Comparative Study of Oil Production Forecast by Decline Curve Analysis and Material Balance

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Abstract—**Comparative analysis of forecast of rate of production of oil from a reservoir using decline curve analysis and material balance was presented. The data for reservoir A Located Southeast, Nigeria was obtained for the study. The analysis on the well using decline curve analysis showed that the rate of production from the well over the years followed an exponential method of decline. The rate of production of the well was predicted to be 158 stb/day in 2020. The second analysis on the well was performed using material balance with MBAL. The rate of production of the well was predicted to be 411.984 stb/day in 2020. It was also read from MBAL that the well will have a constant flow rate from the 20th year to the 31st year of the producing life of the well which is 2020. It is seen that the values of rates of production gotten from the prediction analyses of the well using the two methods of analysis differ. The rate in 2020 was predicted to be 158 stb/day using decline curve analysis and 411.984 stb/day using material balance.**

Index Term—**Decline Curve Analysis; Material Balance; Oil Production; Prediction.**

I. Introduction

Inefficient oil rate prediction poses challenge to the oil industry, some of which are:

- Wrong forecast of production: Operators miscalculate due to inefficient prediction of the rate of oil production from the wells they operate.
- Bad economic analysis: Economic viability of any oil and gas project is determined only with correct data of the project. When the production data of a well is wrongly calculated, the revenue and investment of the well will also be wrongly calculated.

For this, production has to be properly forecasted. There are several methods of doing this which includes production decline curve analysis. Decline curve analysis is important in determining the value of oil and gas wells in oil and gas economics. Decline curves are the most common means of forecasting oil and gas production. Decline curves have many advantages: they use data which is easy to obtain, they are easy to plot, they yield results on a time basis, and they are easy to analyse. Decline curves are also one of the oldest methods of predicting oil reserves [1]. Material balance method is also used in predicting oil production. There are several other methods used in predicting production, but in this work, concentration would be made on prediction using decline curve and material balance analyses.

II. Production Prediction

The techniques for relating production to time is known as decline curve analysis. There are three types of decline curves, although only two of the three techniques are commonly used. Exponential and hyperbolic production declines occur in many reservoirs [2]. While the third type, harmonic decline, is now believed to be uncommon, the method is still used as a conservative projection technique.

The determination of the most probable future life of a well and the estimate of its future production can sometimes be done by volumetric calculations, but sufficient data are not always available to eliminate all guess work.

In that case, the possibility of extrapolating the trend of some variable characteristics of such a producing well may be considerable help. The simplest and most readily available variable characteristic of a producing well is its production rate, and the logical way to determine the future life of a well by extrapolation is to plot this variable production rate either against time or cumulative production, extending the curves obtained to the economic limit. The point of intersection of the extrapolated curve with the economic limit then indicates the possible future life of the future oil recovery. With the future rate known, it is possible to determine the future total production or reserves of the well. This represents the beginning of the art that is since become more of a science known as decline curve analysis.

The purpose of decline curve analysis is to determine future production and ultimate recovery of wells with some production history [3]. Since it depends on a curve-fit of past performance, the accuracy is expected to be greater for a well with several months or years of uninterrupted production history than for a well with only a limited amount of history. The definition of decline curve can be represented both mathematically and graphically with both, the future life of a well can be determined [4].

In order to analyse what influence certain reservoir characteristics may have on the type of decline curves, it was first assumed that we are dealing with the idealized case of a reservoir, where water drive is absent and where the pressure is proportional to the amount of remaining oil [5]. It was further assumed that the productivity index of the wells is constant throughout their life, so that, the production rates are always proportional to the reservoir pressure. In such a hypothetical case, the relationship between cumulative oil produced and pressure would have to be linear and also the relationship between production rate and cumulative production. In most actual reservoirs, however,

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the above mentioned idealized conditions do not occur. Pressures usually are not proportioned to the remaining oil, but seem to decline at a gradually slower rate as the amount of remaining oil diminishes [6]. At the same time the productivity index is generally not constant but show a tendency to decline as the reservoir is being depleted and the gas oil ratios increase. The combined result of these two tendencies is a rate-cumulative relationship, which instead of being a straight line on co-ordinate paper; show up as a gentle curve convex towards the origin.

Existing decline curve analysis are based on Arps equations [7], and there has been a great number of papers on this topic. Fetkovich et al., developed concepts for decline curve forecasting and provided a theoretical basis for the Arps equations [8]. Cheng et al., used stochastic approach to evaluate the uncertainty in reserve estimation based decline curve analysis [9]. A stochastic reserve estimation using decline curve analysis using Monte Carlo simulation to obtain reserve distribution was discussed in [10]

Arps decline curve analysis is an empirical method and requires no knowledge of reservoir parameters. The application of the method involves estimating a parametric model to the historical production data using least squares method. There are many different curve fitting methods available, however there is no one clear method to handle unusual observations. The available methods lead to unsatisfactory results due to the influence of the unusual observation. This paper proposes a modification of Arps decline curve analysis using results from robust regression analysis where the unusual observations receives less weight compared with the other observations. The exponential decline curve is fitted using robust cube polynomial regression to obtain a better representation of the fluctuation of the historical production. The similar approach was developed for harmonic decline curve analysis. Inspired from growth curve modelling, a logistic decline curve is proposed to estimate the global trend and applied to the historical data. The robust trend curve fitting results Arps equations and logistic model are used to extrapolated the future production decline and compared with the reservoir simulation results to evaluate the proposed approach [11].

According to [12], estimating oil reserves is one of the most important phases of the work of a petroleum engineer since the solutions to the problems he deals with usually depend on a comparison of the estimated cost in terms of dollars, with the anticipated result in terms of barrels of oil. His recommendations to management regarding the best course of action are therefore normally based on the most favourable balance between these two. Specific engineering problems which require such a knowledge of recoverable oil reserves and a projection of future rates are: [a.] the exploitation and development of an oil reservoir; [b.] the construction of gasoline plants, pipelines and refineries; [c.] the division of ownership in unitized projects; [d.] the price to be paid in case of a sale or purchase of an oil property, and the magnitude of the loan which it will support; [e.] the proper depreciation rate for the investment in oil properties; and [f.] evaluation of the results of an exploration program.

Reference [12] reviewed the methods in use for estimating primary oil reserves and conducting production prediction and discusses the principles on which these methods are based. Particular emphasis is placed on how these methods change with the type of information available during the life cycle of an oil property.

According to [13], the material balance is a very important part of the reservoir engineer's toolbox that is being relegated to the background in today's reservoir evaluation workflow. Their paper examined some issues that normally preclude its regular use especially as a pre-step before moving into full reservoir simulation and the use of a new method of analysing the material balance equation called the dynamic material balance method for solving some of these issues. The dynamic material balance method allows the simultaneous determination of the initial oil-in-place (N) or initial gas-in-place (G), ratio of initial gas to oil (m), reservoir permeability (K) or skin factor (S) and average pressure history of a reservoir from the combination of solution to the material balance equation and pressure transient analysis theory. Cumulative production history and PVT data of the reservoir are used with limited or no pressure data. By introducing a time variable into the classical material balance equation (MBE) and combining the solutions of the resulting equations with the theory of pressure transient analysis, the cumulative production history of the reservoir and readily available PVT data of the reservoir fluids, they postulated that we can estimate not only the original reserves in place, but also determine the average reservoir pressure decline history as indicated by the net fluid withdrawal from the reservoir. The reservoir permeability and skin factor can then be estimated from the already determined average pressure decline history. Their method is expected to improve the use of material balance by expanding the list of problems that can be tackled using material balance especially to reservoirs in marginal fields and reservoirs in which limited pressure data is available.

III. METHODOLOGY

A. Decline Curve Analysis

A decline curve of a well is simply a plot of the well's production rate on the y-axis versus time on the x-axis. The plot is usually done on a semi-log paper; i.e. the y-axis is logarithmic and the x-axis is linear. When the data plots as a straight line, it is modelled with a constant percentage decline "exponential decline". When the data plots concave upward, it is modelled with a "hyperbolic decline". A special case of the hyperbolic decline is known as "harmonic decline".

The most common decline curve relationship is the constant percentage decline (exponential). With more and more low productivity wells coming on stream, there is currently a swing toward decline rates proportional to production rates (hyperbolic and harmonic). Although some wells exhibit these trends, hyperbolic or harmonic decline extrapolations should only be used for these specific cases. Over-exuberance in the use of hyperbolic or harmonic relationships can result in excessive reserves estimates. Fig. 1 is an example of a production graph with exponential and harmonic extrapolations.

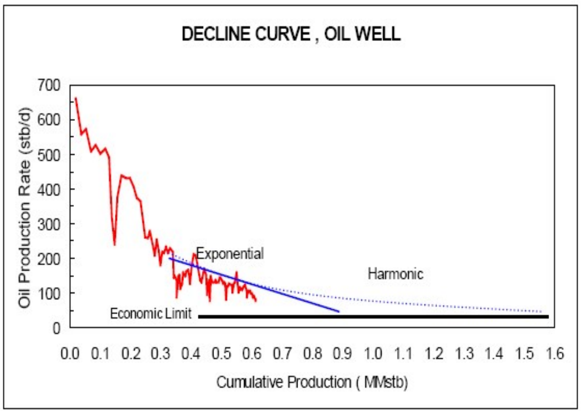

Fig. 1. Decline curve of an oil well

Decline curves are the most common means of forecasting production. They have many advantages: Data is easy to obtain, they are easy to plot, they yield results on a time basis, they are easy to analyse.

If the conditions affecting the rate of production of the well are not changed by outside influences, the curve will be fairly regular, and, if projected, will furnish useful knowledge as to the future production of the well.

According to [12], a production history may vary from a straight line to a concave upward curve. In any case the object of decline curve analysis is to model the production history with the equation of a line. The following table summarizes the five approaches for using the equation of a line to forecast production.

TABLE I: APPROACHES FOR PRODUCTION FORECAST

Log Rate-Time Shape	Name	Model	Decline
Straight	Exponential		Stepwise
Straight	Exponential	Arps	Continuous straight
Curved but converging	Hyperbolic	Arps	Continuous curve
Curved but limit	Harmonic	Arps	Continuous curve which nearly converges
Curved but not converging	Amended		Dual – Infinite acting amended to a limiting curve

1) Exponential Decline

As mentioned above, in the exponential decline, the well's production data plots as a straight line on a semi-log paper. The equation of the straight line on the semi-log paper is given in Table II.

Where:

q = well's production rate at time t, STB/day

q_i = well's production rate at time 0, STB/day

D = nominal exponential decline rate, 1/day

t = time, day

The following table summarizes the equations used in exponential decline.

TABLE II: EXPONENTIAL DECLINE EQUATIONS, B = 0 (PETROBJECTS, 2004)

Description	Equation	
Rate	$q = q_i e^{-Dt}$	(1)
Cumulative Oil Production	$N_p = (q_i - q)/D$	(2)
Nominal Decline Rate	$D = -\ln(1 - D_e)$	(3)
	$D_e = (q_i - q)/q_i$	(4)
Effective Decline Rate	$D_e = 1 - e^{-D}$	(5)
Life	$t = \ln(q_i / q)/D$	(6)

2) Hyperbolic Decline

Alternatively, if the well's production data plotted on a semi-log paper concaves upward, then it is modelled with a hyperbolic decline. The equation of the hyperbolic decline is given in Table III.

Where:

q = well's production rate at time t, STB/day

q_i = well's production rate at time 0, STB/day

D_i = initial nominal exponential decline rate (t = 0), 1/day

b = hyperbolic exponent

t = time, day

The following table summarizes the equations used in hyperbolic decline:

TABLE III: HYPERBOLIC DECLINE EQUATIONS, B > 0, B ≠ 1 (PETROBJECTS, 2004) [14]

Description	Equation	
Rate	$q = q_i (1 + bD_i t)^{-1/b}$	(7)
Cumulative Oil Production	$N_p = [q_i^b (q_i^{1-b} - q^{1-b})]/D_i(1-b)$	(8)
Nominal Decline Rate	$D_i = [(1 - D_{ei})^{-b} - 1]/b$	(9)
Nominal Decline Rate	$D_{ei} = (q_i - q)/q_i$	(10)
Effective Decline Rate	$D_e = 1 - e^{-D}$	(11)
Life	$t = [\ln(q_i / q)^b - 1]/bD_i$	(12)

3) Harmonic Decline

A special case of the hyperbolic decline is known as harmonic decline, where b is taken to be equal to 1. The following table summarizes the equations used in harmonic decline:

TABLE IV: HARMONIC DECLINE EQUATIONS, B = 1 (PETROBJECTS, 2004) [14]

Description	Equation	
Rate	$q = q_i (1 + bD_i t)^{-1/b}$ (13)	
Cumulative Oil Production	$N_p = (q_i / D_i)\ln(q_i / q)$	(14)
Nominal Decline Rate	$D_i = [D_{ei} / (1 - D_{ei})]$	(15)
Effective Decline Rate	$D_{ei} = (q_i - q)/q_i$	(16)
Life	$t = [(q_i / q) \; - 1]/D_i$	(17)

B. Material Balance Analysis using MBAL

For the prediction of the production of a well using material balance method with MBAL, the production history and data of the well are obtained. These data are used on MBAL. Efficient reservoir development requires a good understanding of reservoir and production systems. MBAL helps the engineer better define reservoir drive mechanisms and hydrocarbon volumes. This is a prerequisite for reliable simulation studies. MBAL is commonly used for modelling the dynamic reservoir effects prior to building a numerical simulator model.

MBAL contains the classical reservoir engineering tool and has redefined the use of Material Balance in modern reservoir engineering.

For existing reservoirs, MBAL provides extensive matching facilities. Realistic production profiles can be run for reservoirs with or without history matching.

MBAL is an intuitive program with a logical structure that enables the reservoir engineer to develop reliable reservoir models quickly.

IV. Results

A. Case for Decline Curve Analysis

Data were collected for a well. The production history for the well is presented in Tables V(a) and VI(f).

TABLE V(A): PRODUCTION HISTORY OF WELL A

Year	Time, year	Oil Rate (Q), stb/day	Cumulative Production (N_p), stb
1990	1	2398	
1991	2	1500	863280
1992	3	1411	1403280
1993	4	1320	1911240
1994	5	1195	2386440
1995	6	1083	2816640
1996	7	904	3206520
1997	8	900	3531960
1998	9	837	3855960
1999	10	812	4157280
2000	11	789	4449600
2001	12	774	4733640
2002	13	700	5012280
2003	14	593	5264280
2004	15	529	5477760
2005	16	506	5668200
2006	17	487	5850360
2007	18	440	6025680
2008	19	418	6184080
2009	20	415	6334560

The production history is to be used to predict rate of flow from the well up till 2020. Using the data in Table V(a) for Well A, the semi-log plot of Q against Time in years is shown in Fig. 2(a) below:

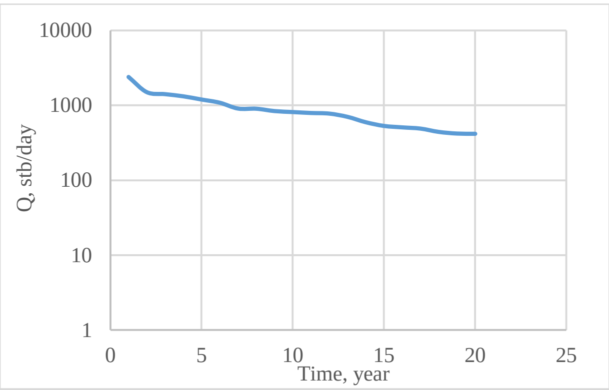

Fig. 2(a). Semi-log Plot of Q against Time (1990 – 2009)

From Fig. 2(a), it can be seen that the plot is approximately linear, therefore the exponential decline method can be used to predict the rate of production from the well at any particular time.

From Table II, the effective decline rate, D_e for the 20 years can be evaluated as:

$$D_e = (2398 – 415)/(2398) = 0.827/20 = 0.04135/\text{year}$$

Then the nominal decline rate, D is:

$$D = -\ln(1 – 0.827) = 1.754/20 = 0.0877/\text{year}$$

The rate of flow at any time can be predicted from (1) in Table II. This is used to estimate the rate of flow from the well from 2010 till 2020 as shown in Table V(b):

TABLE V(B): RATE OF FLOW AND CUMULATIVE PRODUCTION PREDICTION

Year	Time, year	Oil Rate (Q), stb/day	Cumulative Production (N_p), stb
1990	1	2398	
1991	2	1500	863280
1992	3	1411	1403280
1993	4	1320	1911240
1994	5	1195	2386440
1995	6	1083	2816640
1996	7	904	3206520
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2003	14	593	5264280
2004	15	529	5477760
2005	16	506	5668200
2006	17	487	5850360
2007	18	440	6025680
2008	19	418	6184080
2009	20	415	6334560
2010	21	380	8407511.24
2011	22	348	8540523.83
2012	23	319	8662368.1
2013	24	292	8773981.79
2014	25	268	8876223.92
2015	26	245	8969881.35
2016	27	225	9055674.89
2017	28	206	9134264.83
2018	29	188	9206256.03
2019	30	173	9272202.52
2020	31	158	9332611.86

The semi-log plot of Flow rate against time covering 1990 to 2020 is shown in Fig. 2(b):

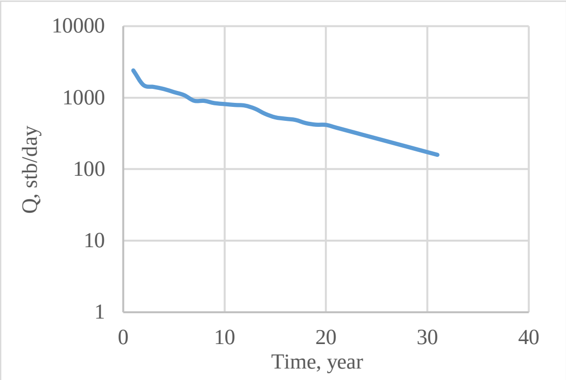

Fig. 2(b). Semi-log Plot of Q against Time (1990 – 2020)

The Cartesian plot of Flow rate against Year covering 1990 to 2020 is shown in Fig. 2(c).

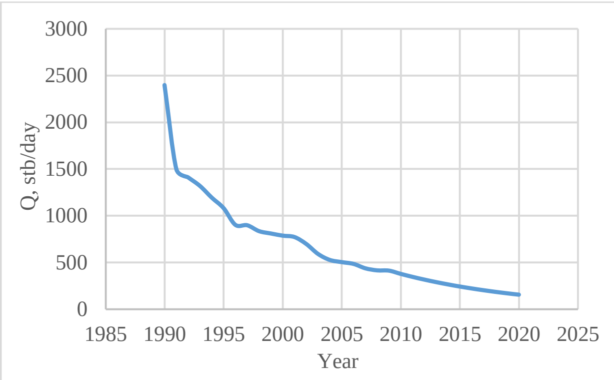

Fig. 2(c). Plot of Q against Time (1990 – 2020)

The Cartesian plots of Cumulative Production against Time covering 1990 to 2020 are shown in Fig. 2(d) and 2(e).

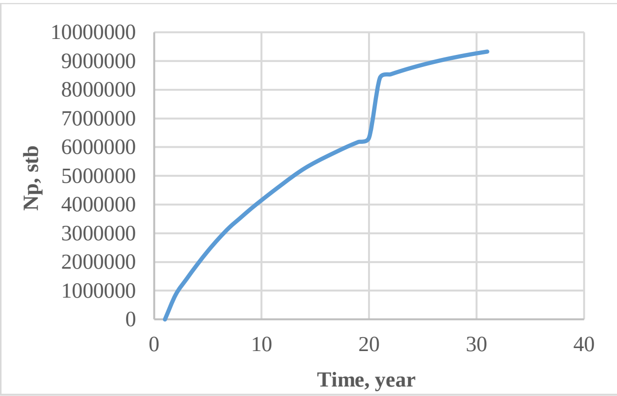

Fig 2(d). Plot of N_p against Time (1990 – 2020)

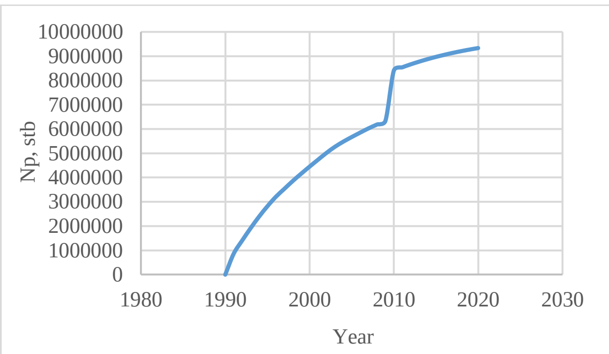

Fig 2(e). Plot of N_p against Year (1990 – 2020)

B. Production Prediction of Well A using Material Balance

The reservoir and well data for prediction of production using material balance method with MBAL is given in Tables VI(a) to VI(f).

TABLE VI(A): PVT DATA

Parameter	Value
GOR	1720 scf/stb
Oil Gravity	41.9 API
Gas Gravity	0.65
Water Salinity	10000 ppm
Mole % Sulphide	0
Mole % Carbon dioxide	0
Mole % Nitrogen	0

TABLE VI(B): TANK DATA

Parameter	Value
Tank type	Oil
Temperature	190^0F
Initial Pressure	4458psig
Porosity	0.24
Connate Water Saturation	0.09
Water Compressibility	Use Correlation
Initial Gas Cap	0
OOIP	42mmstb
Start of Production	01/01/1990

TABLE VI(C): WATER INFLUX (CATER TRACY MODEL)

Parameter	Value	Unit
Res Thickness	208.235	feet
Res Radius	14607.1	feet
Outer/Inner Rad ratio	39.9005	
Encroachment Angle	320.519	degrees
Aquifer Permeability	24.3658	md

TABLE VI(D): PORE VOLUME VS DEPTH

Pore vol	Depth
-1	10032
0	10192
1	10310

TABLE VI(E): RELATIVE PERMEABILITY

	Res Sat. (fraction)	End Point	Exponent
K_{rw}	0.09	0.8	3.6
K_{ro}	0.1	0.81	3.6
K_{rg}	0.05	0.8	3.6

TABLE VI(F): PRODUCTION HISTORY

Year	Time, year	Oil Rate (Q), stb/day	Cumulative Production (N_p), stb
1990	1	2398	
1991	2	1500	863280
1992	3	1411	1403280
1993	4	1320	1911240
1994	5	1195	2386440
1995	6	1083	2816640
1996	7	904	3206520

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2006	17	487	5850360
2007	18	440	6025680
2008	19	418	6184080
2009	20	415	6334560

The first MBAL interface is as shown in Fig. 3(a) where you can start your analysis. The second interface is gotten by clicking Options to fill the system options as shown in Fig. 3(b).

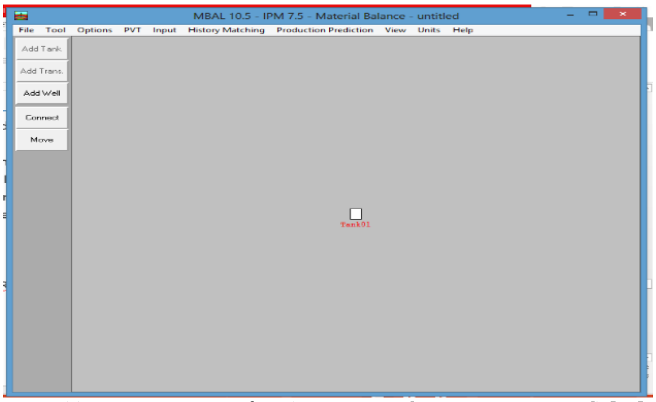

Fig. 3(a). First MBAL Interface (Source: Petroleum Experts Limited) [15]

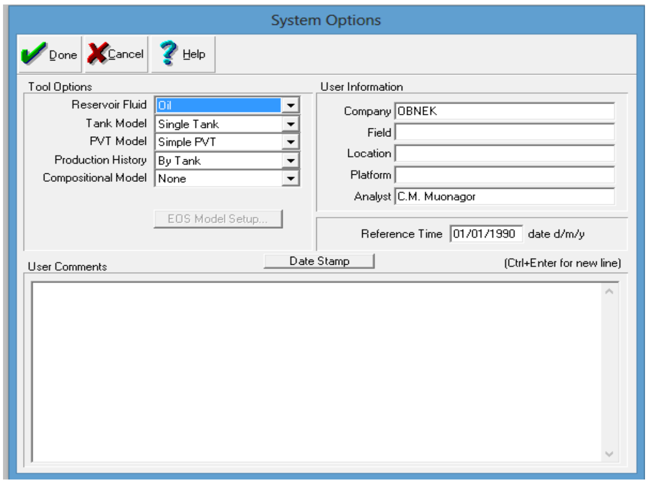

Fig. 3(b). MBAL Interface for System Options (Source: Petroleum Experts Limited) [15]

Then proceed to PVT on the material balance interface, click on PVT, click on Fluid Properties to fill the PVT data as shown in Fig. 3(c).

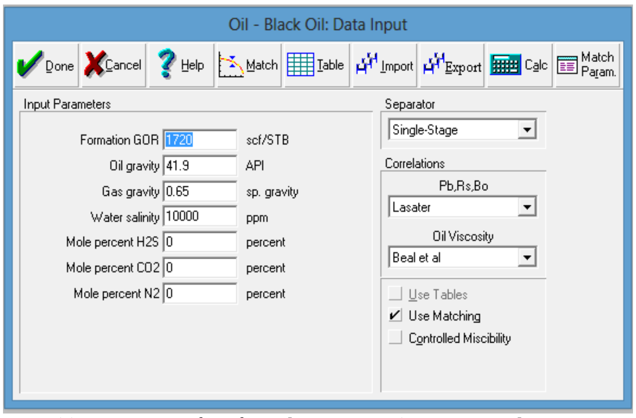

Fig. 3(c). MBAL Interface for Oil Data Input (Source: Petroleum Experts Limited) [15]

The next is to input the production history, tank parameters, pore volume vs depth, relative permeability etc. This is done by clicking Input and then clicking Tank data.

Then go to History Matching and click on Analytical Method and Energy Plot to generate the plot of tank pressure against calculated oil production for with water influx and without water influx and the plots of the effects of different energy drive mechanisms on the production of oil respectively. The Analytical Method and Energy Plots are as shown in Fig. 3(d) and 3(e) respectively.

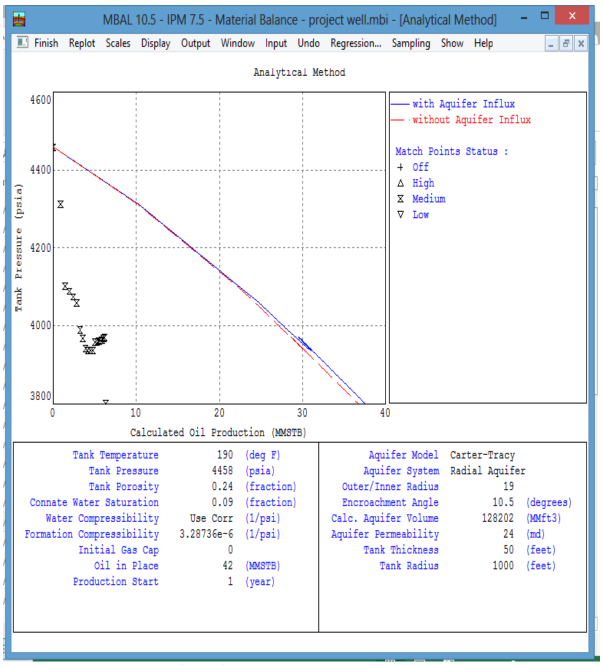

Fig. 3(d). MBAL Interface for Analytical Plot (Source: Petroleum Experts Limited) [15]

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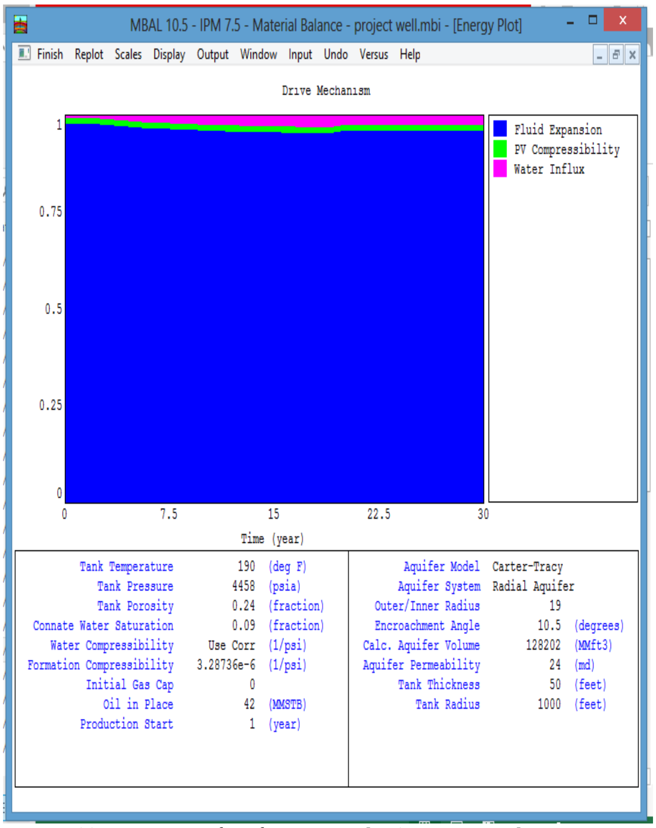

Fig. 3(e). MBAL Interface for Energy Plot (Source: Petroleum Experts Limited) [15]

On the same dropdown of History Matching, click Run Simulation, click Calc.

Move to Production Prediction, click on it, put the prediction setup, production and constraints, schedule and then click Run Prediction. The production prediction is performed and the results up till 2020 which is the well's 31st year are extracted and as shown in Table VII.

TABLE VII: RESULTS OF PRODUCTION PREDICTION USING MATERIAL BALANCE

Time, year	Tank Pressure, psia	Oil Rate (Q), stb/day
7.00	4149.85	890.99
7.99	4118.49	890.99
8.99	4087.14	887.047
9.99	4057.93	824.954
11.00	4029.43	777.645
11.99	4001.73	777.645
12.99	3974.44	762.861
13.99	3949.72	689.926
15.00	3928.74	521.387
15.99	3910.05	521.387
16.99	3892.08	498.718
17.99	3874.69	479.991
19.00	3858.89	411.984
19.99	3843.84	411.984
20.99	3828.67	411.984
21.99	3813.40	411.984
23.00	3797.97	411.984
23.99	3782.46	411.984
24.99	3766.83	411.984
25.99	3751.06	411.984
27.00	3735.11	411.984
27.99	3719.04	411.984
28.99	3702.81	411.984
29.99	3686.39	411.984
31	3669.72	411.984

V. CONCLUSION

Prediction analyses on a well were carried out in this paper. The result of the analyses has shown that the rate of oil production from a well can actually be predicted. Different rates were gotten for the different prediction analyses. The cumulative production of oil from well A was also predicted using decline curve analysis.

From the predictions made using the analyses, the following conclusions may be drawn:

1) The trend followed by the semi-log curve of the flow rate of oil against time determines the particular kind of decline curve prediction method to be used. Exponential decline is used when the decline is approximately linear or linear. Hyperbolic decline is used when the decline is a converging curve. Harmonic decline is used when the decline is a curve that has limit.
2) Different prediction methods give different values of rates of oil.
3) As much as the rate of flow of oil from the well can be predicted, the cumulative production of oil from the well can also be predicted.
4) The rate of oil predicted with material balance far differs from the rate of oil predicted with decline curve analysis.
5) The difference in the results got using decline curve and material balance analyses was due to the fact that the methods make use of variable estimation formulae and parameters. While decline curve analysis estimates decline of production taking into account only the production history, rate and the production decline rate, material balance analysis considers much more factors in estimating oil production from reservoirs. These other factors include oil formation factor, gas-oil ratio etc.
6) For accuracy in predicting production from a particular reservoir, first make a study of the particular production prediction method and trend that the neighbouring reservoirs or reservoirs of similar properties conform to, and apply same for the given reservoir.

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REFERENCES

[1] R. Thompson and J. Wright, *Oil Property Evaluation*, 2nd ed. Golden, Colorado: Thompson-Wright Associates, 1985, ch. 5.

[2] H. C. Slider, "A simplified method of hyperbolic decline curve analysis," *Journal of Petroleum Technology*, pp 235 – 236, vol. 20, issue 3, USA, 1968.

[3] M. A. Mian, *Project Economics and Decision Analysis: Deterministic Models-Volume 1*, USA: PennWell Books, 2011, pp. 121.
[4] S. J. Pirson, "Mathematical method of decline curve extrapolation and reserve calculation," *Oil Weekly*, vol. 123, no. 2, pp. 45-49, Sept. 1946.
[5] K. Li and N. Roland, "A decline curve analysis model based on fluid flow mechanisms," presented at the SPE Western Regional/AAPG Pacific Section, Long Beach, California, May 19-24, 2003.
[6] J. Oloro, G. O. Odu, and O. Oyubu, "Application of decline curve analysis in predicting the life span of a well in Niger Delta reservoir," *Continental Journal of Earth Sciences*, vol. 6, no. 2, pp. 1-8, June. 2011.
[7] J. J. Arps, "Analysis of decline curves," *Trans. AIME*, pp 228 – 247, vol. 160, no. 1, USA, 1945.
[8] M. J. Fetkovitch, E. J. Fetkovitch, and M. D. Fetkovitch, "Useful concepts for decline curve forecasting, reserve estimation and analysis," *SPE Reservoir Engineering*, pp 13 – 22, vol. 11, no. 1, USA, 1996.
[9] Y. Cheng, Y. Wang, D. McVay, and M. Lee, "Practical application of a probabilistic approach to estimate reserves using production decline data," *SPE Economics and Management*, pp 19 – 31, vol. 2, no. 1, USA, 2010.
[10] V. A. Jochen and J. P. Spivey, "Probabilistic reserve estimation using decline curve analysis with the bootstrap method," presented at the SPE Annual Technical Conference and Exhibition, Denver, Colorado, October 6-9, 1996.
[11] D. Sutawanir D., N. R. Budi, and K. P. Asep, "Robust decline curve analysis," *Journal of Indonesia. Mathematical. Society. (MIHMI)*, vol. 15, no. 2, pp. 105-111, Oct. 2009.
[12] J. J. Arps, "Estimation of primary oil reserves," *Trans. AIME*, pp 182 – 191, vol. 207, no. 1, USA, 1956.
[13] K. P. Ojo and S. O. Osisanya, "Material balance revisited," presented at the Nigeria Annual International Conference and Exhibition, Abuja, Nigeria, July 31 – August 2, 2006.
[14] *Decline Curves Estimation Methods*, Petrobjects, Massachusetts, USA, 2004.
[15] *MBAL, Reservoir Engineering Toolkit*, Petroleum Experts Limited, Edinburgh, UK, 2010.

NOMENCLATURE

API = American Petroleum Institute
b = Decline exponent
D = Decline rate
D = Nominal exponential decline rate, 1/day
D_e = Effective exponential decline rate, 1/day
D_i = Initial nominal exponential decline rate (t = 0), 1/day
EIA = Energy Information Administration
GOR = Gas-oil ratio
K_{rg} = Gas relative permeability
K_{ro} = Oil relative permeability
K_{rw} = Water relative permeability
md = Millidarcy
MMstb = Million stock tank barrel
Np = Cumulative oil production
OOIP = Oil originally in place
ppm = Parts per million
PVT = Pressure-Volume-Temperature
q = Well's production rate at time t, STB/day
Q = Oil rate, stb/day
q_i = Well's production rate at time 0, STB/day
Q_i = Oil rate at initial time
Q_t = Oil rate at time, t
Q_{11} = Oil rate at the 11th year
Q_{20} = Oil rate at the 20th year
Scf = Standard cubic foot
Stb/d = Stock tank barrel per day
t = Time, day
^{0}F = Degree Fahrenheit

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