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RESERVOIR SIMULATION AND DECLINE CURVE ANALYSIS: A CASE STUDY OF "DER" FIELD, NIGER DELTA BASIN

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Abstract

This research project gives an insightful glimpse into reservoir simulation using the Material Balance (MBAL) software. The software was used to confirm Stock Tank Oil Initially In-Place (STOIIP) for volumetric analysis. MBAL was used to apply the material balance method, decline curve analysis method, check the aquifer size of the field, and carry out production forecasts. Data from the field was inputted into MBAL and results acquired. These results were used in simulating the reservoir in order to carry out production forecasts. The research showed the impact of MBAL in predicting reservoir performance and carrying out reservoir simulation. The predictions were made based on field data. STOIIP was estimated using non-linear regression with a plot of average reservoir pressure against cumulative oil produced. The history matching tool and the production prediction tool were used to estimate the expected STOIIP, judging from the previous performance of the reservoir and the well. With the use of the analytical tool, the predominant reservoir driving mechanism was determined. This project will focus on the use of reservoir simulation in reservoir engineering and how MBAL can be used as a tool in reservoir simulation.

Keywords: *Simulation; Dedine curve analysis; Volumetric analysis; History matching; Reservoir performance; Material balance.*

1. Introduction

During the development of oil and gas reservoirs, drainage challenges occur. Reservoir engineers then come up with scientific principles to these challenges. Reservoir engineering is the subsurface science of the oil and gas industry. It tries to explain what goes on underground in the reservoir. The main job of the reservoir engineer is to estimate the amount of hydrocarbon in place. Factors that assist in this estimation are subsurface geology, applied mathematics, basic chemistry, and physics. These factors affect the behaviour of the liquid and gas phases of the hydrocarbon [1].

Reservoir simulation is important because it gives us better control of the reservoir. A model is a copy of something original with respect to known parameters. In the oil and gas industry, profit is made by extracting hydrocarbon from a reservoir which is underground. Describing the reservoir is usually difficult because of the in accuracy in measuring parameters. This occurs because the reservoir is underground and the parameters are measured indirectly.

In the estimation of reserves, there might be errors in data collation which may lead to inaccurate estimation, i.e. overestimation or underestimation. Therefore, there is a need to accurately estimate the reserves to determine the viability of the field. This work is focused on the application of the MBAL software in reservoir engineering. The software will be used to carry out reserve estimation using both the decline curve analysis and the material balance methods. Several objectives have been considered which included the confirmation of STOIIP for volumetric analysis, confirmation of aquifer size and driving mechanism of the reservoir, and production forecasting under different scenarios.

2. Review of literature

Reservoir simulation involves the use of a mathematical model in analyzing and predicting fluid behaviour. The model is expected to replicate the geological and petrophysical characteristics of the reservoir. Reservoir Simulation has two main objectives - to optimize development plans in new fields and to delegate on operational and investment decisions [2]. The objective of their experiment was to carry out simulation tasks usually performed with simulators. MBAL is primarily used for reservoir simulation. It is an analytical tool that is used in reserve estimation, determination of drive mechanism, aquifer size assessment and in carrying out production forecast. MBAL can also be used for existing reservoirs, as it provides varied matching facilities. It can run production profiles with or without history matching. MBAL is a good tool in reservoir characterization and simulation under different scenarios. Despite its simplicity, it is still able to predict pressure depletion like other simulators [3]. Another limitation that was discovered was that the single tank does not take account of the heterogeneities of the field that was under study, whereas the multi-tank model had values which were in the range of the results gotten from the single grid model.

In early years, it was discovered that the material balance equation could not be used to determine the size of the field during the early years of production, this was accurate at the time because of the limited data that was available and the change in pressure that was required in the Schilthuis material balance equation [4]. The solution was to find the pressure value that would give the uniformity required in the equation. A relationship between reservoir pressure and oil saturation was developed. The relationship proved that oil saturation doesn't depend on the change in pressure of the reservoir, but the reservoir pressure. It is understandable that due to the limited data available in the early stages of production, material balance can be inaccurate. The subsidiary equation can be used in cases where there is no significant pressure drop [4]. Methods have been developed to examine material balance in oil and gas reservoirs. A new method of carrying out a material balance method in reservoir simulation is the dynamic material balance method. By combining the solution of the material balance equation with pressure test analysis theory, the dynamic material balance method can be used in estimating the initial oil in place, *N,* initial gas in place, *G, the* ratio of the oil to gas *m,* permeability, *K* and skin factor, *s*. It makes use of cumulative production history with PVT data with little or no pressure data. The dynamic material balance method will be able to improve the problem-solving capabilities of the material balance method especially in marginal fields and fields with limited pressure data [5]. Material balance approach was compared with reservoir simulation. It is believed that since the development of reservoir simulation, that material balance is not seen as a modern approach anymore in reservoir analysis. Material balance calculations depend on the uniformity of total pore volume, pressure, temperature, fluid composition and accurate values of volumetric estimation [6].

3. Methodology

The transient rate and the pseudo-steady state decline curves were combined and used in a single graph. Also, the material balance equation was employed. The dataset used for this work are; PVT, reservoir pressure. Production history and geologic data.

The concept of decline curve analysis involves fitting a line through the production history and assuming that the field will continue to behave in that manner. If there is in an inconsistency with the historical trend, then the result will not be reliable. The main assumption of this method is that what controls the trend of a curve in the past will continue to control the trend in the future.

For the material balance method, its calculations are very useful; they provide a method of estimating the oil, water, and gas that can be compared to volumetric estimates. The form of the material balance equation can be adjusted to fit oil or a gas reservoir.

3.1. Material balance for oil reservoirs

The general material balance equation

$$N(B_t - B_{ti}) + N_m B_{ti}\left(\frac{B_{gc}-B_{gi}}{B_{gi}}\right) + N\frac{B_{ti}S_{wio}}{1-S_{wio}}\left(\frac{B_{tw}-B_{twi}}{B_{twi}}\right) + N\frac{mB_{ti}S_{wig}}{1-S_{wig}}\left(\frac{B_{tw}-B_{twi}}{B_{twi}}\right) + N\left(\frac{1}{1-S_{wio}} + \frac{m}{1-S_{wig}}\right)B_{ti}c_f\Delta P = N_pB_o + \left[G_{ps}B_g + G_{pc}B_{gc} - G_iB_g{}'\right] - N_pR_{so}B_g - \left(W_e + W_i - W_p\right)B_w \quad (1)$$

For simplification purposes, some terms are defined:

$$E_o = B_t - B_{ti}\ ,\ \ E_{go} = mB_{ti}\left(\frac{B_{gc}-B_{gi}}{B_{gi}}\right)\ ,\ \ E_w = \frac{B_{ti}S_{wio}}{1-S_{wio}}\left(\frac{B_{tw}-B_{twi}}{B_{twi}}\right)\ ,\ \ E_{gw} = \frac{mB_{ti}S_{wig}}{1-S_{wig}}\left(\frac{B_{tw}-B_{twi}}{B_{twi}}\right)\ ,\ \ E_r = \left(\frac{1}{1-S_{wio}} + \frac{m}{1-S_{wig}}\right)B_{ti}c_f\Delta P \quad (2)$$

Substitute equation (2) in (1) changes the general material balance equation to:

$$N\left[E_o + E_{go} + E_w + E_{gw} + E_r\right] = N_pB_o + \left[G_{ps}B_g + G_{pc}B_{gc} - G_iB_g{}'\right] - N_pR_{so}B_g - (W_e + W_i - W_p)B_w \quad (3)$$

The terms on the right side of (2) represent fluid injection and production, the terms on the left represent volume change.

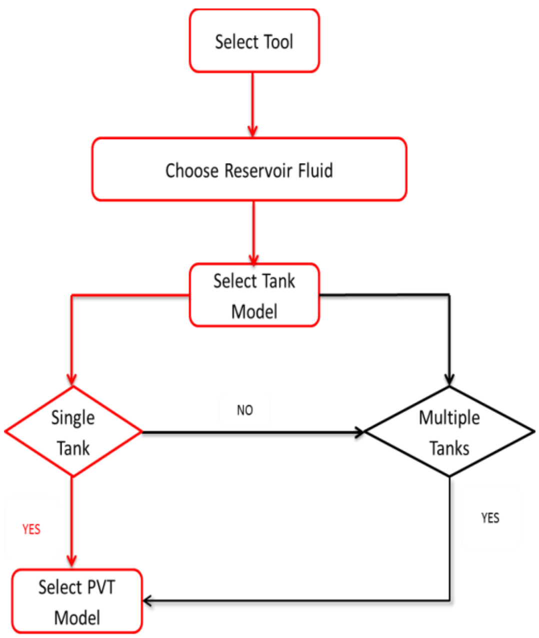

Figure 1a. Material balance workflow in estimating the initial oil in place.

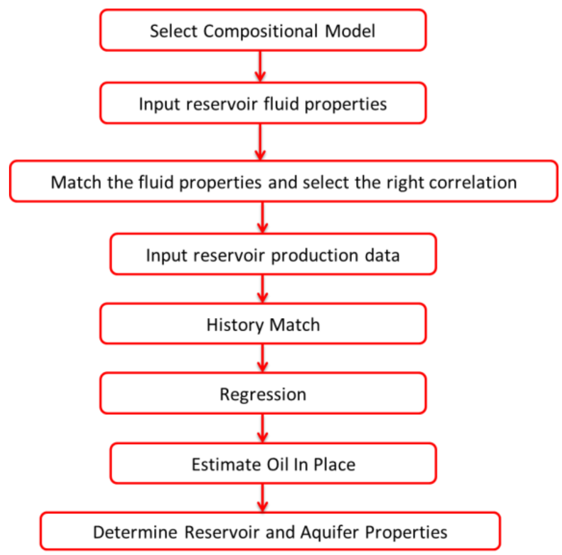

Figure 1c. Material balance workflow in estimating the initial oil in place

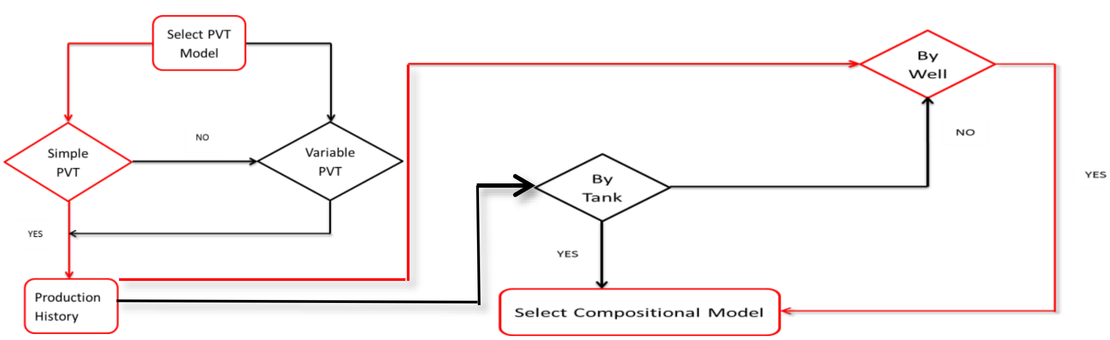

Figure 1b. Material balance workflow in estimating the initial oil in place

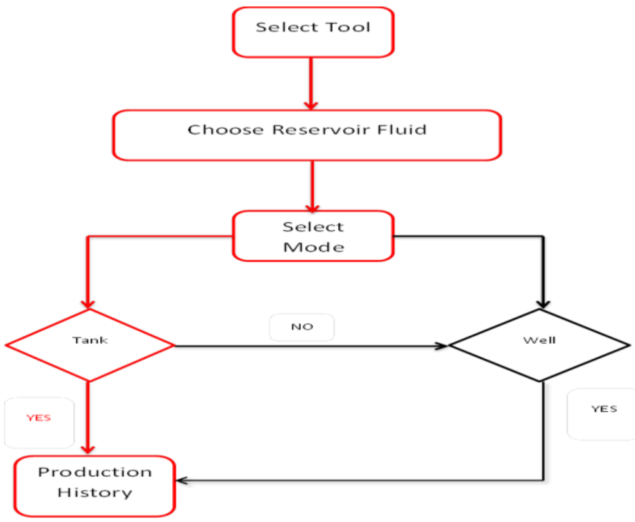

Figure 2a. Workflow for decline curve analysis.

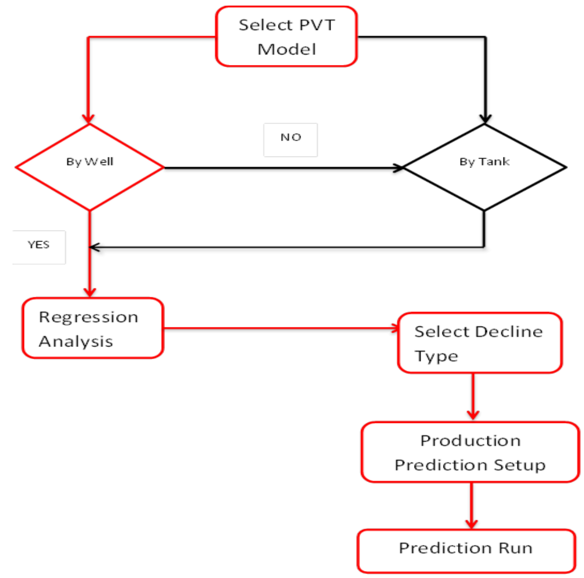

Figure 2b. Workflow of decline curve analysis

4. Results and discussion

The geology, PVT, and relative permeability data are presented in Table 1, Table 2 and Table 3 respectively.

Table 1. Geologic data

Thickness	100ft
Porosity	0.19
Saturation	0.15

Table 2. PVT data

Formation GOR	1589scf/stb
Oil gravity	39API
Gas gravity	0.875spg
Water Salinity	100000spm
Viscosity	0.28cp
Oil Formation Volume Factor	1.89rb/stb

Table 3. Relative permeability data

	Residual Saturation	End Point	Exponent
Krw	0.15	0.0284564	0.01002
Kro	0.15	0.8	2.25388
Krg	0.05	0.000328963	0.01002

From the energy plot (Figure 3), there is a pictorial representation of the different drive mechanisms and their contribution to the energy of the reservoir.

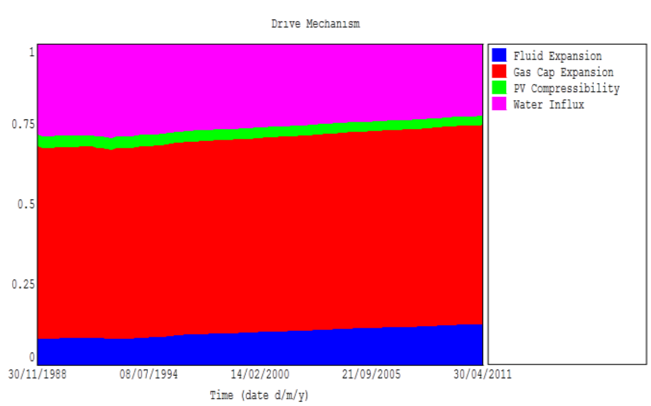

Figure 3. Energy plot

4.1. Graphical method

In this field, an additional energy mechanism went through a turn up seen in Campbell plot (Figure 4.). The aquifer then compensated the turn up in order to get a good history match.

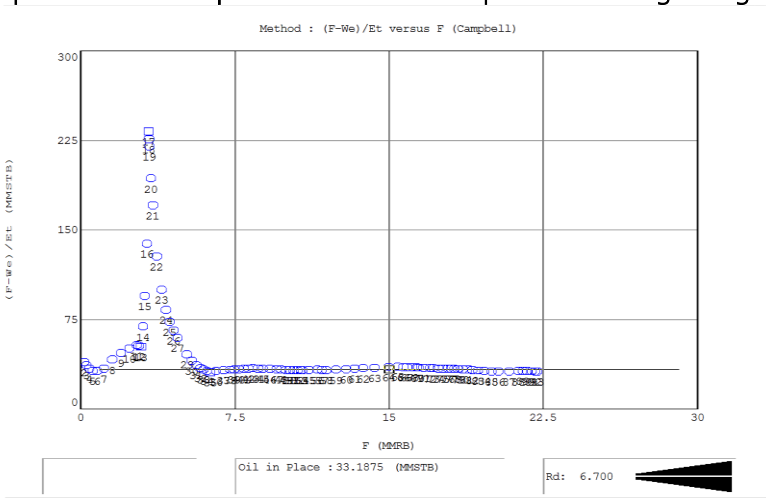

Figure 4. Campbell plot

Analytical plot

This gives an analytical history matched model before and after regression analysis. To improve the quality of the history match regression analysis was carried out.

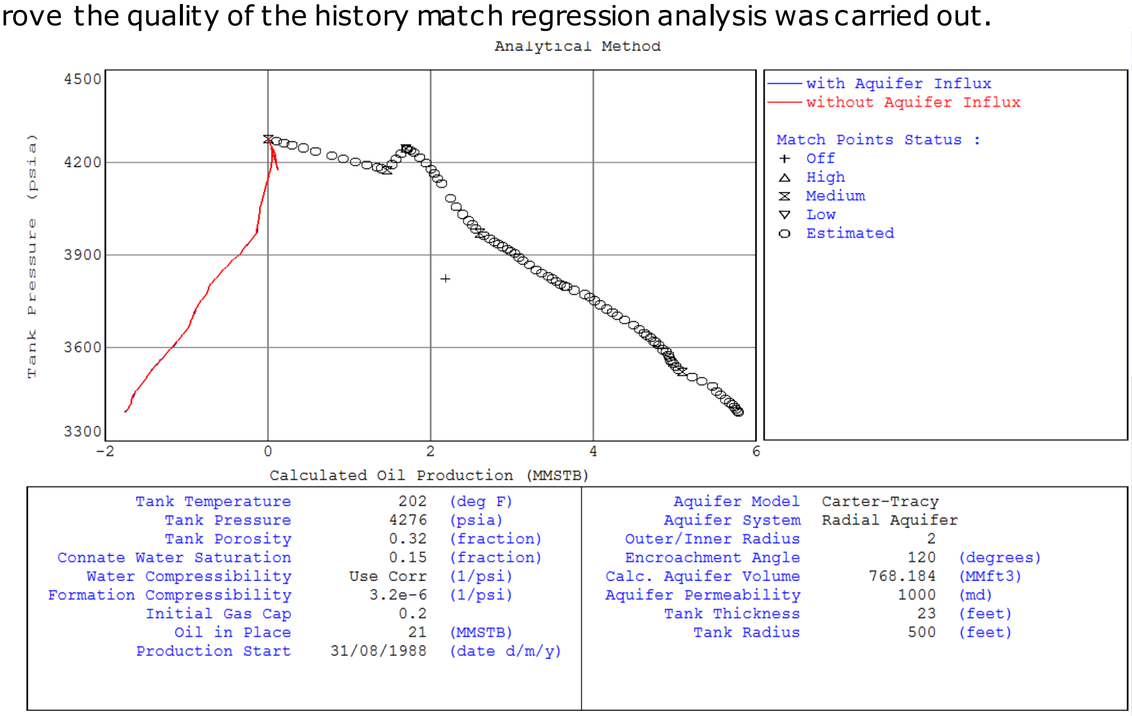

Figure 5. Analytical plot before regression

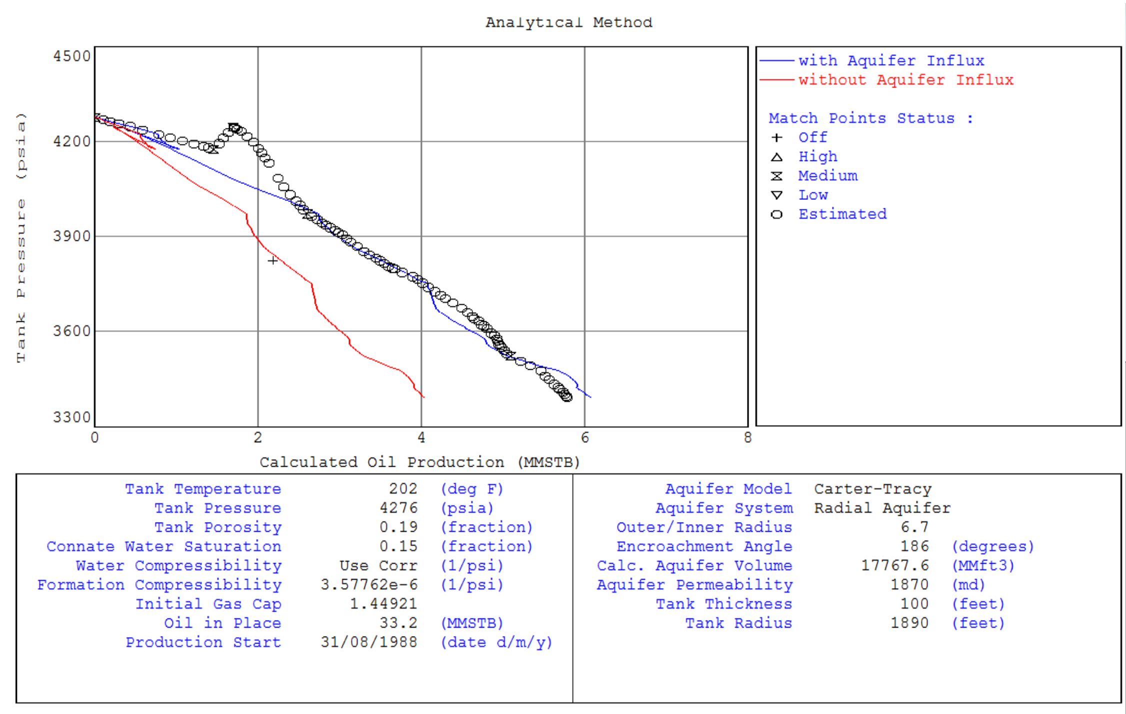

Figure 6. Analytical plot after regression

History match

This gives a graphical representation of the historical production data; it tries to create a model that closely mirrors the reservoir behaviour in order to carry out predictive analysis on the reservoir.

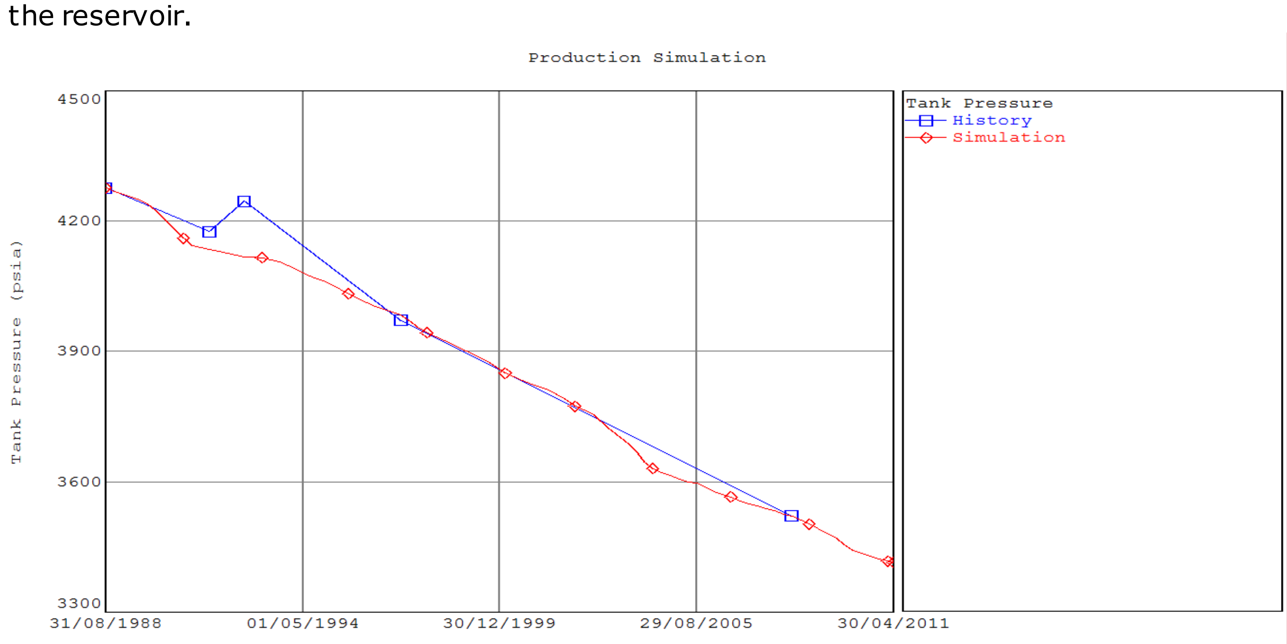

Figure 7. Graph of production simulation

Predictive Analysis

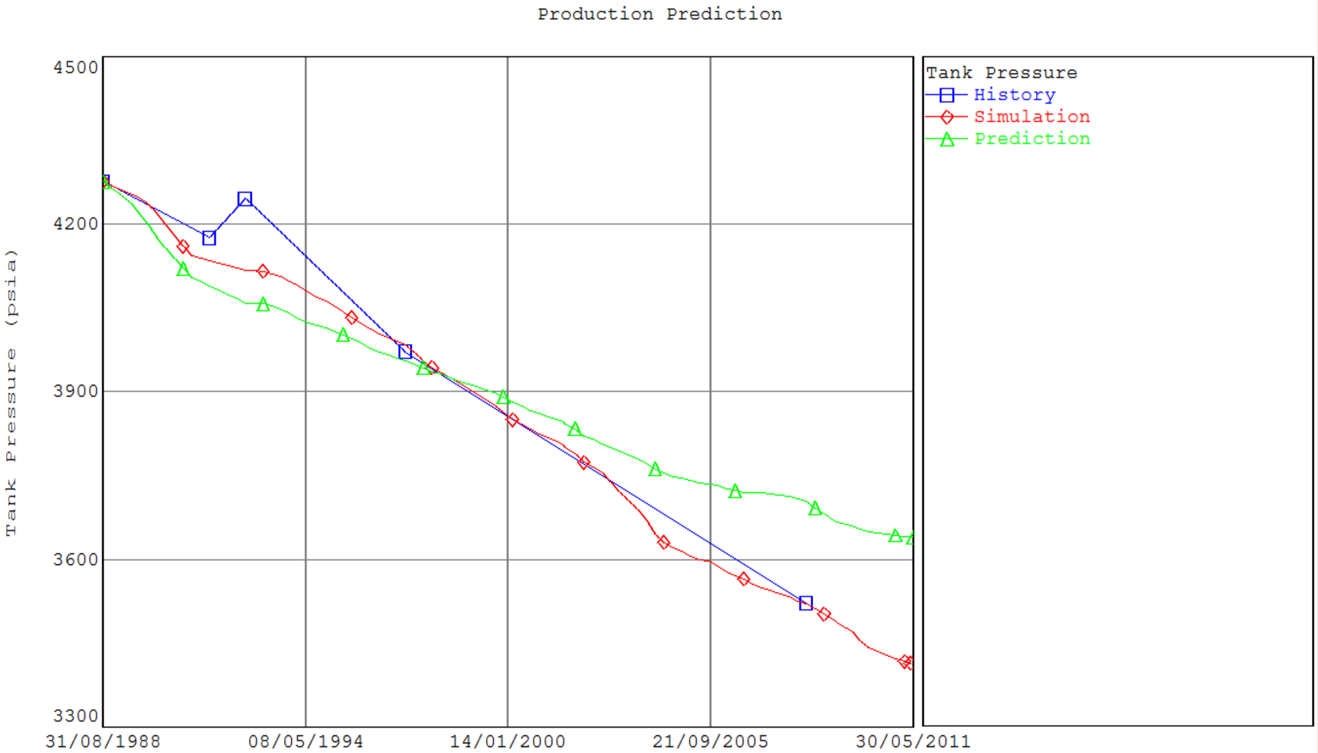

Figure 8. Production prediction of tank pressure from start to end of production

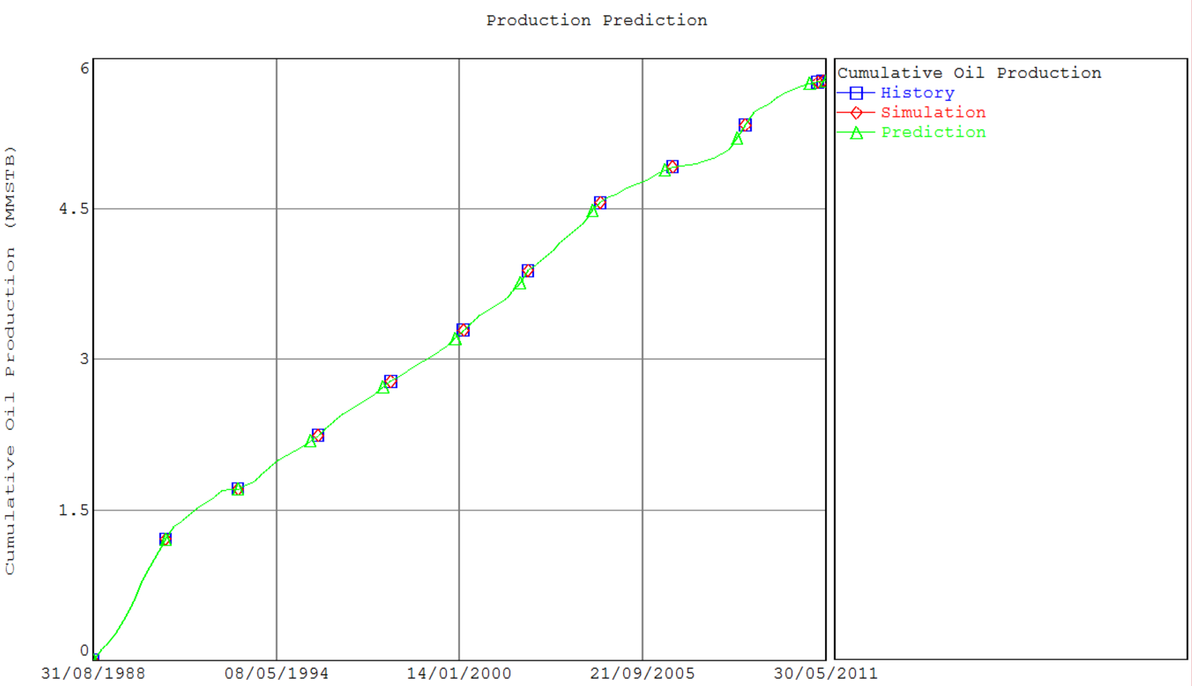

Figure 9. Production prediction of oil production from start to end of production

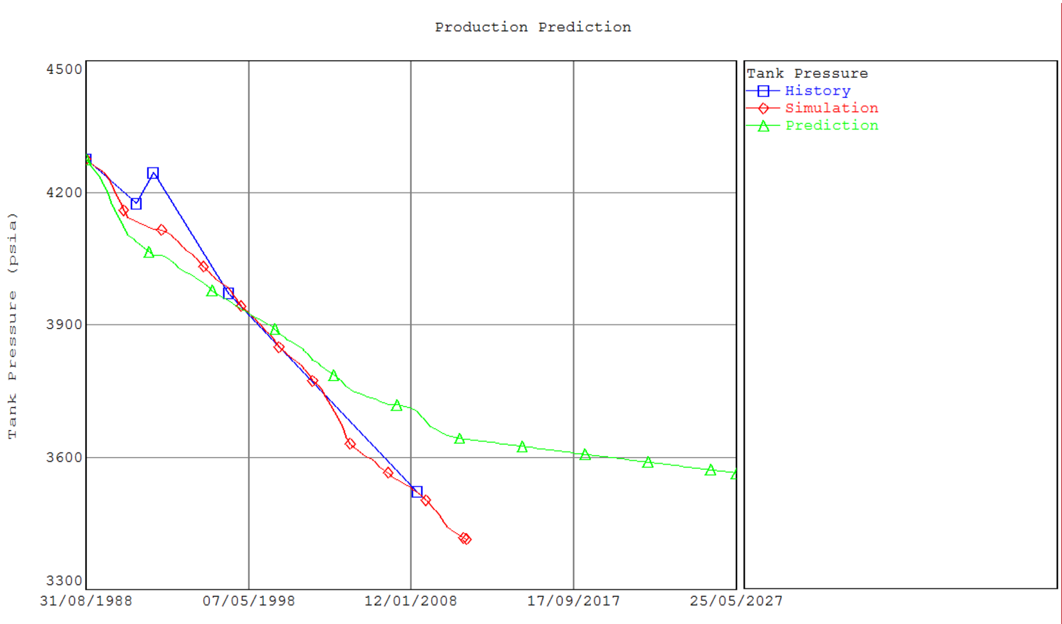

Figure 10. Production prediction of reservoir pressure from start to the year 2027

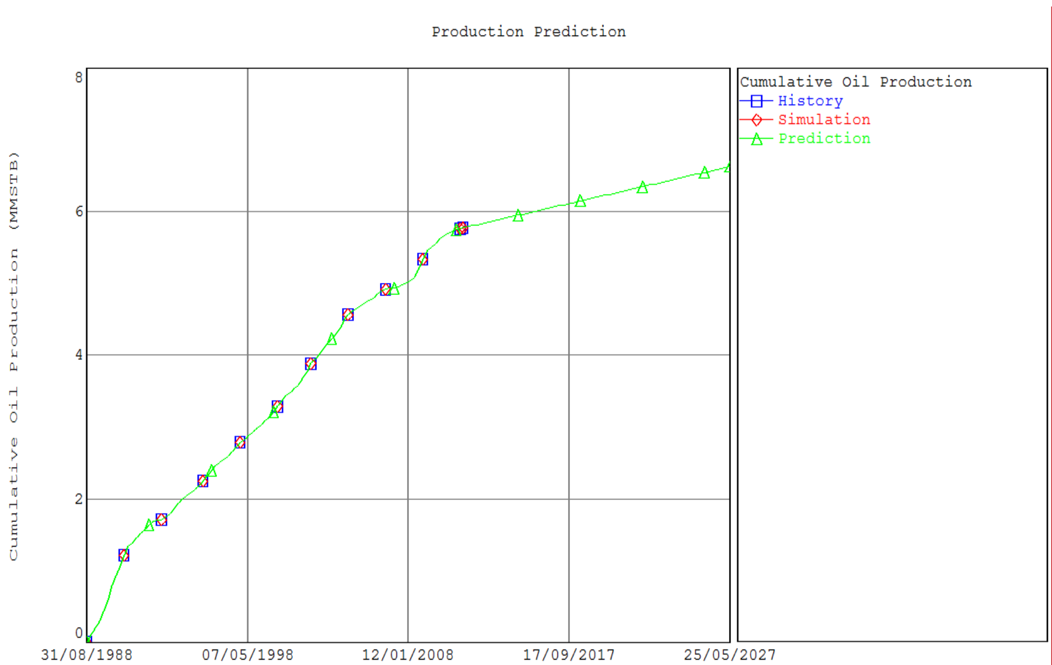

Figure 11. Production prediction of oil production from start to the year 2027

Table 4. Summary of results

Parameter	MBAL estimate	Parameter	MBAL estimate
STOIIP (MMSTB)	33.2	Encroachment Angle (degree)	186
Initial Gas cap (MMSCF)	1.44921	Porosity	0.19
Inner outer radius ratio	6.7	Aquifer Volume (mmft^3)	17767.6
Reservoir Radius (ft)	1890		

Production forecast

In carrying out the predictive analysis, both methods - the material balance method and the decline curve analysis were utilized. Using the material balance and applying MBAL, an estimated date of May 2027 was selected, and this resulted in an estimate of 6.5MMSTB. But by carrying out decline curve analysis and comparing the results, an estimate of 4.5MMSTB was obtained.

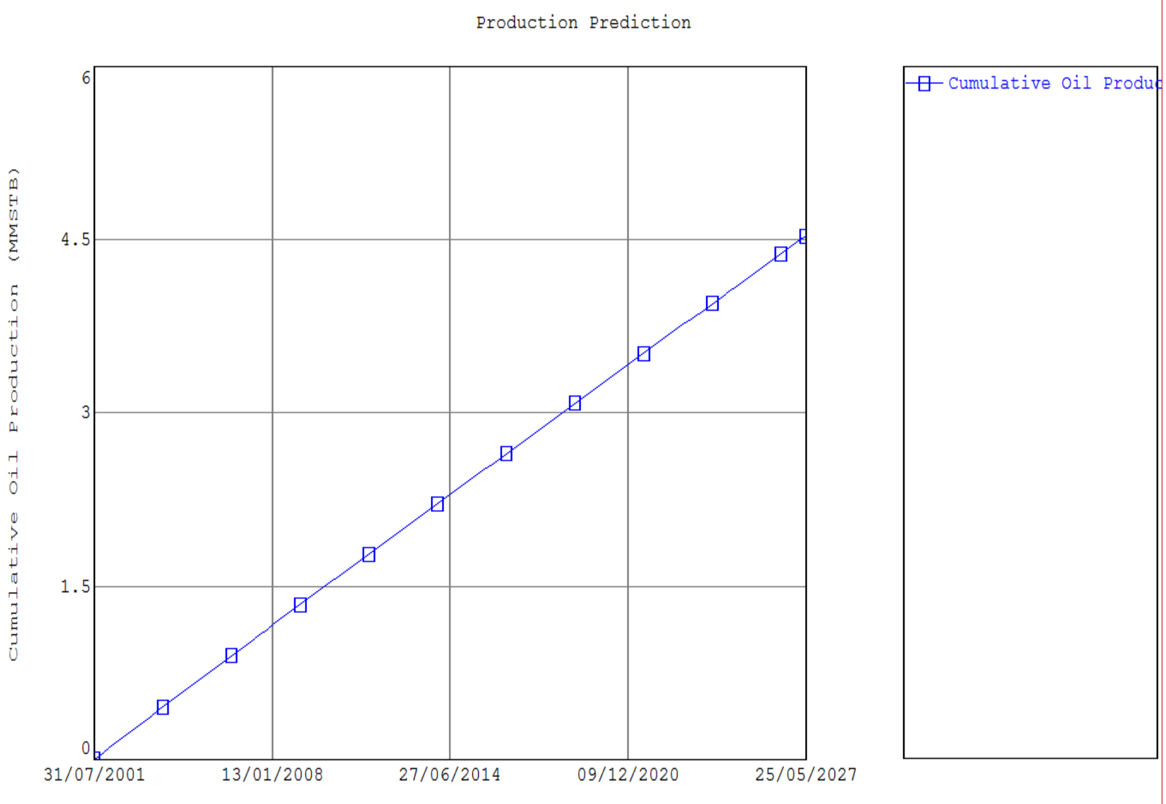

Figure 12. Production prediction based on decline curve analysis

The material balance method gave a STOIIP estimate of 33.5MMSTB. This estimate was made based on dynamic modelling and by utilizing petrophysical and geological properties obtained from a static model. When carrying out the production forecast, the decline curve analysis gave an estimate of 4.5MMSTB by the year 2027; while the material balance software gave an estimate of 6.25MMSTB. The aquifer was radial and with a size of 7767.6mmft^3. It had a permeability of 1870md with a large encroachment angle of 187.63^0. Due to the radial nature of the aquifer, it could be said that the aquifer is a large one and this is why the reservoir pressure was still high in the year 2027. From the energy plot, water influx was one of the major contributors to the drive mechanism, and this must have been due to the size of the aquifer.

5. Conclusion

Reserve estimation is a subsection of reservoir simulation. Material balance and decline curve analysis is based on most of the mathematical equations used for modern petroleum engineering. The material balance method and decline curve analysis method are two different methods of carrying out reserve estimation. The material balance value was higher than the decline curve analysis value. This could have been caused by inaccuracy in the production data. There was also a presence of a strong aquifer; this might have influenced the production history data. The main contributor to the energy of the reservoir was the gas cap expansion and the water influx, as seen from the energy plot in MBAL.

6. Recommendation

From this work, the following recommendations are made:

- Since there is such a large variance between the two methods, (material balance method and decline curve analysis used in the field), further analysis should be carried out on the reservoir. MBAL may not be exactly accurate so a larger simulator could be used.
- Discrepancies in the data can be minimized by the acquisition of more data.
- Monte Carlo analysis is advised to act as another validator; it will enhance the credibility or viability of the estimate.

NOMENCLATURE

MBAL = Material balance software developed by Petroleum Experts (PETEX)
STOIIP =Stock Tank Oil in Place
MMSTB = Million Stock tank Barrel
MMSCF= Million Standard cubic feet
$N(E_w+E_{gw})$ *= Change in volume of connate water*
NE_r *= Change in formation pore volume*
N_pB_o *= Cumulative oil production*
$N_pR_{so}B_g$ *= Cumulative gas produced with oil*
$G_{ps}B_g$ *= Cumulative solution gas produced as evolved gas*
$G_{pc}B_g$ *= Cumulative gas cap gas production*
G_iB_g' *= Cumulative gas injection*
W_eB_w *= Cumulative water influx*
W_iB_w *= Cumulative water injection*
W_pB_w *= Cumulative water production*
N = Original oil in place, STB

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