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Development of a New Model for Oil and Gas Production Prediction

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Abstract-A mathematical model (ANIWART_EHIRIMMODEL) based on Production Index has been developed for the prediction of oil and gas production in a single well and total reservoir.This equation can be used by Petroleum Engineers to estimate initial hydrocarbon in place, hydrocarbon reserves at some abandonment conditions, forecasting future production rate and prediction of reservoir performance. The accuracy of such prediction however, depends on the originality and quality of data and procedure used for analysis. Arps equation,which still remains the most widely used method of analysis, observed exponential, harmonic and hyperbolic forms of decline. In real analysis, the exponential decline is used and its results are extrapolated to hyperbolic decline. Several modifications have been made to the Arps decline approach which included the effect of reservoir parameters.Aniwart_Ehirim model was applied to gas and oil fields in Niger Delta and a comparison was made using the Arps model of decline curve. The results fora gas well in Niger Delta using exponential decline model showed an approximately equal decline rate of 0.3118/ year, for both models. Estimated recoverable reserve usingAniwart_Ehirim model was 3.82MMMSCF as compared to 3.38MMMSCF obtained using the Arps model. The Aniwart_Ehirim model applied to an oil field gave a ERR of 312444bbls while the result for Arps model was 324278bbls.However, the economic recovery reserves, was 510252 bbl for Aniwart_Ehirim model as against 5015411bbl for ARP model. Hence, in the light of economic recoverability of reserves, Aniwart_Ehirim model is preferred.

Keywords- Hydrocarbon reservoir, production prediction, and model.

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I. INTRODUCTION

Production prediction simply means forecasting the behavior of a field, well or reservoir in term of its hydrocarbon in place, recoverable reserves, flow rate and pressure. The accuracy of prediction depends on the originality, quality of data and also on the method of analysis deployed. The importance of production prediction includes; estimation of initial hydrocarbon in place and reserves, time for enhanced oil recovery, time for artificial lift design,time for abandonment and estimation of expected income.

The estimation of reserves and predictions of the future performance of a well-in terms of production-has been and is still a serious and important context and practice in the oil and gas industry. To predict simply means to form an idea of the future condition of a thing, theory or fact using available data. The accuracy of prediction depends on the originality and quality of data[1]. In other words, this prediction can be correct with a very insignificant degree of uncertainties or it can be unacceptable, owed to the fact that it is based on irrelevant facts, wrong data or over idealized assumptions during the prediction.

In exploration and production decisions, alternatives such as development strategies, well placement, drainage strategies, artificial lift and capital investment must be evaluated. The ability to evaluate these terms lies on the effectiveness of the method embarked upon in the establishment of facts. By production forecast, the terms can easily be analyzed and well implemented to achieve maximum result. The prediction can be made with respect to future pressure or future time.

Production prediction provides the production and reservoir engineer with the idea of the behavior of the well in future times. Most reservoir engineering calculations involves the use of the material balance equation, known as MBE. The combination of some fluid flow equation with MBE provides the reservoir engineer with a tool to predict the reservoir future production performance as a function of time. Material balance calculations, relating underground withdrawal and reservoir pressure depletion, can provide the crucial pressure-versus time relationship [2]. Therefore, the associated well deliverability would be the forecast of well production.

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Numerous of factors affect the efficiency, effectiveness and reliability of data obtained from production prediction, the static or geological uncertainties, the dynamic uncertainties and operational uncertainties. Despite the exponential growth in computational memory and speed, computing accurate solutions is still expensive, so that it may not be feasible to consider all alternative models. Advantageously, some methods enable the generation of a truly probabilistic range of forecast that could then be used in decision making. These models are consistent with fundamental principles. However, uncertainties still abound [3].

Production forecast is an important aspect of petroleum and cannot be overemphasized. This concept has been an issue since the discovery of the first oil well in 1856 (Drakes well). Investors were unable to forecast production and therefore ran into magnanimous loss and dangers. After the development of some models between the 19th& 20th century, production prediction became a routine operation in the petroleum industry. Several methods have been developed throughout the years for the prediction of the future performance of a well or reservoir. Some remarkable developments and approaches include those of decline curve analysis,[4,5]and Material Balance Equation [6], etc.

An important part of any form of oil production modeling and hydrocarbon extraction forecasting is to uncover mathematical model for the physical behavior of the production processes [9]. The mathematical principles of the behavior are always important and useful. The production of an oil field tends to pass through a number of stages. This can be described by an idealized production curve. A version of this curve can be seen in Fig.1. After the discovery well, an appraisal well is drilled to determine the development potential of the reservoir. Further development follows and the first oil production mark the beginning of the build-up phase. Later the field enters a plateau phase, where the full installed extraction capacity is used, before finally arriving at the onset of decline, which ends in abandonment once the economical limit is reached. For many fields, especially smaller ones, the plateau phase can be very short and resemble more to a sharp peak, while large fields can stay several decades at the plateau production level. The life time of a field and the shape of the production curve are often related to the kind of hydrocarbon that is produced. This is the concept applied during the decline curve analysis. The shape of the production curve tells the type of fluid. For example, the exponential relationship between production and time is typical of the oil reservoirs. Hyperbolic and harmonic declines can be attributed to gas reservoirs or 3 component reservoirs (i.e containing oil, gas and water).

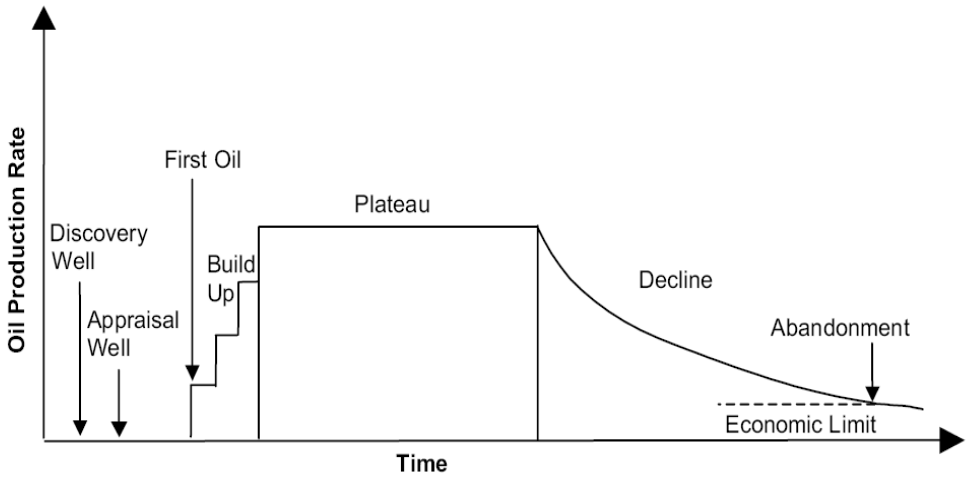


Figure 1. Theoretical production curve describing the various stages of maturity. Source [7].

The exponential method of prediction was first discovered by [5]. The relative decline rate and production rate decline equations for the exponential decline can be derived from volumetric reservoir model. There has never a predictive model that considered production index.The objective of this paper is to present a model based on forecasting the behavior of a field, well or reservoir in term of its hydrocarbon in place, recoverable reserves, flow rate and pressure.

II. MATHEMATICAL MODELING

The Arps equation of 1945, of decline curve analysis approach was proposed more than 67 years ago. However a great number of studies on production decline analysis are still based on this empirical method. The Aniwart_Ehirim model modified this Arps equation by introducing the production index which is a measure of the inflow performance of a well. Arps decline equation representing the relation between product rate and time or cumulative form is given as:

$$q = \frac{q_i}{(1+dbt)^{1/d}} \qquad (1)$$

Where **b** and **d** are empirical constants to be determined based on production data. When d= 0, equation above degenerates to an exponential decline model. When **d=1**, it generates a harmonic decline model, when **0 <d<1** it generates hyperbolic decline model. In real analysis, the exponential model is basically used and then extrapolated to the hyperbolic decline. The relative decline rate and production rate decline equations for the exponential decline can be derived from volumetric reservoir model.

2.1. EXPONENTIAL METHOD

The exponential method was first discovered by [5]. The general equation for the decline is given as:

$$\frac{1}{q}\left(\frac{dq}{dt}\right) = -bq^d \qquad (2)$$

Where **b** and **d** are empirical constants to be determined based on production data.

2.2. RELATIVE DECLINE RATE

Consider a well drilled into an oil volumetric reservoir. Suppose the well's production rate starts to decline when a critical (lowest possible) bottom hole pressure is reached, under the semi-steady (pseudo steady) state flow conditions, the production rate can be presented at a given time**t** as:

$$q = \frac{0.00708\,kh\left(P_t - P_{wfc}\right)}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]} \qquad (3)$$

$P_t = average reservoir pressure at decline time, t$

$P_{wfc} = the bottom hole pressure maintained during the production decline$

The cumulative production expression is obtained by integrating the production rate decline equation (i.e equation, (3)) with respect to time,t:

$$N_p = \int q dt \qquad (4)$$

or

$$N_p = \int \frac{0.00708\,kh\left(P_t - P_{wfc}\right)}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]} dt \qquad (5)$$

The cumulative oil production after production decline upon decline time,t can also be evaluated based on the total reservoir compressibility:

$$N_p = \frac{C_t N_i (P_o - P_t)}{B_o} \qquad (6)$$

Equations (5)and(6)are equal, i.e:

$$-\frac{0.00708\,kh\left(P_t - P_{wfc}\right)}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]} dt = \frac{C_t N_i (P_o - P_t)}{B_o} \qquad (7)$$

Taking the derivative of both sides with respect to time:

$$-\frac{0.00708\,kh\left(P_t - P_{wfc}\right)}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]} = C_t N_i \frac{dP_t}{dt} = q \qquad (8)$$

Differentiating flow rate with respect to time, the left hand side of equation(8) becomes:

$$\frac{dq}{dt} = -\frac{0.00708\,kh}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]}\frac{dP_t}{dt} \qquad (9)$$

Making $\frac{dP_t}{dt}$the subject of the equation and substituting into equation (8):

$$q = \frac{-141.2B_o\mu_o C_t N_i\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]}{kh}\frac{dq}{dt} \qquad (10)$$

Equation (10) can be rearranged to give:

$$\frac{1}{q}\left(\frac{dq}{dt}\right) = \frac{-kh}{141.2B_o\mu_o C_t N_i\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]} \qquad (11)$$

Comparing equations (2) and (11), we obtain

$$b = \frac{kh}{141.2B_o\mu_o C_t N_i\left[ln\left(\frac{0.472r_e}{r_w}\right)+S\right]} \qquad (12)$$

b is the relative decline rate of production

2.3. PRODUCTION RATE DECLINE

From equation (7):

$$-b\left(P_t - P_{wfc}\right) = \frac{dP_t}{dt} \qquad (13)$$

By separating of variables:

$$-bdt = \frac{dP_t}{(P_t - P_{wfc})} \quad (14)$$

Integrating equation (13) from $P_o(time, t = 0)$ to $P_t(time, t = t)$, gives

$$-b \int_0^t dt = \int_{P_o}^{P_t} \frac{dP_t}{(P_t - P_{wfc})} \quad (15)$$

$$-bt = ln\left(\frac{P_t - P_{wfc}}{P_o - P_{wfc}}\right) \quad (16)$$

or

$$\left(\frac{P_t - P_{wfc}}{P_o - P_{wfc}}\right) = e^{-bt} \quad (17)$$

Therefore, $P_t = P_{wfc} + (P_o - P_{wfc})e^{-bt}$ (18)

Substituting equation (17) into equation (8) yields

$$q = \frac{0.00708\, kh(P_o - P_{wfc})}{B_o \mu_o \left[ln\left(\frac{0.472 r_e}{r_w}\right) + S\right]} e^{-bt} \quad (19)$$

or

$$q = \frac{bC_t N_i (P_o - P_{wfc})e^{-bt}}{B_o} \quad (20)$$

The equation above indicates that ,the production rate can be determined at any time, t. provided the oil initial in place value is available, as well as the reservoir parameters. This model is commonly used for decline curve analysis of solution gas drive reservoirs.

In practice, the simple form of the equation is used. Thus:

$$q = q_i e^{-bt} \quad (21)$$

Where q_i is the production rate at time, t=0.

III. DEVELOPMENT OF ANIWART_EHIRIM MODEL

The development of this model is based on the production index of the considered hydrocarbon formation. The productivity index is a measure of the inflow performance of a well. It can be combined with the decline curve exponential equation to estimate recoverable reserves at any time. The productivity index, **J** to be used in this equation is the stabilized productivity index obtained at a stabilized productivity index obtained at a stabilized wellbore flowing pressure.

ASSUMPTIONS

The following assumptions were made in the development of this model:

- Pseudo steady state flow regime
- Under saturated reservoir (just oil flow)
- Constant average reservoir pressure
- Constant productivity index, J obtained at stabilized wellbore flowing pressure

The flow rate from a well flowing at a bottomhole pressure of $\boldsymbol{P_{wft}}$can be written in terms of productivity index as:

$$q_t = J(\overline{P_o} - P_{wft}) \quad (22)$$

Where $\overline{P_o}$=the average reservoir pressure and P_{wft} is the stabilized well bore flowing pressure at any time.

The initial flow rate (maximum flow rate) q_i is obtained when $\boldsymbol{P_{wft} = 0}$. For exponential decline, this is obtained when time**t** =**0**. Thus:

$$q_i = J\overline{P_o} \quad (23)$$

According to Arp's exponential decline equation:

$$q_t = q_i e^{-\alpha t} \quad (24)$$

$$q_t = J\overline{P_o} e^{-\alpha t} \quad (25)$$

The cumulative production at a particular time**t** is given by:

$$N_{pt} = \int_{t_o}^{t} q_i e^{-\alpha t} dt \quad (26)$$

$$N_{pt} = \int_{t_o}^{t} J\overline{P_o} e^{-\alpha t} dt \quad (27)$$

$$N_{pt} = J\overline{P_o}\left[-\frac{e^{-\alpha t}}{\alpha}\right]_{t_o}^{t} \quad (28)$$

$$N_{pt} = J\overline{P_o}\left(\frac{-e^{-\alpha t} + e^{-\alpha t 0}}{\alpha}\right) \quad (29)$$

The initial time,$\boldsymbol{t_o}$ is usually **0** for production decline analysis. The equation above becomes can then be written as:

$$N_{pt} = J\overline{P_o}\left(\frac{1-e^{-\alpha t}}{\alpha}\right) \quad (30)$$

This is the ANIWART_EHIRIM model for estimating cumulative production as a function of productivity index. The productivity index is the stabilized productivity index or constant productivity index. The model above assumed constant average reservoir pressure. The time, $\boldsymbol{t_a}$in the equation is the economic time, $\mathbf{q_i}$ is the initial flow rate, q_t is the flow rate at any time **t**, **J** is the production index, $\mathbf{N_{p(t)}}$ is the cumulative production at any time **t** and $\boldsymbol{\overline{P_o}}$. is the average reservoir pressure . The equation suggests that a plot of cumulative production against time on a semi-logarithmic paper will be a straight line with slope equal to $\frac{\boldsymbol{J\overline{P_o}}}{\boldsymbol{\alpha}}$ and intercept equal to $\boldsymbol{J\overline{P_o}}$.

IV. PRODUCTION DECLINE ANALYSIS WITH SKIN FACTOR

The exponential method is one of the most extensively used types of production decline. Considering a volumetric reservoir, a model could be developed using the rock and fluid properties of the reservoir, the Arps equation can be modified by including the skin factor term. Assuming a well of radius$\boldsymbol{r_w}$, centered in a cylindrical reservoir having an external radius,$\boldsymbol{r_e}$, the production rate, q can be written as:

$$q = \frac{0.00708\,kh(P_0 - P_{wft})}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right) + S\right]} \quad (31)$$

According to [8], the skin factor for a damaged well is given by:

$$S=\left(\frac{k}{k_s} - 1\right)\ln\left(\frac{r_s}{r_w}\right) \quad (32)$$

$$q = \frac{0.00708\,kh(P_0 - P_{wft})}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right) + \left(\frac{k}{k_s} - 1\right)ln\left(\frac{r_s}{r_w}\right)\right]} \quad (33)$$

Cumulative production, $\boldsymbol{N_p}$after the production decline time equal to the economic time is the recoverable reserves for such well or field and this is given by:

$$N_p = \int q\,dt \quad (34)$$

$$\frac{dq}{dt} = \frac{0.00708\,kh}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right) + \left(\frac{k}{k_s} - 1\right)ln\left(\frac{r_s}{r_w}\right)\right]}\frac{-dP_{wft}}{dt} \quad (35)$$

$$\frac{dq}{dt} = c.\frac{-dP_{wft}}{dt} \quad (36)$$

Where:

$$c = \frac{0.00708\,kh}{B_o\mu_o\left[ln\left(\frac{0.472r_e}{r_w}\right) + \left(\frac{k}{k_s} - 1\right)ln\left(\frac{r_s}{r_w}\right)\right]} \quad (37)$$

$$\frac{dq}{dt} = c.slope \quad (38)$$

But the decline rate, α is given by:

$$\alpha = \frac{dq/dt}{q} \quad (39)$$

$$\alpha = \frac{c.slope}{q} \quad (40)$$

$$q = \frac{c.slope}{\alpha} \quad (41)$$

$$N_p = \int \frac{c.slope}{\alpha}dt \quad (42)$$

$$N_p = \frac{c.slope}{\alpha}xt \quad (43)$$

The recoverable reserves (i.e. at the economic time) can be estimated using:

$$N_{pa} = \frac{c.slope}{\alpha}xt_a \quad (44)$$

Where $\boldsymbol{t_a}$ is the economic time.The $\boldsymbol{N_{pa}}$obtained with this equation is the recoverable oil from the oil initially in place. The oil initially in place can be estimated using the recovery factor. A field having same characteristics as the field under consideration is used as an analogous field. The recovery factor of the field is used to estimate the initial hydrocarbon in place.

Oil initial in place (OIIP) = Recoverable reserves x Recovery factor

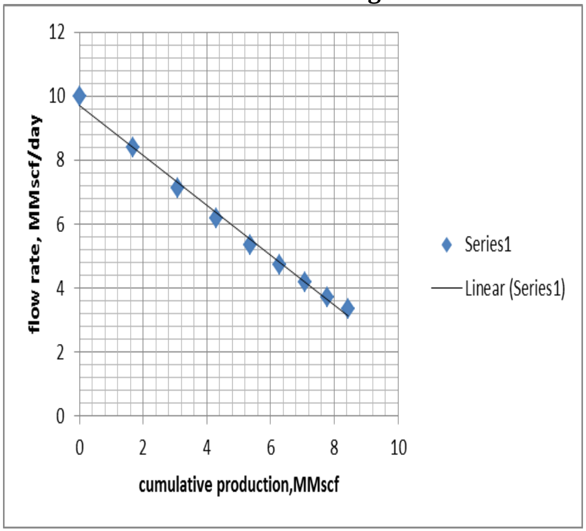
V. APPLICATION OF THE MODEL TO A REAL INDUSTRIAL SITUATION

The developed model was tested on different oil and gas fields in Niger Delta region of Nigeria.This equation required the calculation of the productivity index. The parameters calculated include the decline factor, the initial decline rate, the economic recoverable reserves, and the abandonment time. The results calculated using ANIWART_EHIRIM Model were compared to the ones obtained using the Arps equation. The productivity index was calculated using pressure and drawdown parameters.

The following data were extracted from two oil and gas wells in Niger Delta after producing for a year (12months):

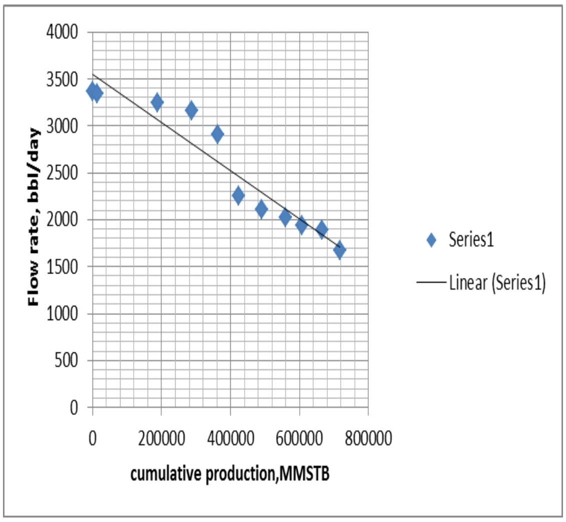
VI. RESULTS AND DISCUSSION

Gas Field in Niger Delta



(a) GAS WELL 1

Oil Field in Niger Delta



(b) OIL WELL 2

Figure 2. A plot of flow rate against cumulative production (a) for a gas well in Niger Delta (b) For oil field in Niger Delta

The results of the calculations made using Arps and ANIWART_EHIRIM models are shown on the tables below for both gas and oil fields from the Niger Delta. The value for α was 0.0027, average initial pressure P_0 was 2011psia, and the time t was 2years for a production index of 81.8147.

Table 1: Results from Gas and Oil Fields in South-Southeast, Niger Delta. Nigeria.

GAS FIELD IN NIGER DELTA (WELL 1)			OIL FIELD IN NIGER DELTA (WELL 2)		
PARAMETER	ARPS MODEL	ANIWART_ EHIRIM MODEL	PARAMETER	ARPS MODEL	ANIWART_ EHIRIM MODEL
Decline rate (1/yr)	0.3118	0.3120	Decline Rate (1/yr)	0.4596	0.4663
Recoverable Reserves(MMMscf)	3.38	3.82	Recoverable Reserves(bbl)	324278	312444

Table 2: Results obtained using both Arps and Aniwart_Ehirim Models for Oil Field in Ebubu, (WELL 3) Niger Delta. Nigeria.

PARAMETER	ARPS	ANIWART_EHIRIM
Decline Exponent	0.4	
Decline Factor (1/month)	0.013534	0.013488
Initial Decline Rate bbl/day	343	347
Economic recoverable Reserves(bbl)	505411	510252
Abandonment Time (year)	38.446	41.232

Fig 2 shows a plot of the increase in production against time for wells 1 and 2. The calculated parameters for these wells using both the ANIWART_EHIRIM and ARPS models are tabulated in Table 1. The decline rate forWell 1 using exponential modeling is equal to 0.3118/year. Observe that the value is the same using ANIWART_EHIRIM model. If extrapolated for hyperbolic decline, the decline rate is equal to 0.3668/year. The estimated recovery reserves using the Arps exponential decline model is 3.38MMMSCF. Using the ANIWART_EHIRIM Model, the estimated recovery reserve is about 3.82MMMSCF. The ANIWART_EHIRIM modelapplied to well (II) in an oil field in Niger Delta gave ERR of 312444bbls as compared to 324278bbls for Arps model. Similar results for well (III) showed that, the Economic Recoverable Reserves was higher in ANIWART_EHIRIM equation than using Arps model. The ANIWART_EHIRIM models had abandonment period of 41 years as against 38 years of Arps.

VII. CONCLUSION

In the light of Economic recoverability the ANIWART_EHIRIM MODEL is preferred. Although ARP method of production prediction remains the most widely used, the ANIWART_EHIRIM model developed in course of this research could be a strong Contemporary Mathematical Tool in the hands of Petroleum Engineers in predicting production parameters.Future research should be based on the modification of the Arps decline model to predict correctly for transient state flow and wells producing below capacity.

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