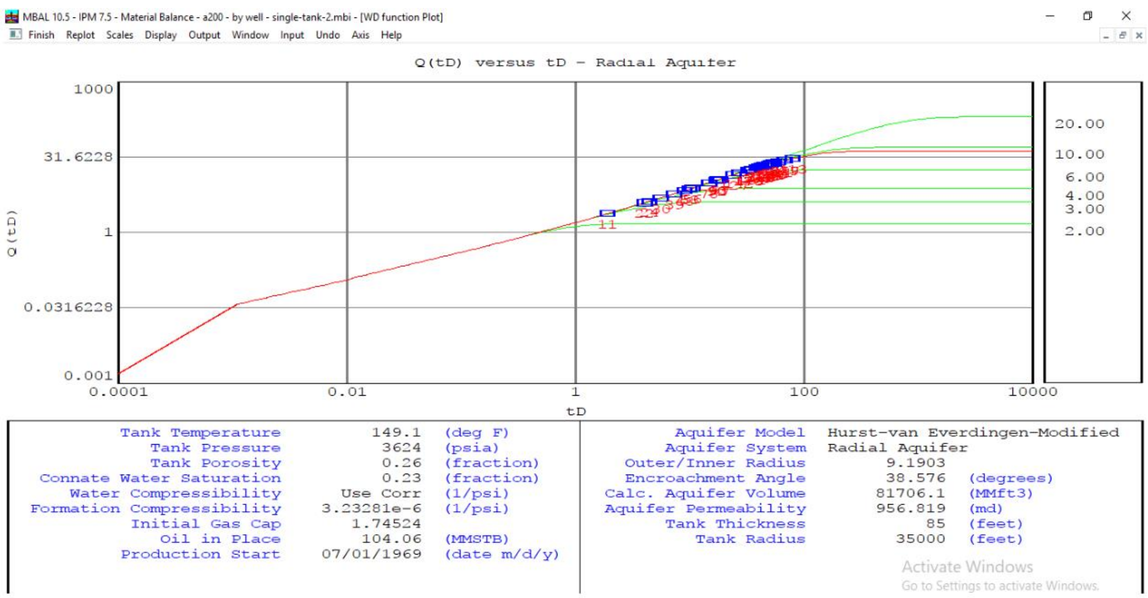

Figure 3.: Aquifer plot

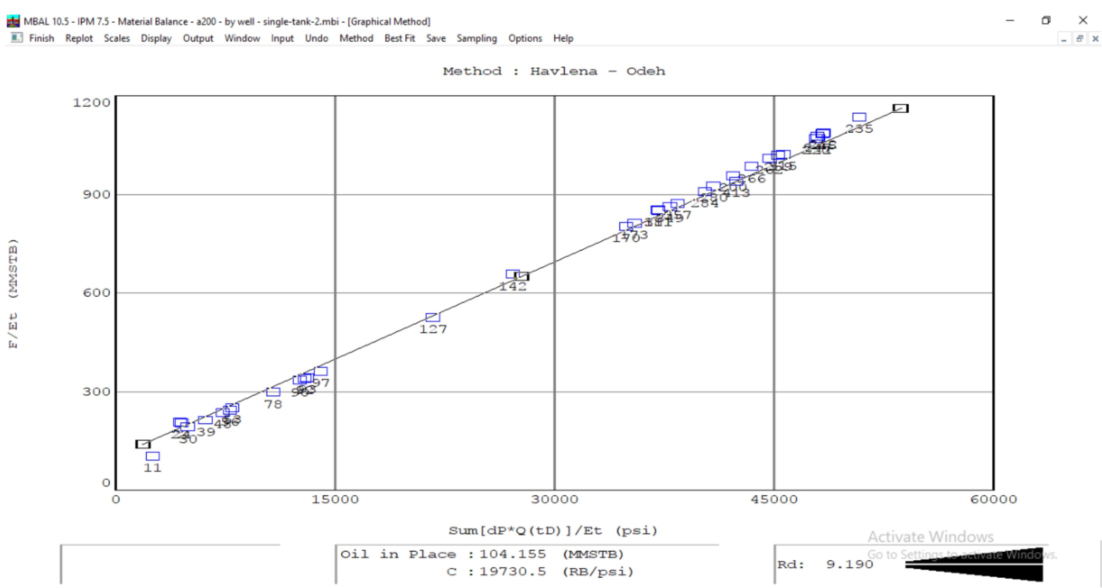

Figure 4: Graphical plot

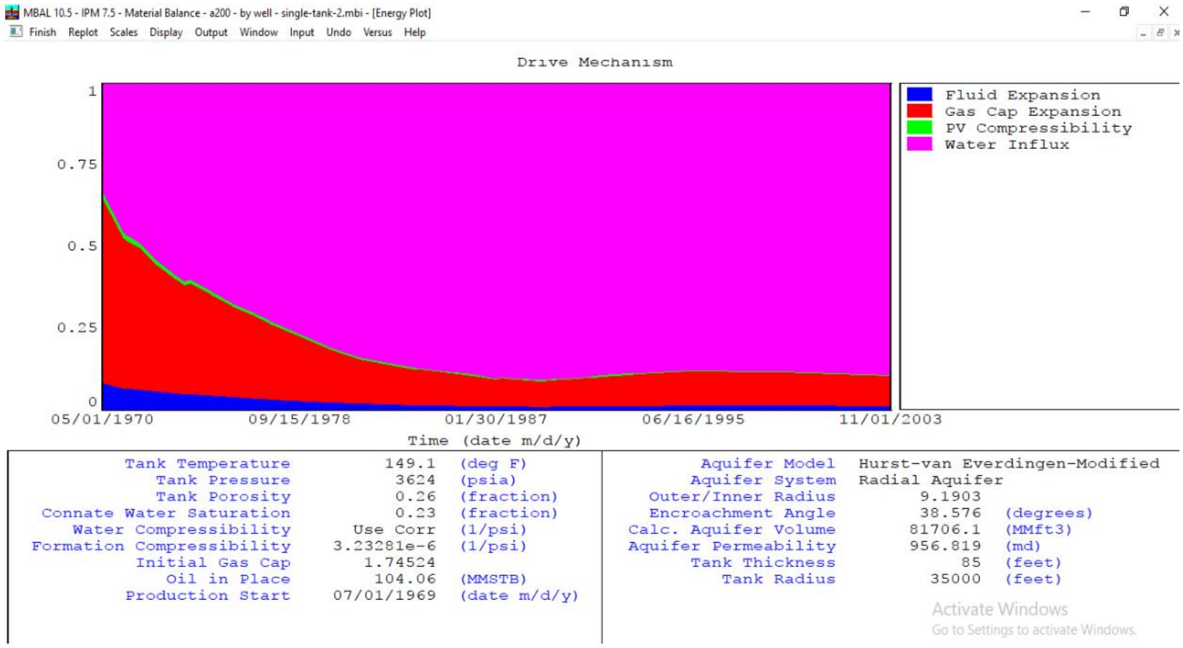

Figure 5: Energy plot

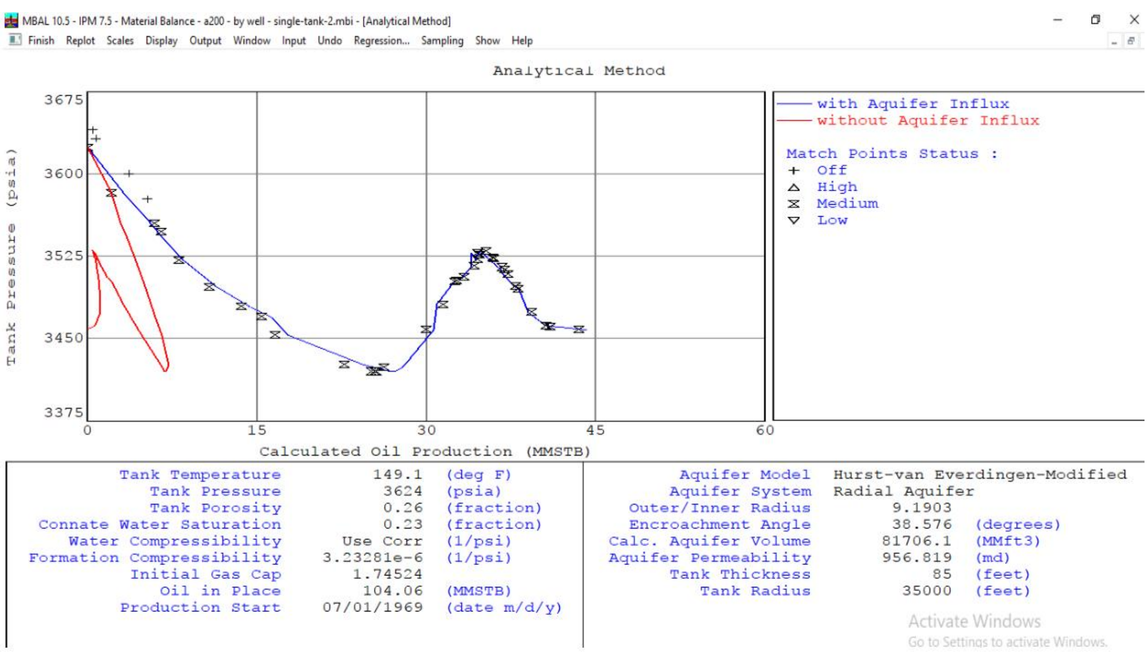

Figure 6: Analytical plot

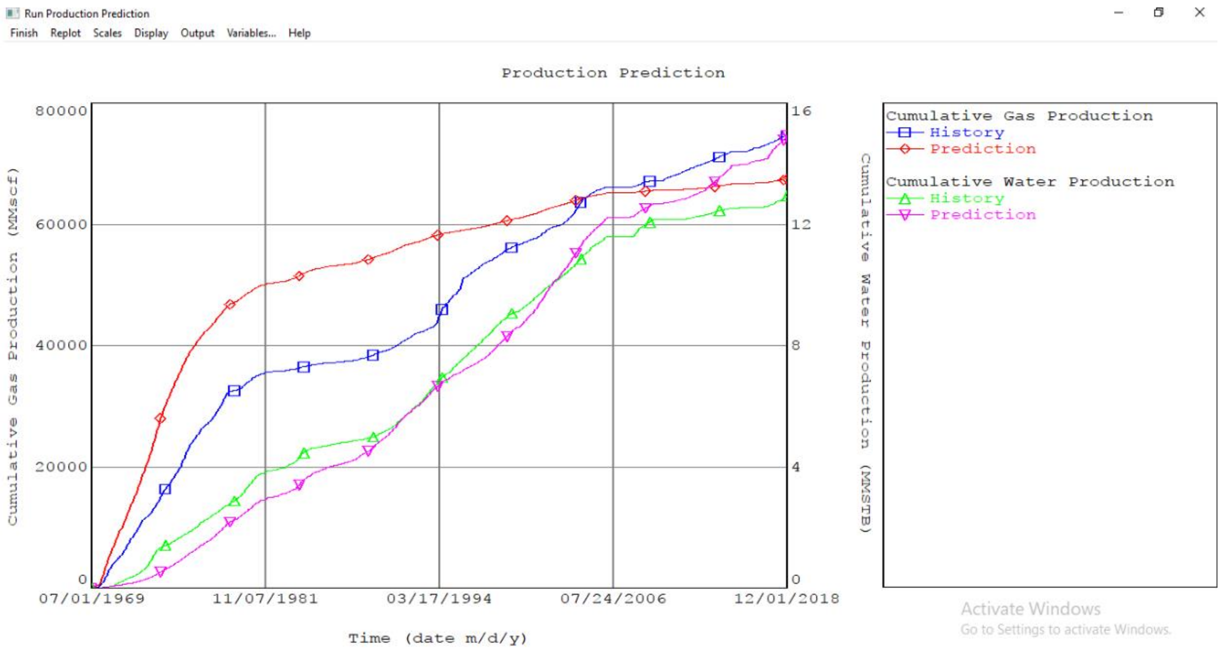

Figure 7: Production Plot of Cumulative Gas Production Vs Cumulative Water

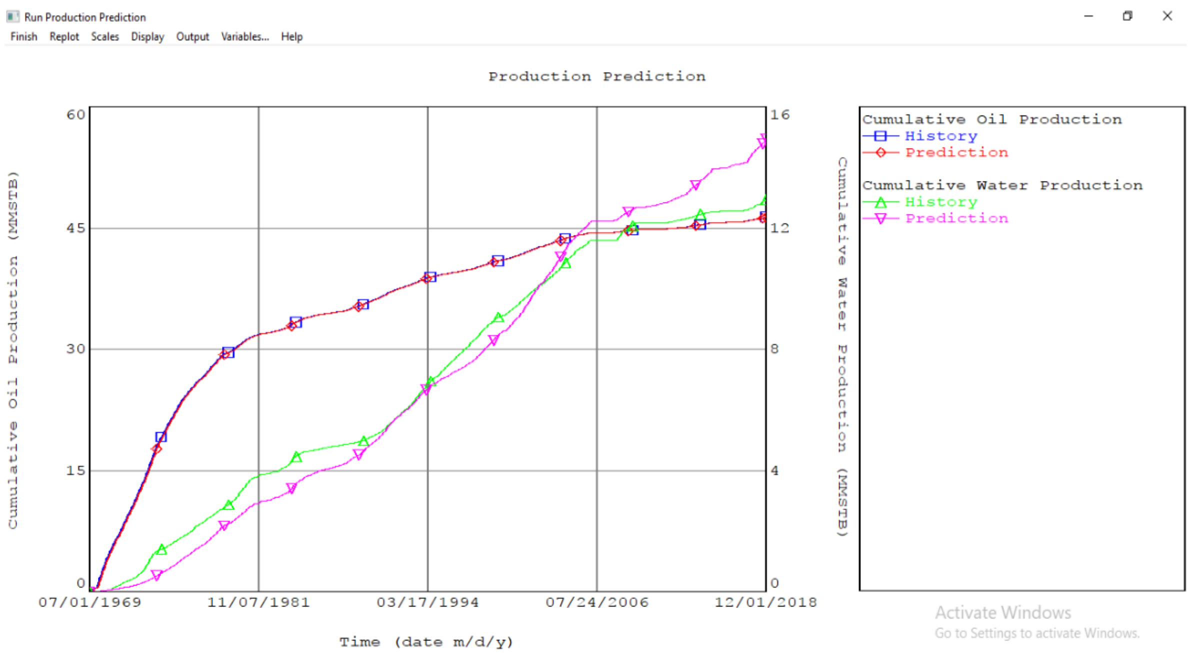

Figure 8: Production Plot of cumulative Oil Production Vs cumulative Water

The Hurst-Van Everdingen model was selected as the most likely case for the reservoir in this field. The parameters that were employed to extract the STOIIP and history match from the Hurst-Van Everdingen radial aquifer compare favorably with the predicted values. After thorough analysis of the various plot , The following points can be drawn from the material balance analysis: Fig. 1 shows the WD Function Plot which shows the dimensionless aquifer function versus the dimensionless time curves. This point also shows where the historical data points are located in dimensionless coordinates.
The Stock Tank Oil Initially in Place (STOIIP) was predicted by MBAL Software to be 104.06 MMSTB, as illustrated in fig. 2**.** From the graph it can be seen that the STOIIP is constant at 104.06MMSTB, with an aquifer present in the reservoir. This aquifer uses the radial aquifer system. Fig. 3 illustrates the reservoir's different drive mechanisms, which include fluid expansion, gas-cap expansion, PV compressibility, and water inflow. From the graph, The predominant drive mechanism is seen to be water influx with the other mechanisms being secondary. Fig. 4 demonstrates the Analytical Plot, which illustrates the effect of the aquifer on reservoir pressure. From the graph, the aquifer volume was predicted to be 81706.1 $MMft^3$.

Fig. 6 shows the Production Plot of Cumulative Gas Production Vs Cumulative Water Production. This plot helps to show the future performance of the production of gas and water with respect to their history. Fig. 7 shows the Production Plot of Cumulative Gas Production Vs Cumulative Water Production. This plot helps to show the future performance of the production of gas and water with respect to their history. Fig. 8 shows the Production Plot of Cumulative Oil Production Vs Cumulative Water Production. This plot also shows the future performance of the production of oil and water with respect to their history.

4. Conclusion

This paper reviewed the Hurst-Van Everdingen Model using the MBAL software and the following conclusions were drawn:

- The Hurst-Van Everdingen model was selected as the most likely case for the reservoir.
- The model was chosen because the parameters used to obtain the history match and STOIIP from the Hurst-Van Everdingen radial aquifer compare favorably with the expected values.
- The reservoir supports water drive, and the use of the MBAL software would save a reasonable amount of time in evaluating the reservoir before a more compositional approach is used to study the reservoir.
- The material balance model is effective at history matching the production performance but has substantial drawbacks when it comes to field predictions.

One of the MBAL tool's limitations is that it cannot be used to estimate trapped gas. The reason for this is that the MBAL tool is unable to handle the task; in other words, it is outside of the MBAL's scope.

References

[1] Havlena, D., and Odeh, A. S., (1963); “The Material Balance as an Equation of a Straight Line,” Trans. AIME, Part 1: 228 I-896; Part 2: 231 I-815.
[2] Schilthuis, R.M. (1935). Active Oil and Reservoir Energy. Transactions of the AIME, 118(1), 33-41.
[3] Tarner, R. (1944). Prediction of performance of depleted (solution-gas)-drive reservoirs utilizing rock and fluid parameters. Journal of Petroleum Technology, 12(02), 43-50.

[4] Muskat, M. (1945). Methods for predicting the performance of depleted (solution-gas)-drive reservoirs. Society of Petroleum Engineers Journal, 41(04), 345-356.
[5] Craft, B., Hawkins, M., and Terry, R., (1991); Applied Petroleum Reservoir Engineering, 2nd edition, Prentice Hall.
[6] Duffaut, K., & Torsaeter, O. (2019). Material balance methods for oil reservoir simulation: Status and future directions. Journal of Petroleum Science and Engineering, 179, 643-662.
[7] Olajumoke, A. F., Adomokai, R., & Aremu, A. O. (2017). Application of material balance methods to analyze oil reservoir performance: A case study of Niger Delta oil wells. Journal of Petroleum Exploration and Production Technology, 7(3), 713-724.
[8] Oseni, O., Adeoye, O., Adekoya, J., & Adeleke, B. (2019). Numerical material balance analysis of an oil reservoir in the Niger Delta region. Journal of Petroleum Exploration and Production Technology, 9(3), 1759-1769. doi: 10.1007/s13202-018-0565-7
[9] Oyekoya, O.A., Adeniran, O.A., Oyawale, F.A., Akinlua, A.A., & Olatunji, S.O. (2021). Comprehensive material balance analysis of a Nigerian oil reservoir: comparison of analytical and numerical methods. Journal of Petroleum Exploration and Production Technology, 11, 2403-2413
[10] Daramola, S. A., Olatunji, S. O., & Isehunwa, S. O. (2019). Material balance and reservoir performance analysis of a depleted sandstone reservoir in offshore Niger Delta. Journal of Petroleum Exploration and Production Technology, 9(2), 1357-1365
[11] Olotu, O. M., Ikporo, S. A., & Ojumah, A. O. (2018). Material balance analysis of an onshore Niger Delta field's oil reservoir. Journal of Petroleum Science and Engineering, 167, 353-361.
[12] Adenuga, I. A., Fadairo, A. S. A., Falode, O. A., & Arowolo, O. O. (2018). Material balance analysis and modeling of an onshore Niger Delta field's oil reservoir. Journal of Petroleum Exploration and Production Technology, 8(1), 23-30.