

Report on the Evaluation of Ugua J2 and J3 Reservoir Performance

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Abstract: Globally, there are different techniques applied in the industry such as analog, volumetric, decline curve, material balance and simulation methods to estimate hydrocarbon reserves which depends upon the volume and quality of available data with some levels of uncertainties. The analogy method is applied by comparing factors for the current fields or wells while the volumetric method implies the determination of the extent of the reservoir, pore volume of the reservoir rock and the content of fluid within the reservoir pore volume when production and pressure data from field become available, decline curve analysis and material balance calculations become the predominant methods of calculating reserves since the hydrocarbon reserve estimates is a continuous process for a field that is producing. This study presents a report on the material analysis of Ugua J2 and J3 reservoirs with MBAL prior to the field's dynamic reservoir simulation. The available data were validated and the analytical plot of pressure and production data indicated that J2 and J3 reservoirs are communicating. Hence multi-tank material balance analysis approach linked with transmissibility was adopted to model the reservoirs. The Hurst-Van Everdingen radial aquifer model was selected as the most likely case. The oil initially in place value obtained for J2 and J3 are 125.006 and 80.689 MMstb.

Keywords: Hydrocarbon Reserves, Material Balance, MBAL, Communication, Data Quality Check, Transmissibility

Introduction

The process of estimating oil and gas reserves for a producing field starts from discovery and then continues in the entire life of the field and at each stage, there are different techniques applied depending upon the volume and quality of available data (SPEE, 1998). At the initial stage of field development, analog and volumetric methods are used to estimate oil and gas reserves which do not give a feel of the behaviour of the reservoir. The analogy method is applied by comparing factors for the current fields or wells while the volumetric method implies the determination of the extent of the reservoir, pore volume of the reservoir rock and the content of fluid within the reservoir pore volume (Petrobjects, 2003). The volumetric technique provides an estimate of the amount of hydrocarbons-in-place with inherent uncertainties in the input parameters such as porosity, saturation, formation volume factor and the bulk volume from geology. Ahmed (2010) stated that a proper

averaging of saturation and porosity data is required. In addition, we should note that all reserve estimates involve some degree of uncertainty or probability distribution, depending mainly on the amount of reliable data but can be reduced within reasonable engineering tolerance of error. Practically, in the industry, a particular cut off is used on some of these parameters with the rational that; though the reservoir is porous but not all pore spaces are connected. This value varies among companies and is applied to account for the fraction not connected. Some companies carry out core-log comparison for quality control and assurance of petrophysical properties. The reservoir sand needs to be evaluated to determine the net-gross ratio to account for the shale sand since some of the reservoirs are not completely sand.

When production and pressure data from a field become available, decline curve analysis and material balance calculations become the methods of calculating reserves. These methods greatly reduce the uncertainty

in reserves estimates; however, during early depletion, caution should be exercised in using them. Decline curve relationships are empirical and rely on uniform, lengthy production periods. Warner *et al.* (1979) stated that the material balance method has some limitations though can be used as a pre-processing tool to infer fluid in place, drive mechanisms and identify aquifer for a more sophisticated tool “reservoir simulation” which gives insight into dynamic rock and fluid properties for evaluation of past reservoir performance, prediction of future reservoir performance and reserve estimation. Besides, the significant different between MBE results and volumetric is usually overemphasized.

It therefore means that one of the fundamental challenges before the geophysicists, reservoir engineers and geologists is the ability for this integrated team to work harmoniously to obtain a near-exact value of the oil in place before field development and optimization start. Hence, a clear understanding of the reservoir is critical to the success of a field development program. This understanding must be developed through the application of an integrated work flow. In the ongoing research on workflow for reservoir study and challenges by Okotie *et al.* (2015) they presented a step by step approach and data require at each stage to assist new reservoir simulation engineers to successfully perform a field study. Prior to running the dynamic model; while build the simulation model, a simulation pre-processing such as PVT Analysis, Core/SCAL Analysis, VLP Curve generation, Production and Events, Material balance and Decline Curve Analysis etc. is required. Hence, this study presents a material balance analysis report of Ugua J2 and J3 reservoirs, a field in the Niger Delta region of Nigeria.

Material Balance Concept of Reserve Estimate

Material Balance Equation (MBE) tool is used to interpret and predict reservoir performance. REPAT developed by author or MBAL by Petroleum expert can be used for the material balance analysis. It uses analytical method, a non-linear regression approach based on reservoir pressure decline against cumulative production. Odeh and Havlena (1963) rearrange MBE into different linear forms (Equation 2). This method requires the plotting of a variable group against another variable group selected depending on the reservoir drive mechanism and if linear relationship does not exist, then this deviation suggests that reservoir is not performing as anticipated and other mechanisms are involved which were not accounted for; but once linearity has been achieved, based on matching pressure and production data then a mathematical model has been achieved. This technique is referred to as history matching. Therefore,

the application of the model enables predictions of the future reservoir performance.

The general material balance equation is given as Equation 1:

$$N = \frac{N_p B_o + (G_p - N_p R_s) B_g - (W_e - W_p) B_w - G_{inj} B_{inj} - W_{inj} B_{inj}}{\left[(B_o - B_{oi}) + (R_{si} - R_s) B_g + m B_{oi} \left(\frac{B_g}{B_{gi}} - 1 \right) \right] + (1 + m) B_{oi} \left(\frac{S_{wi} C_w + C_f}{1 - S_{wi}} \right) \Delta P} \quad (1)$$

The straight line form of the material balance equation is given as:

$$F = N \left[E_o + m E_g + E_{f,w} \right] + W_e B_w \quad (2)$$

Where Equation 3 to 6:

$$E_o = (B_o - B_{oi}) + (R_{si} - R_s) B_g \quad (3)$$

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

$$E_{f,w} = (1 + m) B_{oi} \left(\frac{S_{wi} C_w + C_f}{1 - S_{wi}} \right) \Delta P \quad (5)$$

$$F = N_p B_o + (G_p - N_p R_s) B_g - W_p B_w \quad (6)$$

Material balance analysis was carried out on Ugua J2 and J3 reservoirs. The Material Balance Analysis tool, MBAL, of Petroleum Experts Limited was used for the analysis. The reservoir pressure, PVT and production data, after careful review, served as input data into the MBAL program. Available geological maps and petrophysical data aided the estimation of the aerial extent of the reservoir and the aquifer. The in-place volumes acquired from the study are subject to validation by static and dynamic simulation. The workflow is given in Fig. 1.

Data Quality Control and Quality Assurance

Data QA/QC was performed to ascertain the quality of the data to be used for the project and to provide preliminary data validation that is to validate the allocated and the flow test data. Analytical plot of pressure and production with Microsoft excel was used to check for communication across the J2 and J3 reservoirs (Fig. 2). The samples for Ugua J2 and J3 reservoirs were validated through their opening pressures and saturation pressure for quality control of samples.

Sometimes the measured value can be incorrect but a consistency check was performed before starting the tuning process which is almost impossible to match everything perfectly. It is worthy to not that when performing the PVT analysis, one of the experiments may worsen the others. Prior to fitting an Equation Of State (EOS) model to the laboratory data, adjustments were made to the Differential Liberation formation volume factor and solution Gas oil ratio data to the reported separator conditions. Hence, before starting any study, all the available data should be assessed and any data discrepancies and/or deficiencies should be identified. The data requirements should be consistent with the objectives of the study.

PVT Data

The PVT analysis for Akpet GT9 and GT12 reservoir has been carried out. This is in line with

fitting an Equation Of State (EOS) to the laboratory PVT experimental data and then using the EOS to produce ECLIPSE black oil PVT tables and EOS model for use in dynamic modeling of the Akpet reservoir dynamic simulation. Laboratory PVT Data reports were made available for the analysis. In GT9 and GT12 reservoirs, a total of twelve (12) components were defined in the characterization; eight (8) pure light hydrocarbons (from C1 to C6), two non-hydrocarbons (N₂ and CO₂) and heavy components lumped as C7+ fraction. The C7+ of GT9 is characterized with a mole weight of 205.74 and specific gravity of 0.83184 respectively While GT12 is characterized with a mole weight of 212.72 and specific gravity of 0.834944 respectively. Table 2 shows the fluid composition of the surface recombined fluid sample. Detail analyses of the PVT results are not report in this study.

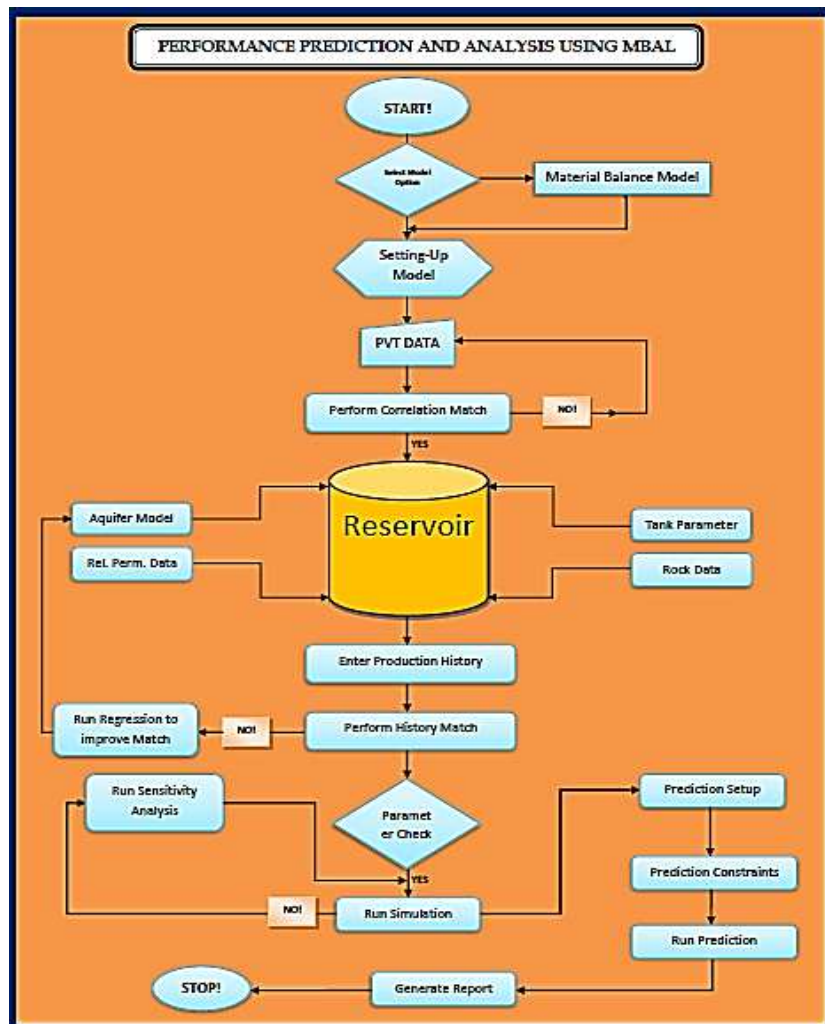


Fig. 1. MBAL workflow

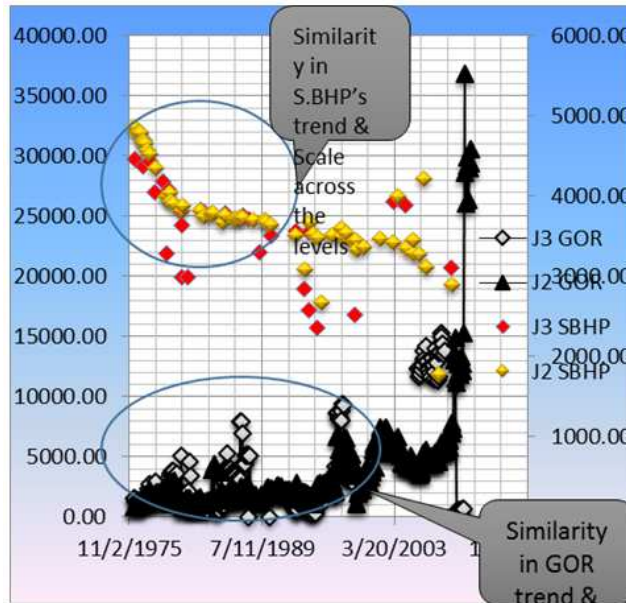


Fig. 2. GOR and SBHP Plots

Table 1. Ugua J2 and J3 reservoir PVT Data

J2 Reservoir		J3 Reservoir	
Property	Value	Property	Value
Formation GOR (scf/STB)	1736.000	Formation GOR (scf/STB)	1253.000
Oil gravity	34.800	Oil gravity	33.700
Gas Gravity	0.863	Gas Gravity	0.698
Mole Percent H2S (%)	0.000	Mole Percent H2S (%)	0.000
Mole Percent CO (%)	1.840	Mole Percent CO (%)	2.750
Mole Percent N2 (%)	1.090	Mole Percent N2 (%)	0.070
Water Salinity (ppm)	10000.000	Water Salinity (ppm)	10000.000
Pb, Rs, Bo correlation	Lasater (1958)	Pb, Rs, Bo Correlation	Glaso (1980)
Oil Viscosity correlation	Petrosky and Farshad (1993)	Oil Viscosity Correlation	Beal (1946)
Separator	Single stage	Separator	Single Stage

Table 2. Ugua J2 and J3 reservoir (Tank) properties

J2 Reservoir		J3 Reservoir	
Parameter	Value	Parameter	Value
Temperature (deg.F)	229.00	Temperature (deg.F)	228.00
Initial Pressure (psi)	4718.00	Initial Pressure (psi)	4711.29
Porosity	0.15	Porosity	0.15
Connate Water Saturation	0.15	Connate Water Saturation	0.15
Water Compressibility (1/psi)	Use correlation	Water Compressibility (1/psi)	Use correlation
Initial Gas Cap	0.038	Initial Gas Cap	0.116

Hydraulic Communication Check

Analytical plots of the pressure and the production data as shown in Fig. 2 have been used to check for a possible communication across the J2 and J3 reservoir levels.

Similar SBHP and GOR trends for J2 and J3 reservoirs indicate possible communication across these levels, hence J2 and J3 was modeled as multiple tanks connected by means of a transmissibility.

Data Presentation

Ugua J2-J3 reservoirs are both saturated oil reservoir. J2 reservoir operates at a temperature of 229 deg. F and a bubble point of 4718 psi while J3 reservoir operates at a temperature of 228 deg. F and a bubble point 4711.29 psi. J2 reservoir production history spans a period of 35 years (May 1976-January 2011) while J3 spans a period of 34 years (February

1977-January 2011). The PVT and reservoir (tank) data used in the analysis for both reservoirs are as shown in the Table 1 and 2.

Procedure

The Havlena-Odeh and the F/Et Vs. We/Et straight line plots of the graphical method incorporating various radial aquifer models were used to evaluate the aquifer properties, match the reservoir pressure and determine the Gas Initially In-Place (GIIP). The accuracy of the results was validated with the history match of the model's pressure and production.

The analysis procedure is as follows:

- Pressure and production data is entered on a Tank basis
- The matching facility in MBAL is used to adjust the empirical fluid property correlations to fit measured PVT laboratory data. Correlations are modified using a non-linear regression technique to best fit the measured data

- The graphical method plot is used to visually determine the different Reservoir and Aquifer parameters. The Havlena-Odeh and the F/Et Vs. We/Et straight-line plots of the graphical method were used to visually observe and determine the appropriate aquifer model and parameters
- The non-linear regression engine of the analytical method is used in estimating the unknown reservoir and aquifer parameters and fine tune the pressure and production match. This is done for various aquifer models and their standard deviations from the actual field data are compared
- The accuracy of the model is validated by history matching the field pressure and production data with the simulation data

Results

The summary of the result from the analysis is shown in Table 3.

The summary of the aquifer parameters used in the Material Balance calculations and the source of each data is depicted in Table 4 and 5.

Table 3. Summary of Uguia J2 and J3 reservoir analysis results

J2 Reservoir		J3 Reservoir	
Aquifer model	Hurst-Van everdingen-modified	Aquifer model	Hurst-Van everdingen-dake
Reservoir Thickness (m)	282.000	Reservoir Thickness (m)	96.170
Reservoir Radius (m)	5000.000	Reservoir Radius (m)	3576.000
Outer/Inner Radius	2.560	Outer/Inner Radius	3.930
Encroachment Angle	224.000	Encroachment Angle	139.000
Aquifer Permeability (md)	2.480	Aquifer Permeability (md)	35.000
OIIP (MMSTB)	125.006	OIIP (MMSTB)	80.689
GIIP (Bscf)	42.720	GIIP (Bscf)	68.700

Table 4. Summary of input data for Uguia J2 reservoir aquifer model and transmissibility

J2 Reservoir		
Parameter	Value	Source
Aquifer permeability	2.48000	Regression in MBAL
Encroachment Angle (deg.)	224.00000	Fault Polygon
Reservoir Radius (m)	5000.00000	Estimation from seismic map
Outer/Inner radius (Ratio)	2.56000	Estimation from seismic map
Reservoir Thickness (m)	282.00000	Logs
Transmissibility (Rb/day*cp/psi)	4.76925	Regression in MBAL

Table 5. Summary of input data for Uguia J2 reservoir aquifer model and transmissibility

J3 Reservoir		
Parameter	Value	Source
Aquifer permeability	35.00000	Regression in MBAL
Encroachment Angle (deg.)	139.00000	Fault Polygon
Reservoir Radius (m)	3576.00000	Estimation from seismic map
Outer/Inner radius (Ratio)	3.93000	Estimation from seismic map
Reservoir Thickness (m)	96.70000	Logs
Transmissibility (Rb/day*cp/psi)	4.76925	Regression in MBAL

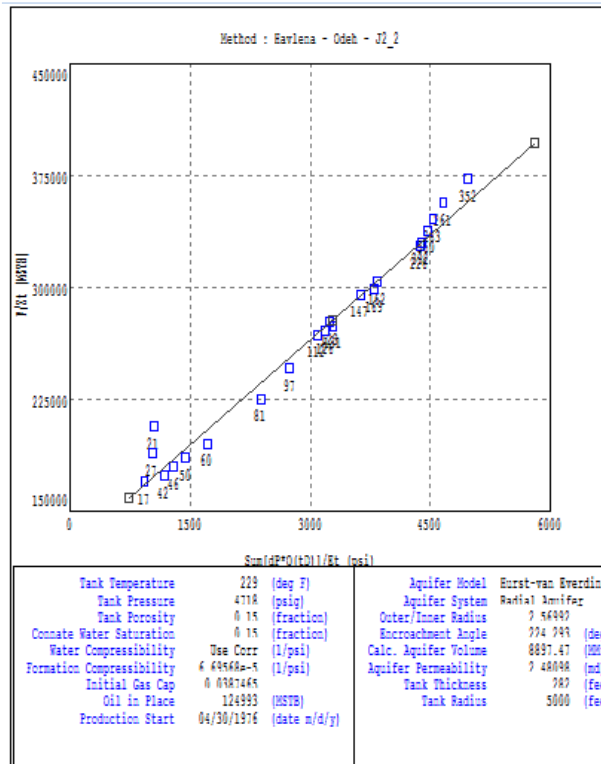


Fig. 3. J2 Reservoir graphical diagnostic plot

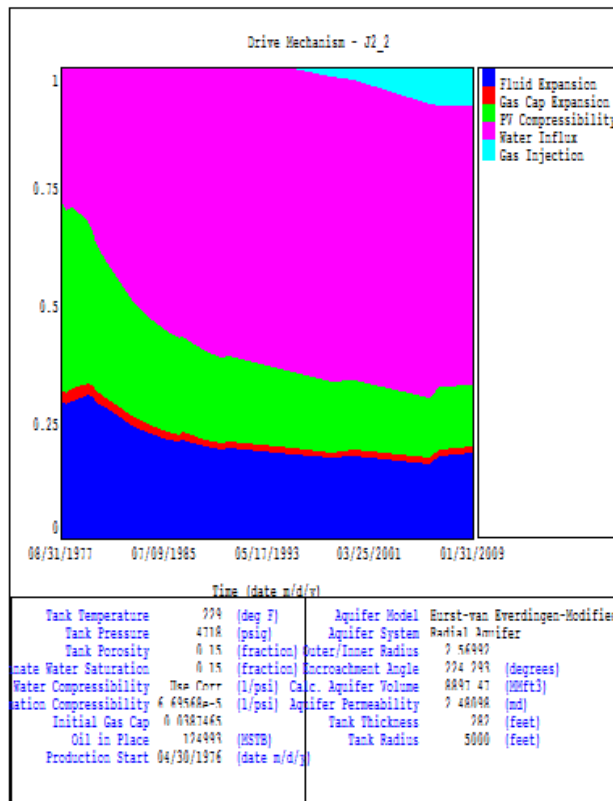


Fig. 4. J2 reservoir energy plot

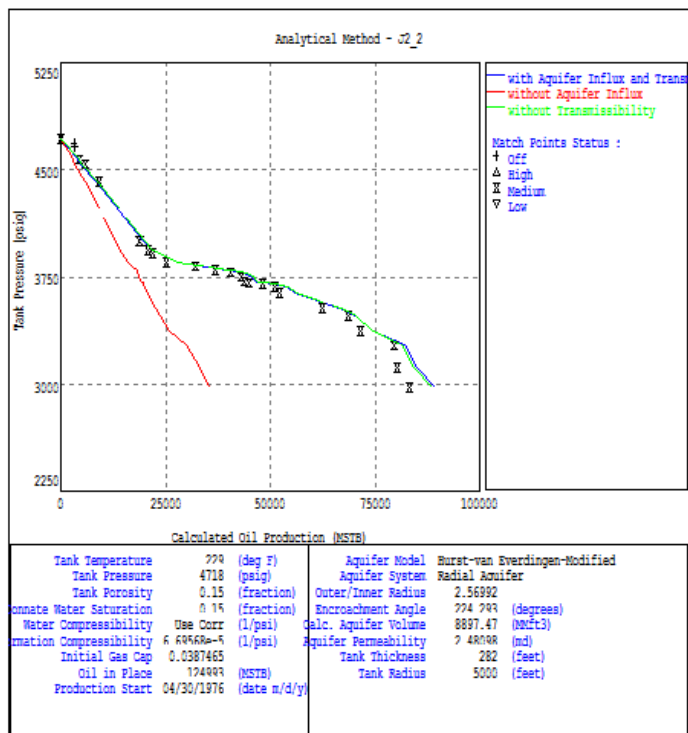


Fig. 5. J2 reservoir analytical plot

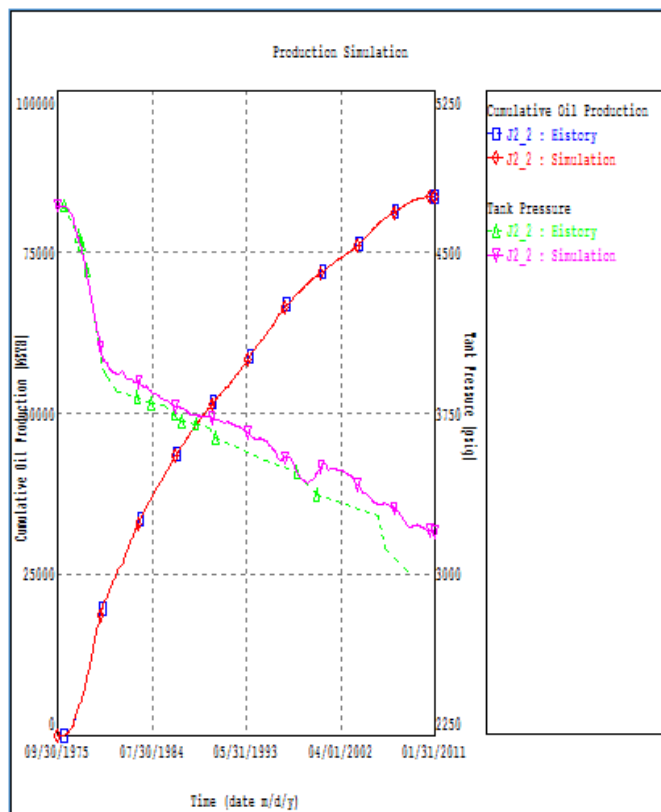


Fig. 6. J2 reservoir pressure history match plot

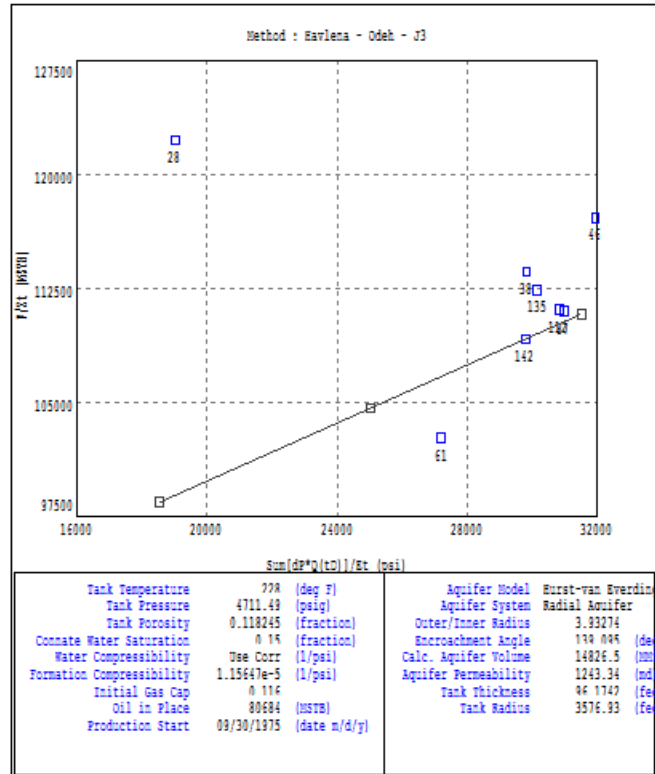


Fig. 7. J3 reservoir graphical plot

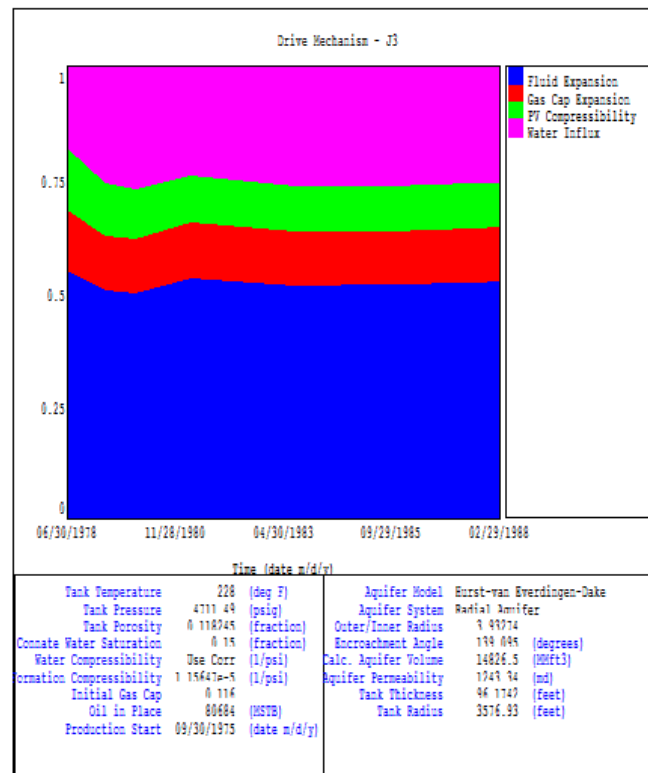


Fig. 8. J3 reservoir energy plot

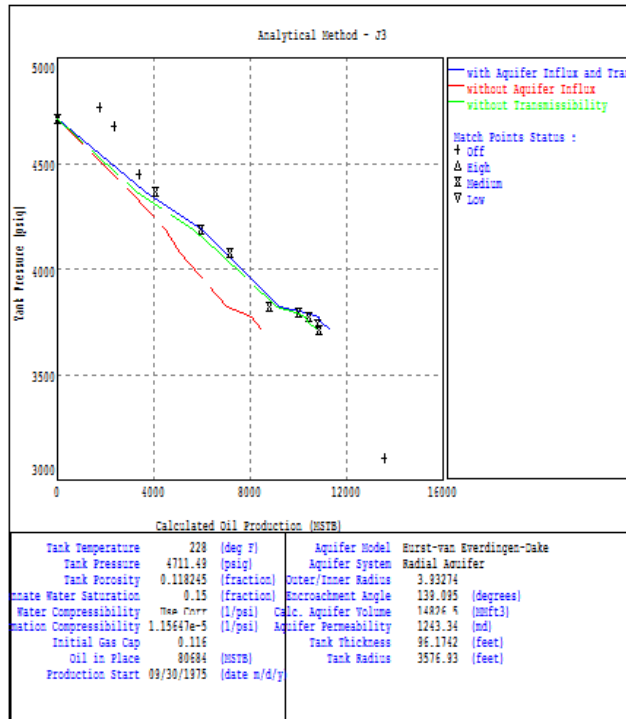


Fig. 9. J3 reservoir analytical plot

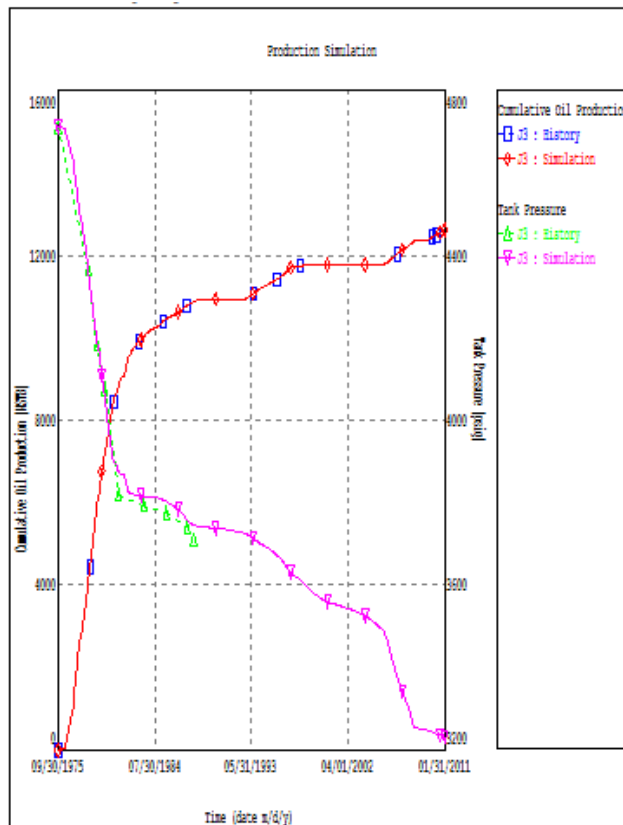


Fig. 10. J3 reservoir analytical plot

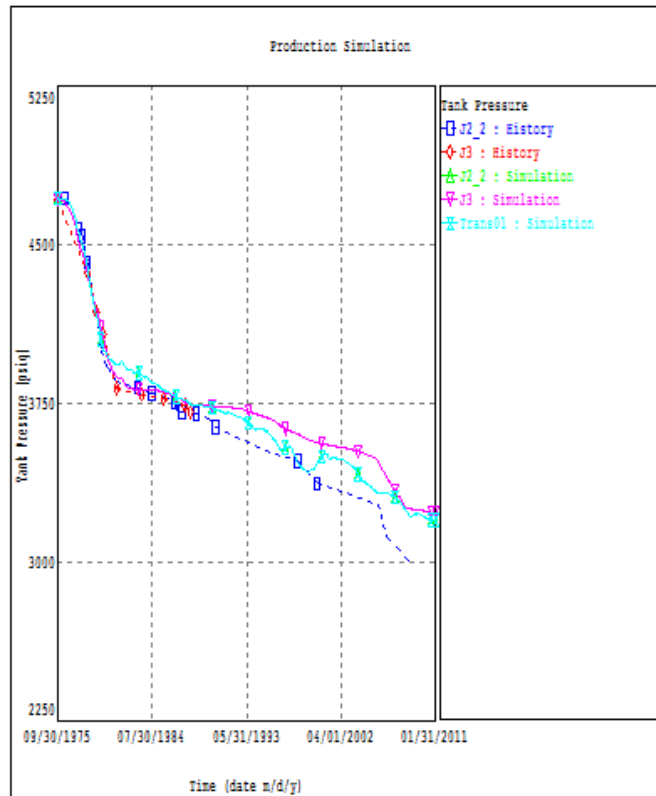


Fig. 11. J2 and J3 reservoirs pressure plot with a transmissibility

The Hurst-Van Everdingen Modified model was selected as the most likely case for J2 while Hurst-Van Everdingen-Dake for J3. The parameters used to obtain the history match and the OOIP from both models with the Hurst-Van Everdingen Modified and Hurst-Van Everdingen radial aquifer compare favorably with the expected values. The plots generated from the most likely case models are shown in Fig. 3-11.

Constraints

- Unknown aquifer characteristics and properties

Inference from Analysis

Inferences from the Material Balance analysis of the Uguu J2 reservoir are as follows:

- The OOIP is 125.006MMstb
- The most likely aquifer model is the Hurst-Van Everdingen Modified radial aquifer
- The reservoir is supported by a combined drive majorly of water influx, fluid expansion and gas injection mechanisms

Inferences from the Material Balance analysis of the Uguu J3 reservoir are as follows:

- The OOIP is 80.689MMstb
- The most likely aquifer model is the Hurst-Van Everdingen-Dake radial aquifer
- The reservoir is supported by a combined drive majorly of fluid expansion and water influx with a minimal gas cap expansion mechanisms
- It can be established there is communication between J2 and J3 as can be seen from the combined history match pressure and transmissibility plot of Fig. 11

Conclusion

From the hydraulic communication check performed given in Fig. 2, we suspect communication between J2 and J3 reservoirs, hence multi-tank material balance analysis approach linked with transmissibility was adopted to model the reservoirs. The results obtained will be used in the full field Uguu reservoir simulation study and the oil initially in place volume will be validated with the static and dynamic models. The Hurst-Van Everdingen radial aquifer model was selected as the most likely case.

The summary of the results from the material balance analysis of the Uguu J2 and J3 reservoir levels is depicted in the Table 6.

Table 6. Ugua J2 and J3 material balance results

Reservoir level	OIIP (MMstb)	GIIP (Bscf)	Available drive mechanism	Likely aquifer
J2	125.006	42.72	Combination drive	Hurst-Van Everdigen-Modified
J3	80.689	68.70	Combination drive	Hurst-Van Everdigen-Dake

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Author's Contributions

Okotie Sylvester: Participated in the data QA/QC, hydraulic communication check, development of study methodology, model build with MBal and contributed to the writing of the manuscript.

Ikporo Bibobra: Participated in the collection of data, PVT model, result analysis and contributed to the writing of the manuscript.

Ovuma Augustina: Participated in the collection of data, result analysis and contributed to the writing of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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