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Petroleum & Petrochemical Engineering Journal
ISSN: 2578-4846

Advancing Reservoir Performance Optimization through User-Friendly Excel VBA Software Development

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Research Article

Volume 8 Issue 1

Received Date: November 30, 2023

Published Date: Janaury 23, 2024

DOI: 10.23880/ppej-16000374

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Abstract

This study addresses the pressing demand for streamlined field performance analysis within oil and natural gas development, which currently necessitates substantial expertise and time investment. The principal aim involves developing a user-friendly software tool dedicated to optimizing reservoir rendition. Leveraging the Havlena and Odeh material balance straight line equation form, this tool integrates a zero-dimensional reservoir model with Decline Curve Analysis. The implementation of this user-friendly software enables achievable material balance optimization by aligning cumulative produced fluid with historical production data, akin to the widely acknowledged concept of history matching in material balance analysis. This accomplishment not only facilitates further endeavors like pressure simulation and forecasting but also augments the comprehension of reservoir dynamics. The analysis incorporated three datasets: one modeled from L.P. Dake's textbook and two drawn from real-life reservoirs in the Niger Delta. Assessment of estimated water influx and cumulative oil production indicated minimal discrepancies between Np Real and Np model for these reservoirs. Consequently, material balance history matching for these reservoirs seems feasible. Achieving reservoir rendition optimization involved a Microsoft Excel VBA code consisting of two hundred and thirty-five (235) lines, meticulously designed to replicate MBAL functionality. The software demonstrated congruent outcomes with MBAL, affirming its reliability for history matching and enhancing reservoir performance. We strongly advocate the utilization of this software for optimizing reservoir performance across diverse global regions. Its capacity to streamline field analysis could significantly benefit the oil and natural gas industry.

Keywords: Reservoir performance; Excel VBA; Oil and gas production; Material balance; Simulation

Introduction

Forecasting the rendition of reservoirs support engineers in reserve estimation and develop a plan which requires a comprehensive knowledge of the features of the reservoir and optimization of production, to also create a model that will show the physical processes taking place in reservoirs [1-3]. In oil and gas reservoir development, projected field performance is the information required by oilfield workers that are into the design, risk, and decision-making process. Field performance analysis can require a substantial number of skills. Implementing the appropriate modeling approach is therefore the key to analyzing a field's performance efficiently [4,5]. Sophisticated and detailed models rely on the set of fluid and reservoir data that are available. Prediction of a field's performance has to do with calculations of pressures, flow rates, cumulative productions, and expected production times using the available reservoir, production network, and production constraint data [6-8]. Every reservoir is made up of a unique arrangement of geometric form, rock properties, fluid properties and primary drive mechanisms. Though no two reservoirs are similar, they are categorized according to the primary recovery mechanism which they produce with. The performance characteristics of every producing mechanism are studied based on Decline rate of Pressure, Gas-oil ratio, Water production and Ultimate recovery [9-11]. The physical process behind material balance was reviewed and validated first by Schilthuis [9]. Odeh, et al. [12] put the equation into linear form making it simpler to understand and use. Plots were created considering the drive mechanism supporting the reservoir. Once a horizontal straight line is obtained in the plots, it means a purely depletion drive influence. If it deviates, then it's not performing as anticipated which automatically suggests that other drive mechanisms effects are present. Coats, et al. [13] worked on the prediction of gas well performance. They investigated the gas well performance by developing a numerical model. Three field applications were conducted considering the effects of various parameters. The gas well performance was forecasted [14-16]. Miranda, et al. [17] in their work used cumulative reservoir withdrawals in place of the original fluid in place. DeSorcy [18] estimated the accuracy of each of the parameters. Galas [19] investigated an automated history matching system for the method by evaluating non-linear regression function and established that the boundary of matching parameters should not be overlooked. Esor, et al. [5] and Amudo, et al. [15] considered the application and methodology of the MBAL tool in developing connected oil and gas volumes in place. Bui, et al. [4] carried out their work to investigate the mature Samarang field's reservoir compartmentalization using material balance analysis. They investigated the relationship between relative permeability curves and their effectiveness on history matching using the workflow of material balance analysis. Baker, et al. [20] provided a workflow process in Eclipse simulator. Mazloom, et al. [21] assessed the MB prognosis results from the models of single- and multi-tank. They discovered that the multi-tank model results were better than that of the single-tank model. Garcia, et al. [22] evaluated a meaningful parameter that disturbs material balance computation. His work showed the reservoir pressure and PVT data affects the OOIP calculation. Tarek [23,24] stated in his work that MBE is used by reservoir engineers for future rendition forecast by continuously showing ways to optimally produce hydrocarbons in situ. Adeboye, et al. [14] used an enhanced model to forecast reservoir rendition. They stated that the parameters that govern decline must be understood. Mike, et al. [25] studied how reservoir rendition of reservoir changed with time. They stated in their work that the MBE is a handy tool for quickly defining reservoir drives, possible fluid contact, fluid-in-place for reservoirs and prediction of reservoir performance with time. Okotie, et al. [10] developed software called REPAT forecast reservoir rendition. MBE, expansion of Tarners method were utilized to produce the software which put into consideration aquifer influx and time. They discovered that water drive and fluid expansion drive supported the reservoir's performance. Yong [26] made a method that showed reservoir variety and field development method change on the rendition of a reservoir. The time consumed by the new method is shorter than that of the tine reservoir simulation. Written computer programs known as software, are employed in performing this analysis that involves complex mathematical models [10,27- 29]. Most of the commercial software is very expensive and as such extremely difficult for students and researchers to purchase. With sound understanding of the physics behind reservoir analysis coupled with good mathematical and programming skill, one can design a software that can perform like or even better than most commercial software, in agreement with this vision, I thought it wise to develop a software using Microsoft Excel VBA that can perform Material balance optimization analysis.

Predicting Reservoir Performance

Four methods are used in reservoir performance rendition. They include volumetric, Decline Curve Analysis, Reservoir simulation and Material balance methods [2,3,23,24,30,31].

Volumetric

Volumetric technique deals with the calculation of reservoir rock volume, the hydrocarbon in place contained in that rock volume and that which can be recovered. Important considerations are Rock Volume, Elevation of fluid contacts, Petrophysical parameters such as porosity, permeability, and Recovery factor [32,33].

Decline Curve Analysis

Historically, Arps' observed that fluid production rate declines exponentially with time stimulated emergence and further development of decline curve analysis [34]. Many researchers Agarwal, et al. [35] and Fetkovich's, et al. [36] contributed to the improvement and extension of this method applicability.

Reservoir Simulation

Reservoir simulation is based on the methodology put into a certain approach, where specific mathematical relationships describe ongoing physical processes in the reservoir Odeh [12]. These descriptions, i.e., models, define the engineering tasks that will be solved, and parameters used. By its nature, any methodology is developed considering specific assumptions, stipulations, simplifications, and solving methods, which further establishes opportunities, requirements, and constraints for the implementation of the specific method [37].

Material Balance

The Material Balance equation is the relationship that exists between the average reservoir pressure and reservoir performance [30,38,39] (Figure 1).

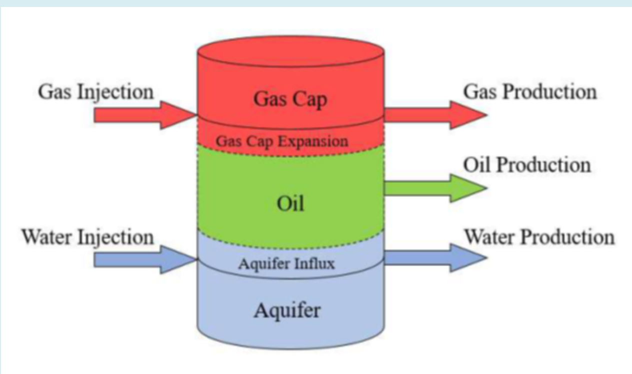

Figure 1: Material balance tank model assumption [2].

Generalized Material Balance Equation

Generalized material balance equation is:
Total underground withdrawal= oil produced+ gas produced+ water produced.

Gas produced, $G_p = \left(N_p R_p - N_p R_s\right) B_g$

$$= N_p\left(R_p - R_s\right)B_g$$

$\therefore$ Withdrawal = $N_p B_0 + N_p\left(R_p - R_s\right)B_g + W_p B_w$

The generalized material balance equation becomes:

$$N_p\left[B_0 + \left(R_p - R_s\right)B_g\right] = N\left[\left(B_o - B_{oi}\right) + \left(R_{si} - R_s\right)B_g\right] + mNB_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) + NB_{oi}\left(1+m\right)\left[\frac{c_w s_{wi} + c_f}{1 - s_{wi}}\right]ÄP + \left(W_e - W_p\right)B_w \quad (1)$$

Predicting Reservoir Future Performance as a Function of Time

Prediction of future performance as a function of time is achieved by combining MBE with a fluid-flow equation and Darcy's equation. Predicting the reservoir's future performance is conducted in two phases [25]. Phase one predicts production of hydrocarbon cumulative as it links to the decline in reservoir performance. Phase two is relating reservoir performance with time.

Two kinds of reservoir with their prediction techniques considered are Under-saturated oil reservoir and Saturated oil reservoir.

Under-Saturated Oil Reservoir

Cumulative production prediction involves a straightforward determination. The MBE is:

$$N = \frac{N_p B_o}{B_{oi} C_e ÄP} \quad (2)$$

Where; $C_e = \frac{1}{S_o}\left[S_{oi}C_o + S_{wi}C_w + C_f\right]$

$$C_e = \frac{B_o - B_{oi}}{B_{oi} ÄP}$$

From Equation (2), cumulative production will be derived for any given pressure decline as:

$$N_p = \frac{N C_e B_o}{B_{oi}} ÄP \quad (3)$$

Saturated Oil Reservoir

The three techniques for predicting primary recovery performance are The Tarner's technique, The technique of Muskata and The Tracy's technique [40-42].
Material Balance Equation as a Linear Equation [12]
Equate:

$F = N_p\left[B_o + \left(R_p - R_s\right)B_g\right] + W_p B_w$ Production

$E_o = \left(B_o - B_{oi}\right) + \left(R_{si} - R_s\right)B_g \Rightarrow$ Oil + originally dissolved gas

$E_g = \left(\frac{B_g}{B_{gi}} - 1\right)B_{oi} \Rightarrow$ Free gas expansion

$E_{f,w} = B_{oi}\left(C_w S_{wi} + C_f\right)ÄP / \left(1 - S_{wi}\right) \Rightarrow$ Connate water + rock

$$\therefore F = N\left[E_o + mE_g + \left(1+m\right)E_{f,w}\right] + W_e B_w \quad (4)$$

Depletion Drive: A reservoir having no initial gas cap where m=0 and negligible influx of water, rock compressibility and connate water (We=0, Ef,w=0), the equation degrades to:

$F = NE_o \Rightarrow$ (Straight line) (5)

$$F = NE_o + W_e \Rightarrow \frac{F}{E_o} = N + \frac{W_e}{E_o} \quad (6)$$

Water Drive: No initial gas-cap (m=0).

$$F = N\left(E_o + E_{f,w}\right) + W_g \quad (7)$$

But below bubble point, is negligible.

$$\therefore F = NE_o + W_e \Rightarrow \frac{F}{E_0} = N + \frac{w_e}{E_o} \quad (8)$$

Gas-Cap Drive: No water drive, is negligible.

$$\therefore F = N\left(E_o + mE_g\right) \Rightarrow \frac{F}{E_0} = N + \frac{mNE_g}{E_o} \quad (9)$$

Reservoir Drive Mechanisms

The drive mechanism is the energy responsible for transporting the hydrocarbon in the pore space of the reservoir to the wellbore. The common natural drive mechanism includes Depletion drive, Gas-cap drive, Water drive and Combination drive. Other drive mechanisms include Compaction drive, Imbibition and Gravity drainage drive [43-45] (Figure 2).

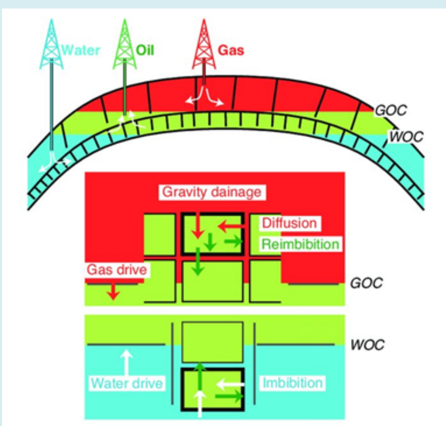

Figure 2: Reservoir drive mechanisms [45].

Reservoir Drive Indices

Each respective drive mechanism contributes to production.

Therefore, reservoir Drive Index =

$$\frac{\textit{individual production contribution}}{\textit{total underground HC production}}$$

$$\therefore Depletiondriven, DDI = \frac{N[(B_o - B_{oi}) + (R_{si} - R_s)B_g]}{N_p[B_o + (R_p - R_s)B_g]} \quad (10)$$

$$\therefore Depletiondriven, DDI = \frac{N[(B_o - B_{oi}) + (R_{si} - R_s)B_g]}{N_p[B_o + (R_p - R_s)B_g]} \quad (11)$$

$$\therefore Depletiondriven, DDI = \frac{N[(B_o - B_{oi}) + (R_{si} - R_s)B_g]}{N_p[B_o + (R_p - R_s)B_g]} \quad (12)$$

$$\therefore Depletiondriven, DDI = \frac{N[(B_o - B_{oi}) + (R_{si} - R_s)B_g]}{N_p[B_o + (R_p - R_s)B_g]} \quad (13)$$

$$DDI+SDI+EDI+WDI = 1.0 \quad (14)$$

The determination of each index shows the different contribution of each drive mechanism towards production and hence, shows the dominant drive mechanism.

Methodology

In this study, Microsoft Excel Visual Basic for Application combined with a tank model of zero dimensions was developed to predict reservoir performance. It is a powerful programming language embedded by Microsoft. The program is fixed in MS-Office applications i.e., MS-Word, MS-Excel, MS-Access. Many engineers use VBA to establish calculation subroutine suchlike menus, toolbars, worksheets, charts, etc Walkenbach [46]. This makes MS-Excel, which has VBA, a very advantageous platform for developing models and simulations. The main reason is that most engineers are acquainted with MS-Excel applications. Microsoft Excel is a user-friendly workbook that contains several worksheets. It is easily used for data analysis. It also provides some ability for engineering calculations and analysis [47]. Microsoft Excel is easily available to every Microsoft user and ridiculously cheap when compared to other domain based commercial software. Behind Excel spreadsheet is another environment used by its users to execute complex calculations on the worksheet. This environment is called Visual Basic Application, thus the name Excel VBA. Excel has inbuilt functions that users can leverage on while manipulating through their data but in a circumstance where the user wants a new functionality that did not come with Excel as inbuilt function, the user can navigate to the VBA environment and write some lines of code as shown in figure 3, that works as functions in Excel. Figure 3 shows the coding page of the software. Reservoir analysis is a key task in oil and gas exploration. During such analysis, hydrocarbon reservoirs are studied using some mathematical models. These models have large runtime and require a computer to perform such tasks faster, and accurately. With this technology, Engineers can design Excel to execute the needed task.

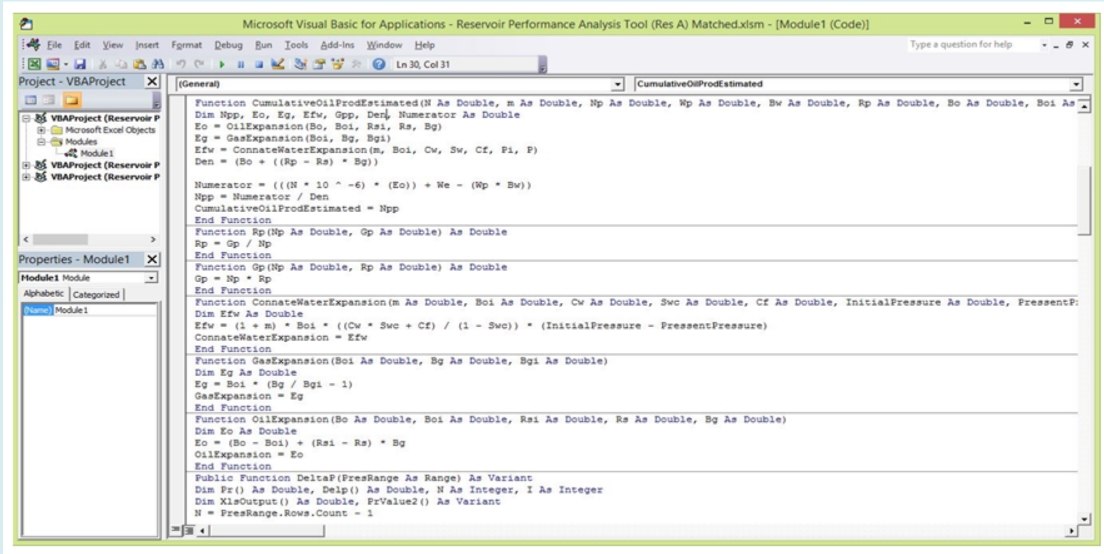

Figure 3: Microsoft Excel Visual Basic for Application Coding Software Page.

Figure 4 shows the interface of the Application. With this software, material balance optimization can be done on the cumulative produced fluid to obtain the history production data to match the model data. The common concept in material balance analysis is called history matching. When this is achieved, other activities like pressure simulation and forecasting can be executed to have more understanding and knowledge about the reservoir.

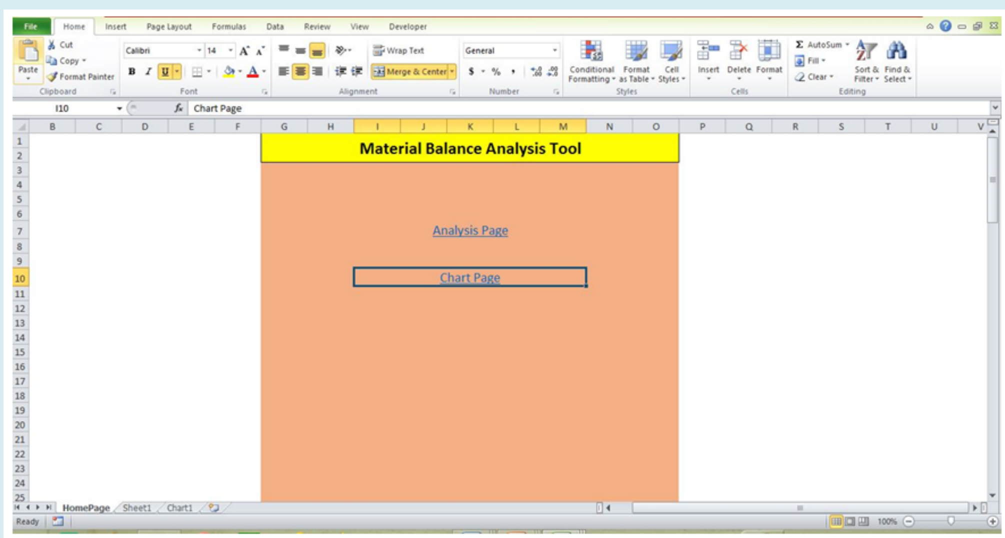

Figure 4: Microsoft Excel Visual Basic for Application Homepage.

Functionality of the Excel Based Software

There are five major functions used during the setting up of the PVT and Production data used for the material balance optimization. DeltaP, TD, DimensionlessWaterInflux, WaterInfluxA and CumulativeOilProdEstimate. There are other functions in this Microsoft Excel software but these listed are the major ones. The appendix page has some of the functions. The reservoir, production and PVT data are displayed in the software as shown in Figure 5.

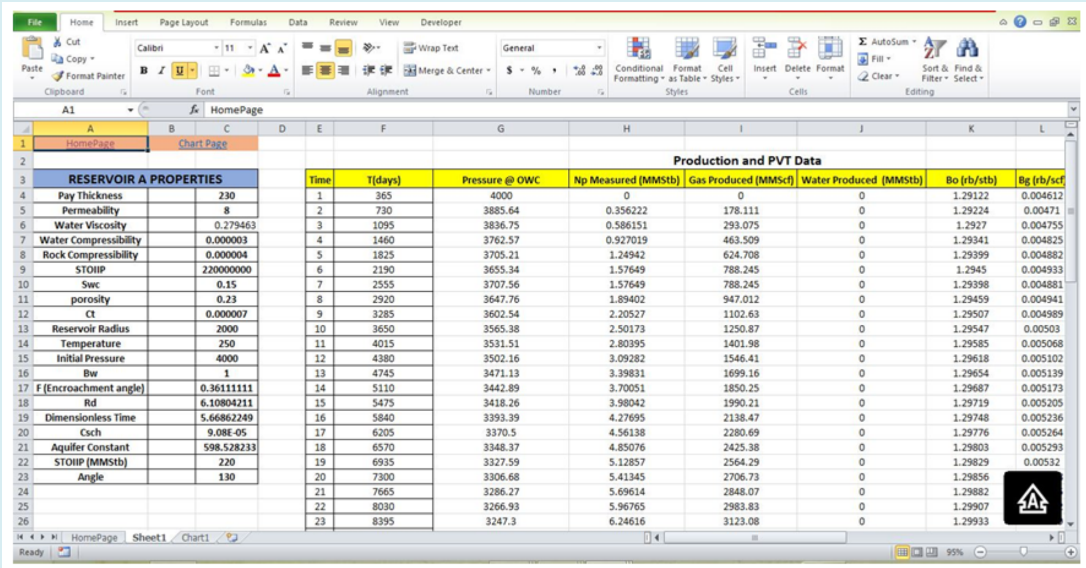

Figure 5: Software displaying Reservoir, Production and PVT data.

To perform the optimization after setting up the algorithm for sum of the square difference between Np Measured (oil reservoir) and Np Model; followed using the Microsoft Excel Solver to conduct the final optimization. This is what helps the software to history match these two parameters and try to get them match closely by changing some of the reservoir properties.

Reservoir engineering judgment comes in when selecting the right parameters to regress on. The reservoir engineer should be able to identify if the values he/she estimated is much or low that might not be the true value, but now that we have cumulative production from the reservoir, trying to align the models is like changing the parameters to suit what is observe from the reservoir.

Data Gathering and Acquisition

Three groups of data were used in carrying out this study; the first is a modeled data from the textbook by Dake [2] on water influx estimation while the second and third are real life data of reservoirs in Niger Delta. Reservoir A is a wedged shape reservoir. Initially the reservoir existed at Pb but no initial gas cap (m=0). Reservoir B is a linear-aquifer drive reservoir with strong water drive. It is still under depletion drive condition meaning it has no gas cap size (m=0). Reservoir Properties, Production, pressure and PVT data for reservoir A, B and C over a period are presented in Tables 1-9 respectively.

Property	Value
Pay Thickness	100
Permeability	200
Water Viscosity	0.55
Water Compressibility	0.000003
Rock Compressibility	0.000004
STOIIP	312000000
Swc	0.05
Porosity	0.25
Ct	0.000007
Reservoir Radius	9200
Temperature	200
Initial Pressure	2740
Bw	1
F (Encroachment angle)	0.388888889
Rd	5.033837773
Dimensionless Time	5.668622493
Csch	9.08E-05
Aquifer Constant	6445.688667
STOIIP (MMStb)	312
Angle	140

Table 1: Reservoir A Properties [2].

Time	T(days)	Pressure @ OWC	Plateau Pressure	Np_ Measured (MMstb)
0	0	2740	2740	0
1	365	2500	2620	7.88
2	730	2290	2395	18.42
3	1095	2109	2199	29.15
4	1460	1949	2029	40.69
5	1825	1818	1883	50.14
6	2190	1702	1760	58.42
7	2555	1608	1655	65.39
8	2920	1535	1571	70.74
9	3285	1480	1507	74.54
10	3650	1440	1460	77.43

Table 2: Production and Pressure Data of Reservoir A.

Time	T(days)	Pressure @ OWC	Plateau Pressure	Np_ Measured (MMstb)
0	0	2740	2740	0
1	365	2500	2620	7.88
2	730	2290	2395	18.42
3	1095	2109	2199	29.15
4	1460	1949	2029	40.69
5	1825	1818	1883	50.14
6	2190	1702	1760	58.42
7	2555	1608	1655	65.39
8	2920	1535	1571	70.74
9	3285	1480	1507	74.54
10	3650	1440	1460	77.43

Table 3: PVT Data of Reservoir A.

Property	Value
Pay Thickness	230
Permeability	8
Water Viscosity	0.279463
Water Compressibility	0.000003
Rock Compressibility	0.000004
STOIIP	220000000
Swc	0.15
Porosity	0.23
Ct	0.000007
Reservoir Radius	2000
Temperature	250
Initial Pressure	4000
Bw	1

F (Encroachment angle)	0.361111111
Rd	6.108042106
Dimensionless Time	5.668622493
Csch	9.08E-05
Aquifer Constant	598.5282333
STOIIP (MMStb)	220
Angle	130

Table 4: Reservoir B Properties.

Time	T(days)	Pressure @ OWC	Np Measured (MMStb)	Gas Produced (MMScf)	Water Produced (MMStb)
1	365	4000	0	0	0
2	730	3885.64	0.356222	178.111	0
3	1095	3836.75	0.586151	293.075	0
4	1460	3762.57	0.927019	463.509	0
5	1825	3705.21	1.24942	624.708	0
6	2190	3655.34	1.57649	788.245	0
7	2555	3707.56	1.57649	788.245	0
8	2920	3647.76	1.89402	947.012	0
9	3285	3602.54	2.20527	1102.63	0
10	3650	3565.38	2.50173	1250.87	0
11	4015	3531.51	2.80395	1401.98	0
12	4380	3502.16	3.09282	1546.41	0
13	4745	3471.13	3.39831	1699.16	0
14	5110	3442.89	3.70051	1850.25	0
15	5475	3418.26	3.98042	1990.21	0
16	5840	3393.39	4.27695	2138.47	0
17	6205	3370.5	4.56138	2280.69	0
18	6570	3348.37	4.85076	2425.38	0
19	6935	3327.59	5.12857	2564.29	0
20	7300	3306.68	5.41345	2706.73	0
21	7665	3286.27	5.69614	2848.07	0
22	8030	3266.93	5.96765	2983.83	0
23	8395	3247.3	6.24616	3123.08	0
24	8760	3228.61	6.51371	3256.86	0
25	9125	3212.06	6.77893	3389.46	0
26	9490	3195.21	7.0423	3521.15	0
27	9855	3179.94	7.27854	3639.27	0
28	10220	3163	7.53836	3769.18	0
29	10585	3146.66	7.788	3894	0

30	10950	3129.82	8.04415	4022.07	0
31	11315	3109.13	8.28415	4142.07	0.028936
32	11680	3088.14	8.53215	4266.07	0.059586
33	12045	3067.3	8.78015	4390.07	0.091
34	12410	3047.2	9.02015	4510.07	0.122132
35	12775	3026.48	9.26815	4634.07	0.15504
36	13140	3006.46	9.50815	4754.07	0.18761
37	13505	2985.81	9.75615	4878.07	0.221995
38	13870	2965.19	10.0041	5002.07	0.257123
39	14235	2946.59	10.2281	5114.07	0.289503
40	14600	2926.01	10.4761	5238.07	0.326034
41	14965	2906.12	10.7161	5358.07	0.362088
42	15330	2885.58	10.9642	5482.07	0.400052
43	15695	2865.73	11.2042	5602.07	0.437484
44	16060	2845.24	11.4521	5726.07	0.476864
45	16425	2824.77	11.7001	5850.07	0.516957
46	16790	2804.98	11.9401	5970.07	0.556438
47	17155	2784.55	12.1882	6094.07	0.597924
48	17520	2764.81	12.4281	6214.07	0.638744
49	17885	2744.42	12.6761	6338.07	0.681605
50	18250	2724.07	12.9241	6462.07	0.725159
51	18615	2705.7	13.1481	6574.07	0.765106
52	18980	2685.39	13.3961	6698.07	0.809969
53	19345	2665.76	13.6361	6818.07	0.854039
54	19710	2645.5	13.8841	6942.07	0.900239
55	20075	2625.93	14.1242	7062.07	0.945597
56	20440	2605.73	14.3721	7186.07	0.993121
57	20805	2585.56	14.6201	7310.07	1.04131
58	21170	2566.08	14.8601	7430.07	1.08858
59	21535	2545.98	15.1082	7554.07	1.13808
60	21900	2526.57	15.3481	7674.07	1.1866
61	22265	2506.54	15.5961	7798.07	1.23738
62	22630	2486.55	15.8441	7922.07	1.28881
63	22995	2467.89	16.0761	8038.07	1.33751
64	23360	2447.98	16.3241	8162.07	1.39019
65	23725	2428.75	16.5641	8282.07	1.44177
66	24090	2408.92	16.8121	8406.07	1.4957

Table 5: Production Data of Reservoir B.

Bo (rb/stb)	Bg (rb/scf)	Rp (scf/stb)	Rs (scf/stb)
1.29122	0.0046118	0	500
1.29224	0.0047099	500	500
1.2927	0.0047546	499.999147	500
1.29341	0.0048249	499.9994606	500
1.29399	0.0048818	499.9983993	500
1.2945	0.0049332	500	500
1.29398	0.0048805	500	500
1.29459	0.0049414	500.001056	500
1.29507	0.0049894	499.9977327	500
1.29547	0.0050302	500.0019986	500
1.29585	0.0050684	500.0017832	500
1.29618	0.0051024	500	500
1.29654	0.0051388	500.0014713	500
1.29687	0.0051727	499.9986488	500
1.29719	0.0052053	500	500
1.29748	0.0052357	499.9988309	500
1.29776	0.0052645	500	500
1.29803	0.0052928	500	500
1.29829	0.0053199	500.0009749	500
1.29856	0.0053476	500.0009236	500
1.29882	0.0053752	500	500
1.29907	0.0054017	500.0008379	500
1.29933	0.005429	500	500
1.29958	0.0054554	500.0007676	500
1.2998	0.0054792	499.9992624	500
1.30003	0.0055036	500	500
1.30025	0.0055261	500	500
1.30048	0.0055513	500	500
1.30071	0.005576	500	500
1.30095	0.0056017	499.9993784	500
1.30125	0.0056337	499.9993964	500
1.30156	0.0056668	499.999414	500
1.30187	0.0057002	499.9994305	500
1.30217	0.0057329	499.9994457	500
1.30248	0.0057672	499.9994605	500
1.30279	0.0058009	499.9994741	500
1.30312	0.0058363	499.9994875	500
1.30344	0.0058722	500.0019992	500
1.30372	0.0059024	500.0019554	500
1.30406	0.0059401	500.0019091	500

1.30439	0.0059768	500.0018664	500
1.30474	0.0060153	499.9972638	500
1.30508	0.0060531	499.9973224	500
1.30543	0.0060927	500.0017464	500
1.30579	0.0061329	500.0017094	500
1.30614	0.0061725	500.001675	500
1.30651	0.006214	499.9975386	500
1.30688	0.0062548	500.0016093	500
1.30725	0.0062977	500.0015778	500
1.30764	0.0063413	500.0015475	500
1.30799	0.0063812	500.0015211	500
1.30838	0.0064262	500.001493	500
1.30877	0.0064704	500.0014667	500
1.30917	0.0065169	500.0014405	500
1.30957	0.0065626	499.997876	500
1.30999	0.0066106	500.0013916	500
1.31041	0.0066594	500.001368	500
1.31082	0.0067074	500.0013459	500
1.31125	0.0067579	499.9980143	500
1.31168	0.0068075	500.0013031	500
1.31212	0.0068597	500.0012824	500
1.31258	0.0069127	500.0012623	500
1.31303	0.0069665	500.0012441	500
1.31349	0.0070206	500.0012252	500
1.31394	0.0070741	500.0012074	500
1.31442	0.0071304	500.0011896	500

Table 6: PVT Data of Reservoir B.

Property	**Value**
Pay Thickness	230
Permeability	8
Water Viscosity	0.302872
Water Compressibility	0.000003
Rock Compressibility	0.000004
STOIIP	130000000
Swc	0
Porosity	0.25
Ct	0.000007
Reservoir Radius	2000
Temperature	210
Initial Pressure	3266.32

Bw	1
F (Encroachment angle)	0.361111111
Rd	3
Dimensionless Time	5.668622493
Csch	9.08E-05
Aquifer Constant	650.5741667
STOIIP (MMStb)	130
Angle	130
Gas Cap Size	0.2

Table 7: Reservoir C Properties.

Time	T(days)	Pressure @ OWC	Np Measured (MMStb)	Gas Produced (MMScf)	Water Produced (MMStb)
1	365	3266.32	0	0	0
2	730	3216.22	3.44123	2214.55	0.00852448
3	1095	3186.2	6.73255	4303.1	0.0442557
4	1460	3158.78	9.89839	6290.55	0.109722
5	1825	3132.77	12.942	8182.31	0.203372
6	2190	3107.86	15.8707	9985.28	0.323232
7	2555	3100.67	18.6263	11666.7	0.463631
8	2920	3072.79	21.2086	13230.6	0.619443
9	3285	3010.51	23.6457	14696.7	0.787383
10	3650	2987.86	25.9579	16079.4	0.964876
11	4015	2950.09	28.1436	17379.6	1.14834

Table 8: Production Data of Reservoir C.

Bo (rb/stb)	Bg (rb/scf)	Rp (scf/stb)	Rs (scf/stb)
1.31981	0.0053781	0	650
1.31396	0.0054502	643.5344339	637.663
1.31082	0.0054904	639.1486138	631.027
1.30772	0.005531	635.5124419	624.47
1.30476	0.0055708	632.2291763	618.186
1.3019	0.0056101	629.1644351	612.129
1.29967	0.0056415	626.3562812	607.397
1.29771	0.0056694	623.8318418	603.238
1.29595	0.005695	621.537954	599.502
1.2944	0.0057179	619.4414802	596.191
1.29304	0.0057382	617.5329382	593.297

Table 9: PVT Data of Reservoir C.

Results and Conclusion

The Microsoft excel software was developed first for each of the three different reservoirs. For unmatched Reservoir A, when the Np measured is 7.88 MMstb, the Np model is 7.93 MMstb. After history matching, the Np model gives a value of 7.91 MMstb with a square difference of 0.000767118 as clearly shown in Table 10 and Table 11 respectively.

Np Measured (MMstb)	Np Model (MMstb)
0	0
7.88	7.92996777
18.42	18.7664914
29.15	30.4817589
40.69	43.8164223
50.14	55.7345093
58.42	67.0134398
65.39	77.4142619
70.74	86.4666023
74.54	92.763234
77.43	101.264173

Table 10: Np Model and Np Real (Unmatched Reservoir A).

Np Measured (MMstb)	Np Model (MMstb)	Square Difference
0	0	0
7.88	7.90769689	0.000767118
18.42	18.45123718	0.000975761
29.15	29.23059583	0.006495687
40.69	40.85721089	0.027959481
50.14	50.36716779	0.051605204
58.42	58.679471	0.0673252
65.39	65.6818746	0.08519078
70.74	71.07091353	0.109503766
74.54	73.30750672	1.519039686
77.43	77.81607688	0.149055356

Table 11: Np Model and Np Real of Matched Reservoir A with their Square Differences.

The analysis of Reservoir A was done using the developed software depicted in Figure 6 which gives the correct values of DeltaP, Np model and Np measured with the respective time.

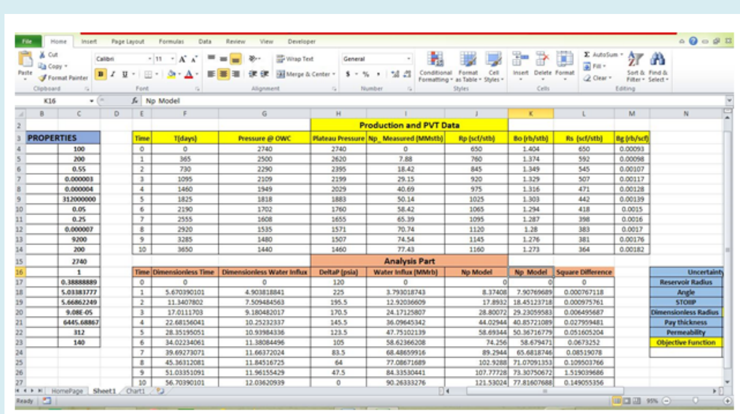

Figure 6: The Analysis page of matched Reservoir A.

The uncertainty analysis of matched Reservoir A with STOIIP of 312MMstb gives a dimensionless radius of 5.03 alongside the objection function, pay thickness, permeability, angle, upper bound and lower bound values as shown in Figure 7.

Uncertainty Analysis			Ubound	Lbound
Reservoir Radius	9200		8500	10000
Angle	140		120	180
STOIIP	312000000		280000000	3.5E+08
Dimensionless Radius	5.033837773		2	15
Pay thickness	100		80	120
Permeability	200		180	250
Objective Function	2.01791804			

Figure 7: The Uncertainty Analysis of Matched Reservoir A.

The history matching of the Np model and Np measured were carried out with their respective pressures. The plot of the matched reservoir A Np model value blended so perfectly with the Np measured as clearly depicted in Figure 8 and Figure 9.

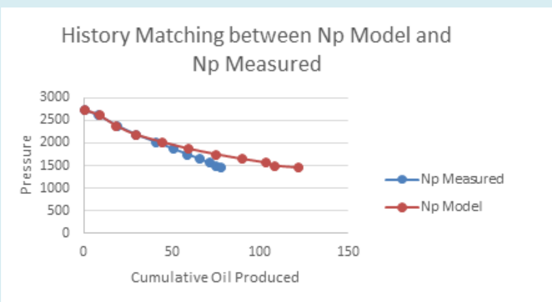

Figure 8: Plot of Np Measured Versus Np Real for Unmatched Reservoir A.

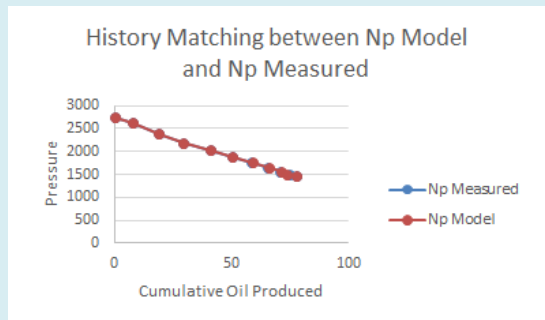

Figure 9: Plot of Np Measured Versus Np Real for Matched Reservoir A.

To test the accuracy of the developed software results, it was validated with MBAL. The blue in Figure 10 is with aquifer influx and the red line is without aquifer influx. It shows a high match points status.

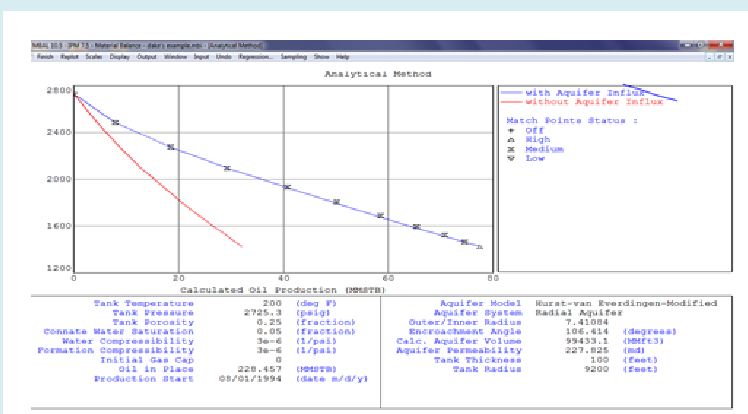

Figure 10: MBAL validation of Reservoir A.

Same process was repeated for reservoir B and C. The Np measured value of 9.78MMstb gives 10.04MMstb Np model with a square difference of 0.08 as shown in Table 12. Figure 11 shows the analysis page of Reservoir B indicating the reservoir properties, Production and PVT data.

Np Measured (MMStb)	Np Model	Square Difference
0	0	0
0.356222	0.4765031	0.014467535
0.586151	1.0530375	0.217982955
0.927019	1.6349144	0.501115831
1.24942	2.237253	0.97581412
1.57649	2.7808229	1.450417746
1.57649	2.8588125	1.644350891
1.89402	3.0873704	1.42408523
2.20527	3.5163371	1.718896884
2.50173	3.905998	1.971968721
2.80395	4.270592	2.151038763
3.09282	4.6047966	2.286073077
3.39831	4.9309404	2.348955917
3.70051	5.2441195	2.38273017
3.98042	5.534756	2.415960258
4.27695	5.8054107	2.336192163
4.56138	6.0639103	2.257597233
4.85076	6.3088486	2.126022497
5.12857	6.5419821	1.99773373
5.41345	6.7694534	1.838745229
5.69614	6.9910135	1.676697441
5.96765	7.2044221	1.529605184
6.24616	7.4150713	1.366353556
6.51371	7.6203424	1.224635173
6.77893	7.811036	1.065242869
7.0423	7.9956227	0.908824239
7.27854	8.1723812	0.798952042
7.53836	8.3484569	0.656256927
7.788	8.5257766	0.544314258
8.04415	8.7040871	0.435516994
8.28415	8.8809805	0.356206678
8.53215	9.0713449	0.290731161
8.78015	9.2652781	0.235349315
9.02015	9.4578839	0.191610943
9.26815	9.6513963	0.146877705
9.50815	9.8454615	0.113779074
9.75615	10.041408	0.081372128
10.0041	10.236701	0.054103401
10.2281	10.422759	0.037892257
10.4761	10.614188	0.019068193
10.7161	10.807077	0.008276873
10.9642	11.002109	0.001437091
11.2042	11.195719	7.19E-05

11.4521	11.389081	0.003971397
11.7001	11.585286	0.013182348
11.9401	11.778803	0.026016722
12.1882	11.973833	0.045953194
12.4281	12.168539	0.067371741
12.6761	12.361596	0.098912781
12.9241	12.558693	0.133522594
13.1481	12.747099	0.160801655
13.3961	12.936901	0.210863618
13.6361	13.129857	0.256281579
13.8841	13.322843	0.315009085
14.1242	13.516612	0.369163631
14.3721	13.711197	0.436793254
14.6201	13.906969	0.508556114
14.8601	14.100217	0.577422278
15.1082	14.294651	0.66186171
15.3481	14.488875	0.738267487
15.5961	14.682735	0.834235793
15.8441	14.880479	0.928564882
16.0761	15.075283	1.001633857
16.3241	15.26765	1.116085701
16.5641	15.460211	1.218571443
16.8121	15.655358	1.338052854

Table 12: Table of Np Model and Np Real of Matched Reservoir B with their Square Differences.

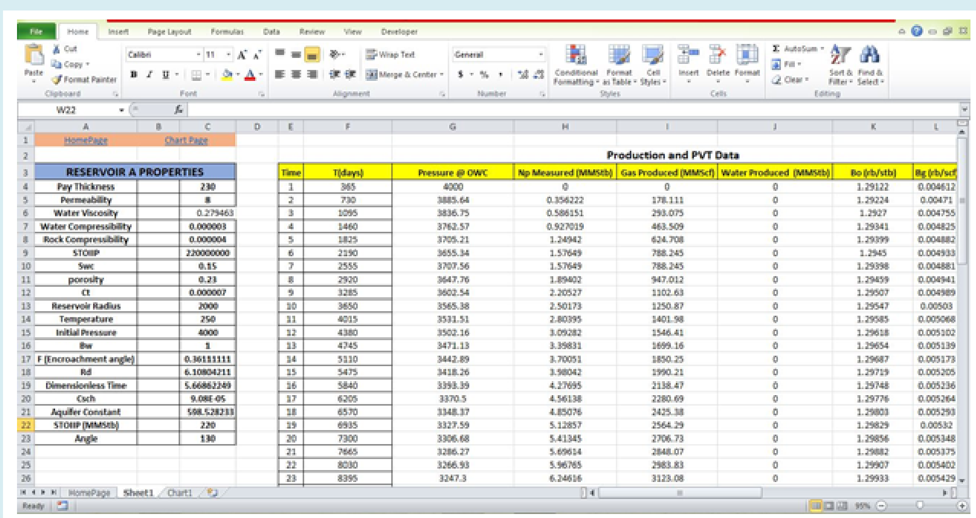

Figure 11: The Analysis page of matched Reservoir B.

The uncertainty analysis yields a dimensionless radius of 6.10 with a STOIIP value of 220MMstb, reservoir radius of 2000 ft, pay thickness and the upper bound and lower bound values as shown in Figure 12.

Uncertainty Analysis			Ubound	Lbound
Reservoir Radius	2000		2000	4000
Angle	130		130	180
STOIIP	220000000		205000000	220000000
Dimensionless Radius	6.108042106		3	12
Pay thickness	230		230	260
Permeability	8		8	15
Objective Function	54.86442009			

Figure 12: The Uncertainty Analysis page of Matched Reservoir B.

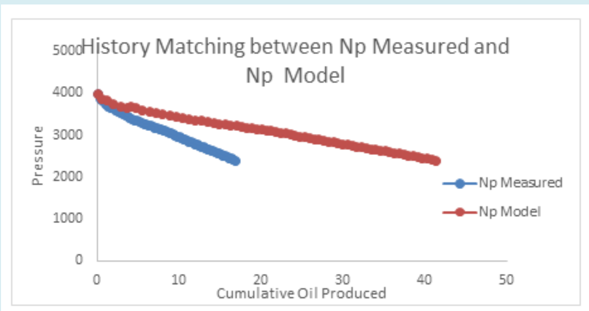

Figure 13: Plot of Np Measured Versus Np Real for Unmatched Reservoir B.

The history matching of the Np model and Np measured improved in the matched reservoir B plot compared to the unmatched reservoir B. The plots of pressure against the measured and model cumulative oil produced are shown in Figure 13 (Unmatched) and Figure 14 (Matched) respectively.

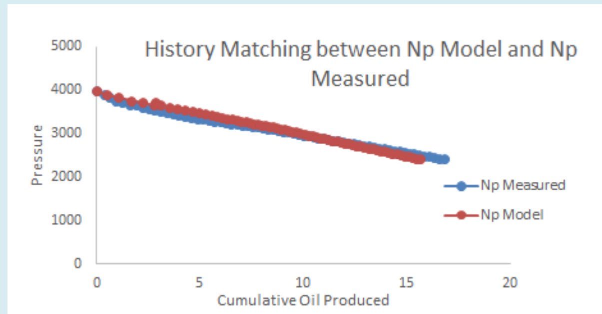

Figure 14: Plot of Np Measured Versus Np Real for Matched Reservoir B.

Figure 15 shows the software validation with MBAL. The Tank temperature is 250 deg F and tank pressure of 4000 psi. The calculated aquifer volume is 38296.9 MMft3 with aquifer permeability of 9.36911 md.

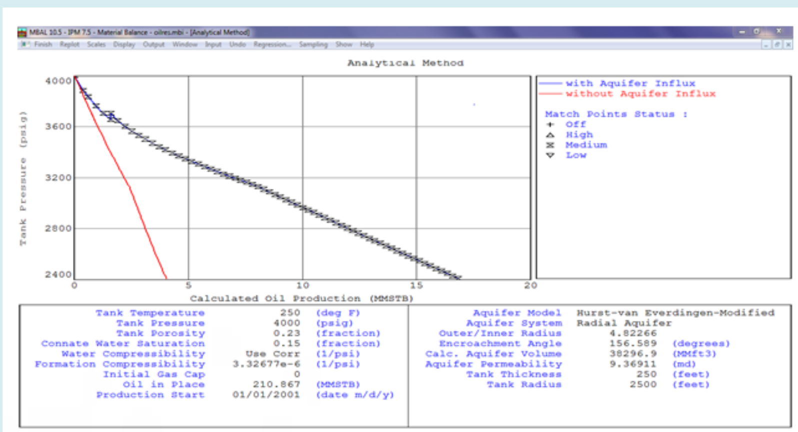

Figure 15: MBAL validation of Reservoir B.

Np Model	Np Measured (MMStb)	Square Difference
0	0	0
5.971361026	3.44123	6.401563009
9.221039061	6.73255	6.192577805
12.36085017	9.89839	6.063710103
15.3245561	12.942	5.676573566
18.13870163	15.8707	5.143831381
20.32121837	18.6263	2.872748293

22.2272811	21.2086	1.037711176
23.97652918	23.6457	0.109447944
25.51907409	25.9579	0.192568183
26.84394561	28.1436	1.689101526

Table 13: Table of Np Model and Np Real of Matched Reservoir C with their Square Differences.

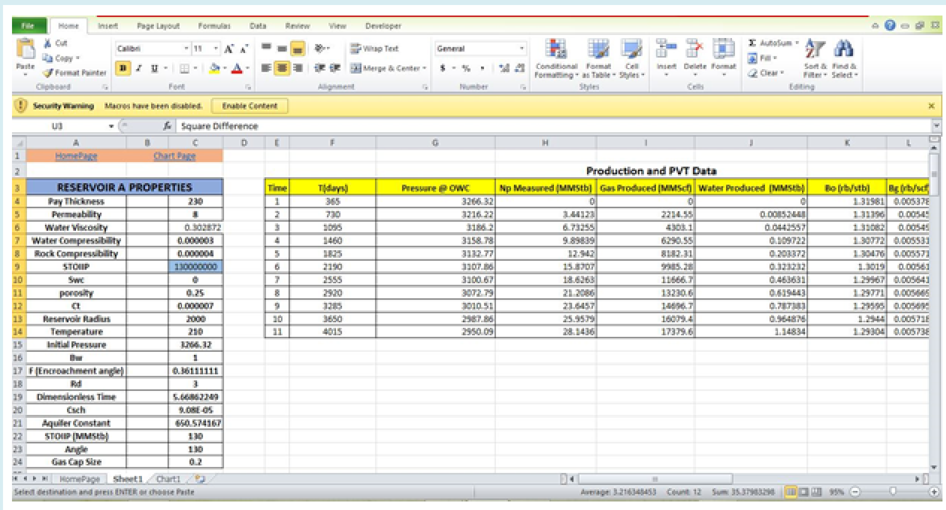

Figure 16: The Analysis page of matched Reservoir C.

Uncertainty Analysis			Ubound	Lbound
Reservoir Radius	2000		2000	4000
Angle	130		130	180
STOIIP	80000000		205000000	220000000
Dimensionless Radius	3		3	12
Pay thickness	230		230	260
Permeability	8		8	15
Objective Function	35.37983298			

Figure 17: The Uncertainty Analysis page of Matched Reservoir C.

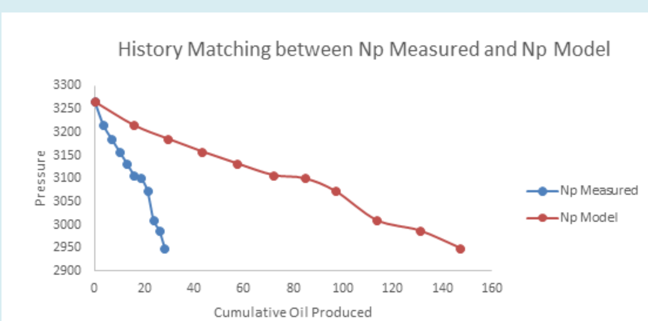

Figure 18: Plot of Np Measured Versus Np Real for Unmatched Reservoir C.

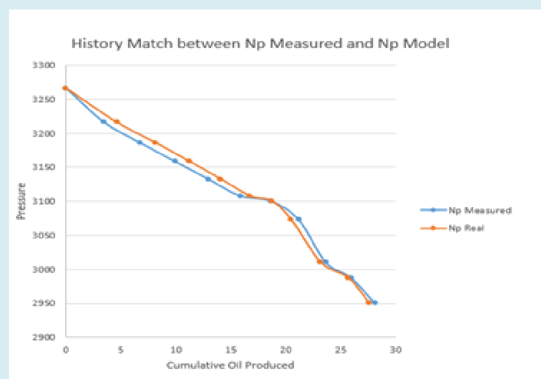

Figure 19: Plot of Np Measured Versus Np Real for Matched Reservoir C.

Reservoir A has no gas cap initially (m=0) and the compressibility term is negligible meaning that Eg and Efw term of the MBE will cancel out. Aquifer to reservoir radius value has a great impact in history matching for material balance. From LP Dake example, the first Np model estimation was done with aquifer to reservoir radius value of 10. The difference in the Np Model was extremely large but when we reduced it to 5, the two values matched each other. With the Excel VBA software, this was accomplished with ease. Reservoir B water-drive energy is strong like a typical Niger Delta reservoir, and still under depletion drive condition meaning no initial gas cap (m=0). Thus, material balance history matching of these two reservoirs will no longer be a difficult task as such. If the differences are too large, it will call for another water influx estimation or perhaps tedious iterative guessing on the aquifer parameters because uncertainties in the given data are as result of unknown aquifer parameters.

The optimization of reservoir performance by means of the 235 lines of code of the Microsoft Excel VBA mimics that of MBAL. The software gave results the same as MBAL, thus its usage for history matching is encouraged. For reservoir A, an example 9.2 in L.P. Dake, the difference in Np real and Np model were not significantly large. The Np model of the software follows the trend of the real when it was history matched. With little or no square differences. For reservoir B and C in this study, difference in Np real and Np model were not significantly large for real NIGER DELTA reservoirs. The Np model of the software follows the trend of the real when it was history matched. With little or no square differences. With the results obtained with this Excel VBA software, we can confidently say that the performance of any reservoir in any region can be enhanced using the obtained reservoir properties, production, and PVT data.

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