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Oilfield Performance Prediction using Integrated Modeling and Simulation (MBAL) Suite

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ABSTRACT

The Material Balance (MBAL) software is a component of the Petroleum Experts' Integrated production modeling (IPM) tool kit and it is used for the development of the Reservoir model. It allows and improves the understanding of the field behavior in terms of the field performance, production, flow behavior and optimization of the field at any given time of the lifespan of the field. The paper demonstrates reservoir performance prediction using dynamic MBAL and predictive material balance method after proper history matching of the models and validated with appropriate data. The objective of the research is to set up a basic Reservoir Model with the PVT analysis, production and tank data. The paper further shows history matching by matching Original Hydrocarbon in place (OHIP) and Aquifer size and plots with required parameters against simulated results and prediction of future hydrocarbon production.

Keywords: Integrated production modeling, Oilfield performance, Reservoir simulation, MBAL.

1. INTRODUCTION

The real oilfield consists of the Reservoirs, Wells, the Production gathering system, the Distribution Network and the Injection Network. The Production gathering system receives the fluid from the functional producing wells and delivers to the flow station or gathering station for separation of fluids/ processing into its constituent components of Oil, Water and Gas. The Injection network inject fluid (water or gas) into the reservoir to enhance further recovery. The philosophy of the design of any Oilfield facility remains the same as the optimization of hydrocarbon production with minimal cost over the long run period of the investment outlay, though the layout of the production assets in the fields differ. Integrated Oilfield design implies that producing facility and the gathering system including the distribution pipeline network form a single total integrated system [1]. Integrated Oil production design covers an entire span of production activities ranging from the sub-surface structure, which comprises the drainage area, wells and wellhead assembly and surface facilities. The optimization models of the integrated system comprise of several component models including the Reservoir model, Choke model, Gathering

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model and Economic model. Others are Pipeline model, Wellhead model, Thermodynamic model and the Integrated model. Economic goals however govern the objective function.

The Petroleum Experts' (PETEXs), Integrated Production Modeling (IPM) suite comprising of Pressure, Volume and Temperature Package (PVTP), the Material Balance software (MBAL), the Production and System Performance Analysis Software (PROSPER) and the General Application Package (GAP) suite provides an efficient multi-disciplinary understanding of the complete production systems. The Integrated model is made up of the reservoirs and Wells (Subsurface) and the Surface facilities. The IPM provides an integrated analysis on all components leading to an effective product development, forecasting, surveillance and production network optimization. The MBAL suite is utilized to model the Reservoir components and PROSPER models the Well component while GAP tools model the Surface facilities [2]. IPM can be depicted as:

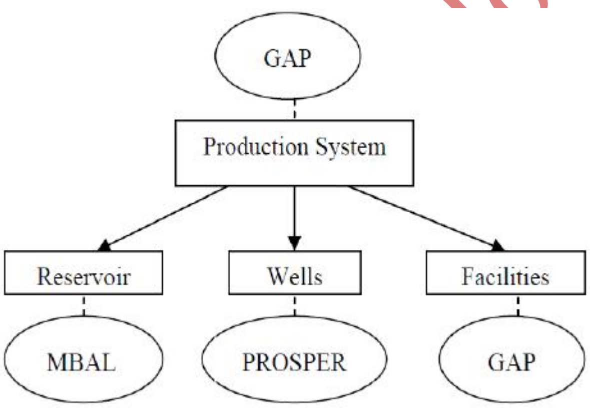


Fig.1 Production System Modeling

2. RELATED WORK

Emmanuel et al [3] developed a multi-Tank model to evaluate future well performance in reservoir using Material Balance (MBAL). This was in contrast to single tank model and achieved a better calibration and forecast of future opportunities. The methodology improved brownfield production forecast without requiring 3D dynamic models. The work was presented at the society of Petroleum Engineers (SPE) Nigeria annual international Conference and exhibition held in Lagos, Nigeria, 4-6 August 2015.

MR Woodman, J.Rodriguez, KC Wade and NJ Sanisatli [4] developed a Production and Facilities modeling and optimization technology. The work utilized a Physics-based prediction model coupled with mathematical optimization to model a complex Asset comprising separator, Riser, manifold, Well and Wellhead.

R.R.Kumar and H.K.B.Mahmud [5] focused on the optimization of a gas well with complex behavior by introducing condensate near wellbore. The work implemented sensitivity analysis in PROSPER and Monte Carlo resulting improved production

3. METHODOLOGY

3.1 Development of the Reservoir Model (MBAL)

Material Balance (MBAL) is based on the law of mass conservation and is derived as a volume balance that compares observed cumulative volume of production with reservoir fluid expansion due to drop in finite pressure. The MBAL software defines the hydrocarbon volume and drive mechanisms that allows reliable production forecast through simulation [6]. This is expressed as:

Mass of fluid originally in place = Fluids produced
+
Remaining Fluids in place.
*Production=STOIIP*Unit Expansion + water Influx*

The material balance equation was modified by Havlena and Odeh to derive a straight-line equation [7] as follows:

$$N_p\left[B_o + (R_p - R_s)B_g\right] + W_pB_w = N\left[(B_o - B_{oi}) + (R_{si} - R_s)B_g\right] + mNB_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) + \frac{(1+m)NB_{oi}(C_wS_w + C_f)\Delta p}{1 - Sw} + W_eB_w \quad (1)$$

The reduced form is

$$F = N_p\left[B_o + (R_p - R_s)B_g\right] + W_pB_w (rb) \quad (2)$$

$$E_o = \left[(B_o - B_{oi}) + (R_{si} - R_s)B_g\right] (rb/stb) \quad (3)$$

$$E_g = B_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) \quad (rb/stb) \quad (4)$$

$$E_{fw} = (1+m)B_{oi}\left(\frac{C_wS_{wc} + C_f}{1 - S_{wc}}\right)\Delta p\, (rb/stb) \quad (5)$$

The simplified form can be stated as

$$F = N\left(E_o + E_{fw} + E_g\right) + W_eB_w \quad (6)$$

Therefore, taking a plot of $(F/E_0 + E_{fw} + E_g)$ Vs $W_eB_w/(E_0 + E_{fw} + E_g)$ gives a linear relationship with intercept (W_eB_w) estimating the original Hydrocarbon in place(OHIP)with a unit slope meaning a reservoir model is achieved and the aquifer is identified. A situation where this does not exist implies, the deviation is a dynamic mechanism and further tunning of parameters is required to obtain linearity and presence of corrupted data in the analysis. It is important to note that MBAL does not account for reservoir geometry, Well orientation and formation geology and its analysis requires the average pressure and cumulative gas production.

The PVT data is one of the critical elements in the design of the Reservoir model. The crude composition differs from one region to another and research works carried out few dcades ago indicates the following Black Oil PVT Correlation coefficient[8].

3.2 Standing Type Model

The Standing correlation predicted bubble point pressure using readily available field data from 105 experimentally measured PVT from California, USA. The parameter used are: Bubble point pressure(Psi), solution gas-oil ratio(scf/stb), Gas Specific Gravity(lb/ft^3), Oil Relative Density(^{0}API), and the Reservoir Temperature(^{0}F).

The Original Standing equation is stated as shown:

$$Pb = a_1\left[\left(\frac{Rs}{\gamma_g}\right)^{a2} 10^X - a_5\right],\ X = \left[a_3\,T - a_4\gamma_{oAPI}\right]$$

(1)

where $[a_1 = 18.2, a_2 = 0.83, a_3 = 0.00091, a_4 = 0.0125, a_5 = 1.4]$.

Other variants of the Standing correlation are:

Vazquez and Beggs:

$$Pb = \left[a_1\left(\frac{Rs}{\gamma_g}\right)10^X\right]^{a_2},\ X = \left[-a_3\frac{\gamma_{oAPI}}{(T+460)}\right]$$

For API > 30 a1 = 56.06, a2 = 0.84246, a3 = 10.393

(2)

Petrosky and Farshad

$$Pb = a_1\left[\left(\frac{Rs^{a_2}}{\gamma_g{}^{a_3}}\right)10^X - a_4\right],\ X = \left[a_5\,T^{a_6} - a_7\gamma_{oAPI}{}^{a_8}\right]$$

$a_1 = 112.727$, $a_2 = 0.5774$, $a_3 = 0.8439$, $a_4 = 12.34$, $a_5 = 4.561 \times 10^{-5}$, $a_6 = 1.3911$, $a_7 = 7.916 \times 10^{-4}$, $a_8 = 1.541$

(3)

Farshad et al

$$Pb = a_1\left[\left(\frac{Rs}{\gamma_g}\right)^{a2} 10^X\right],\ X = \left[a_3\,T - a_4\gamma_{oAPI}\right]$$

$a_1 = 33.22$, $a_2 = 0.8283$, $a_3 = 0.000037$, $a_4 = 0.0142$

(4)

Didoruk and Chrismas

$$Pb = a_1\left[\left(\frac{Rs^{a_2}}{\gamma_g{}^{a_3}}\right)10^X - a_4\right]^{a_9},\ X = \frac{a_1\,T^{a_2} - a_3\gamma_{oAPI}{}^{a_4}}{\left(a_5 + \frac{2Rs^{a_6}}{\gamma_g{}^{a_7}}\right)^2}$$

$a_1 = 1.42828 \times 10^{-1}$, $a_2 = 2.8445918$, $a_3 = -6.74896 \times 10^{-4}$, $a_4 = 1.2252264$, $a_5 = 0.03338$, $a_6 = -0.272945$, $a_7 = -0.084226$, $a_8 = 1.869979$, $a_9 = 1.221486$, a10 = 1.370508, $a_{11} = 0.011688308$

(5)

GOR Correlation

The Gas-Oil-Ratio(GOR) correlation can be calculated by solving the bubble point pressure correlation for R_s when our Standing's correlation is re-arranged and presented as:

$$P_b = 18.2(A - 1.4) \quad (6)$$

Where

$$A = \left(\frac{R_{sb}}{\gamma_g}\right)^{0.83} \times 10^{(0.00091T - 0.0125API)} \quad (7)$$

Therefore solving equations 6 and 7, R_s can be derived as

$$R_s = \gamma_g \left[10^x \left(\frac{P}{18.2} + 1.4\right)\right]^{1.2048} \quad (8)$$

Where

$$x = 0.0125API - 0.00091T \quad (9)$$

Moreso, the Standing 1947 California crude, Standing constructed a graphical Correlation of Oil Formation Volume Factor(Oil FVF) with an average error of 1.2% and in 1981 expressed it as:

$$B_o = 0.972 + 0.000147\left[R_s\left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25T\right]^{1.175} \quad (10)$$

Thus , these Standing's correlations are valid for oil with trace composition of non hydrocarbon components.

3.3 Input Parameters

The MBAL input comprises the PVT data, tank data data, History matched Aquifer properties, relative permeability data, Production data(History) and

reservoir thickness. The Input parameters are as summarised below in table 1(PVT Data), table 2(Tank Data), table 3(Relative permeability) and table 4 shows Reservoir Data.

Table 1: PVT Data and Model Type

Reservoir Name	X
Reservoir Fluid	Oil
Tank Model	Single Tank
PVT Model	Simple PVT
Formation GOR	325.028 scf/stb
Oil Gravity	35.2 API
Gas Gravity	0.8718
Water Salinity	78000ppm
Mole percent H2S	0
Mole percent CO2	2.17%
Mole percent N2	0.6%
Reservoir Temperature	215°F
Bubble point	1537.85 psia
Oil Viscosity at Pb	0.698534 cp
Bo @Pb	1.23047 bbl/stb

Table 2: Tank Data and History Matched Aquifer Properties

RESERVOIR	X
Initial Reservoir Pressure	5150 psia
Porosity	0.21
Connate water saturation	0.15
Initial Gas cap	0
STOIIP	425.704 MMSTB
Start of Production	01-01-2006
Reservoir Thickness	120 ft
Reservoir radius	4200 ft
Outer/Inner Radius ratio	6
Encroachment Angle	360 degrees
Aquifer Permeability	10md
Aquifer Model	Hurst-van Everdingen-Modified
Aquifer System	Radial Aquifer

Table 3: Relative permeability X

	Residual Saturation	End Point	Exponent
Krw	0.15	0.676301	0.527657
Kro	0.15	0.8	0.710008
Krg	0.01	0.9	1

Table 4: RESERVOIR X

Time (dd-mm-yyyy)	Reservoir pressure (psig)	Cumulative Oil Produced (MMSTB)	Cumulative GOR (Scf/Stb)	Cumulative Water Produced (MMSTB)
01-01-2006	5150	0	0	0
02-04-2006	5092.89	0.4277	325.027	0.0121601
01-05-2006	5078.26	0.564	325.028	0.0200325
31-07-2006	5010.96	1.18744	325.029	0.0704627
30-10-2006	4956.73	1.81088	325.028	0.141712
29-01-2007	4910.14	2.43432	325.028	0.231005
30-04-2007	4868.96	3.05776	325.028	0.336346
30-07-2007	4831.86	3.68121	325.026	0.456274
29-10-2007	4797.98	4.30465	325.028	0.589664
28-01-2008	4766.79	4.92809	325.029	0.735621
28-04-2008	4737.84	5.55153	325.028	0.893424
01-08-2008	4709.46	6.20237	325.027	1.07008
01-10-2008	4681.16	6.6825	325.028	1.20747

3.4 Overview of Reservoir X

Description: Reservoir X is an undersaturated oil reservoir with an initial pressure of 5150 psia, a temperature of 215°F and a bubble point pressure of 1537.85 psia. It contains crude oil with an API gravity of 35.2 and has an initial solution gas oil ratio of 352.028 scf/stb. It has a thickness of about 120ft and an initial oil in place of about 425 MMSTB.

4. RESULTS AND DISCUSSION

4.1 PVT matching:

The available PVT data was matched using different Black Oil PVT Models, to select the model that provides the best match for the acquired data. From the analysis, the Glaso correlation was found to provide the best match for Bubble point, Solution Gas-Oil Ratio and Oil formation volume factor. The Petrosky et al. correlation also provided the best match for Oil viscosity, gas viscosity and gas formation volume factor. Below are plots of the different matched properties against pressure:

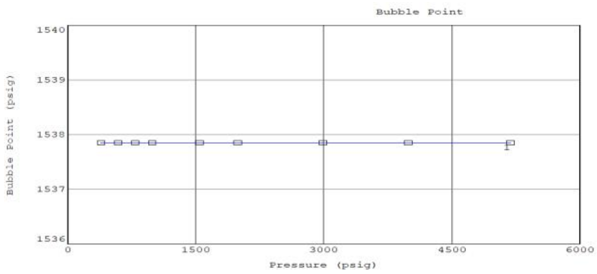


Fig.2: Bubble-point vs pressure

Shows the pressure at which the first bubble of the gas came out of the liquid oil solution. Bubble-point determination is a crucial element in modeling and managing a reservoir. In this study, the Glaso-Correlation gave the best match for bubble-point with perfect horizontal line.

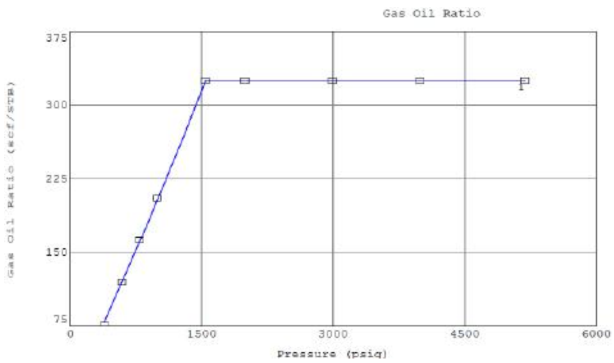


Fig. 3: GOR Vs Pressure.

This shows the surface gas dissolved in a stock tank at specific pressure and temperature. mathematically as R_s (SCF/STB). Best plot for Gas-Oil-Ratio was given by Glaso-Correlation.

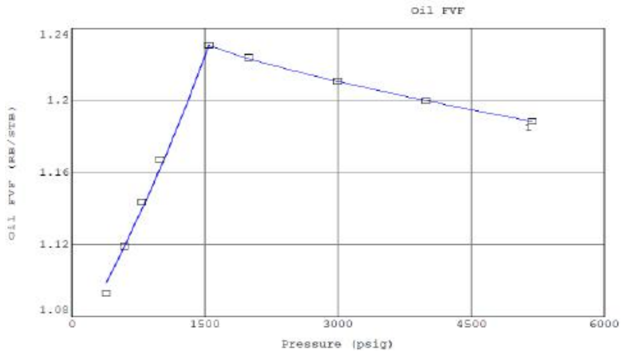


Fig. 4: Oil FVF Vs Pressure

Formation volume factor (FVF) vs pressure shows ratio of phase volume in relation to surface phase volume at standard condition when materials of reservoir are brought to the surface. Glaso-correlation shows best plot.

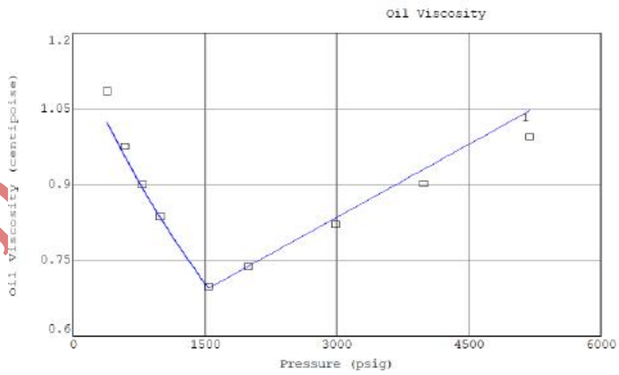


Fig. 5: Oil viscosity Vs pressure

Oil viscosity generally shows inverse relationship with pressure as oil viscosity increases with decrease in pressure at suturated condition due to disolved gases below bubble-point but viscosity increases with pressure due to liquid compression above bubble-point. However, Petrosky gave the best plot for Viscosity.

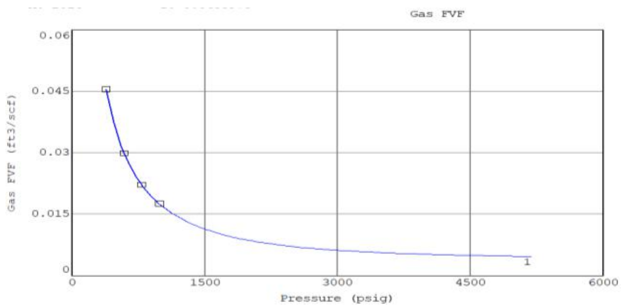


Fig. 6: Gas FVF Vs Pressure

The Glaso-Correlation provided the best match as shown.

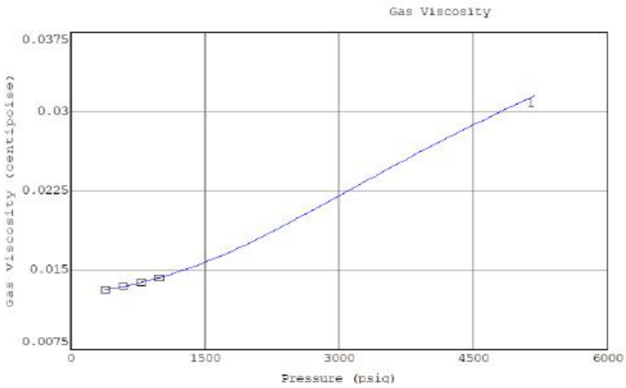


Fig. 7: Gas Viscosity Vs Pressure

Best plot was provided by Petrosky et al correlation.

4.2 Production History Match

4.2.1 Without Aquifer:

From the production history match without adding an aquifer, the following plots were obtained for the analytical and graphical methods as in figures 7 and 8.

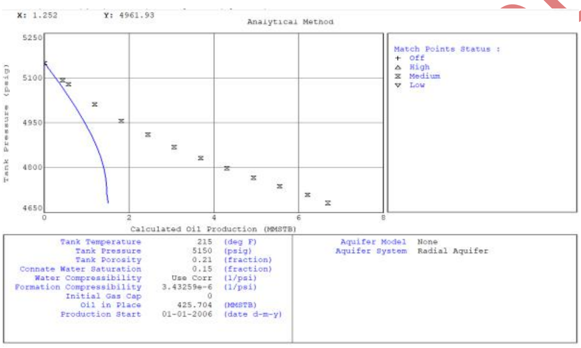


Fig. 8: Shows Analytical/Graphical plots without Aquifer.

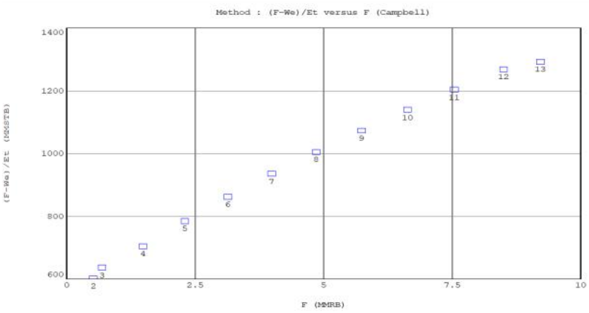


Fig. 9: Shows Cambell plot without Aquifer.

From the Campbell plot, the history data points do not lie on a straight line, showing that a good match has not be made and there may be the presence of an aquifer.

The Analytical plot also shows a mismatch between historical cumulative production and that derived from the model. It shows an underprediction of cumulative oil produced for a given pressure drop. For this reason, the presence of an aquifer is also suspected to be contributing to historical production.

4.2.1.1 With Aquifer:

A modified Van-Everdingen and Hurst aquifer model was set up to match historical production and the aquifer parameters with the highest uncertainties were regressed on to match historical data, all within well-defined boundaries that suit reasonable engineering and geological judgment. The parameters regressed on include: The encroachment angle, outer/inner radius, and aquifer permeability.

The following plots were generated after the regression on the different parameters:

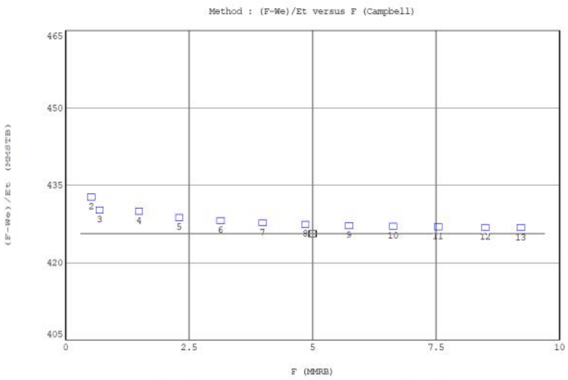


Fig. 10: Shows cambell plot with Acquifer/Regression

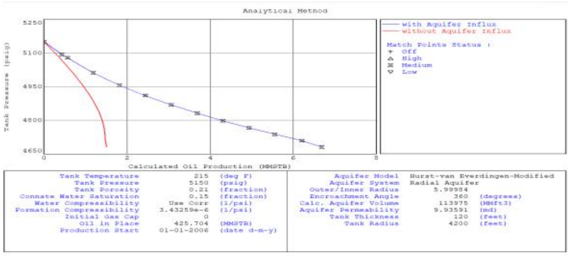
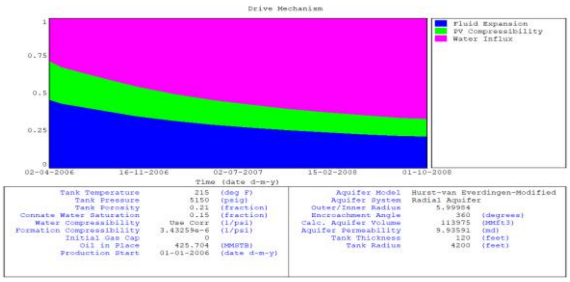


Fig. 11: Analytical plots with Acquifer



Fig, 12: Shows the Drive mechanism/Energy that drive the Reservoir

After defining an aquifer, and regressing on the uncertain parameters, it can now be seen that the Campbell plot now falls on straight line and the Analytical plot now follows the historical trend. The matched aquifer properties can be seen in the analytical plot above. The energy plot also shows that fluid expansion was initially the major drive mechanism, after which water drive became a major contributor to production.

With this, a good historical match has been made and predictions can now be carried out, after a good fractional flow model is obtained.

A pressure simulation was also carried out to determine the validity of the model, as shown below:

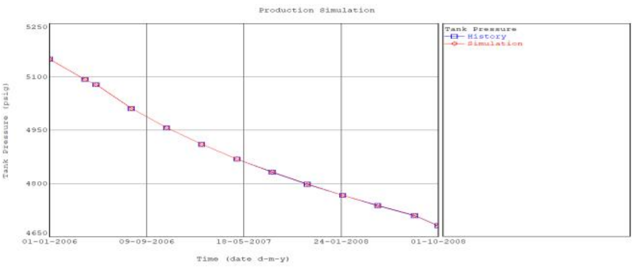


Fig. 13: Plot shows pressure simulation to check validity of model.

From the pressure simulation, we can see a good match between historical pressure and simulated pressures for reservoir X.

Using the historical data, a good fractional flow match was obtained, as shown below:

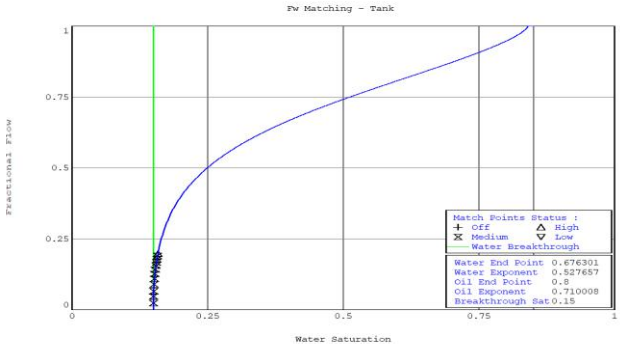


Fig. 14: Shows historical pressure and simulated pressures matching.

5. CONCLUSION

The material Balance (MBAL) is a sophisticated analytical tool to evaluate the volume of reservoir through historical production, data, results and plots obtained upon which the following conclusions have been drawn from the research work. Reliable PVT data is required to carry out reservoir volume evaluation in MBAL which initializes, calibrates and benchmarks the history matching. The energy plot shows fluid expansion as the major drive mechanism but thereafter, water drive became a major contributor to production. Further findings include the effect of salinity on water density and compressibility on water formation. The study also posited that reservoir analysis requires adequate understanding of the behaviors of oil, gas and water when flowing simultaneously through porous medium. Finally, it should be stated that, the reservoir model using MBAL suite does not take into account the geometry of the reservoir, position and well formation.

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Nomenclature:

API – American Petroleum Institute
Bbl – Barrel
Bg – Gas formation volume factor
Bo – Oil formation volume factor
Cp – Centipoise
GOR – Gas Oil Ratio
Krg – Relative Permeability to Gas
Kro – Relative Permeability to Oil
Krw – Relative Permeability to Water
MD – Measured Depth
Md – milli Darcy
MMSTB – Million Stock Tank Barrel
MSTB – Thousand Stock Tank Barrel
Pb – Bubble point
Ppm – Parts Per Million
Psia – Pounds per square inch (Absolute)
Psig – Pounds per square inch (Gauge)
PVT – Pressure, Volume, Temperature
R_p-Producing Gas Oil Ratio
Scf – Standard Cubic Feet
SSSV – Subsurface Safety Valve
Stb – Stock Tank Barrel
STOIIP – Stock Tank Oil Initially in Place
TVD – True Vertical Depth