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# Decline Curve Analysis and Material Balance, as Methods for Estimating Reserves (A Case Study of $D_4$ and E1 Fields)

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***Abstract:***
*Reserve estimation entails the interpretation of geologic and/ or quantitative calculation of the petro physical data, PVT(Pressure, Volume, and Temperature), and production histories of the reservoir to estimate the reserve[1]. Reserve estimation using Decline Curve Analysis andMaterial Balance andattempts to answer the question of reserve evaluation based on performance trend. Various techniques have been developed for computing reserve[2].This study therefore focused on comparing Decline Curve Analysis and Material Balance using two fields as a case study. These are $D_4$ Sand Guico field, and the Eleke (E1) field. Particular emphasis was laid on the determination of decline rate from the graph of production rate versus cumulative production which was also used to obtain the maximum produced oil and consequently the stock tank oil initially in place (STOIIP) when the decline curve analysis was used.*
*Since the two reserves used are combination drives, the graph of the variables plotted against each other gave a slope U, known as the reservoir constant and the stock tank oil initially in place as the intercept when the material balance approach was used[3].*

## 1. Introduction

Many petroleum engineer spend a major part of their professional lives developing estimates of reserves and production capabilities, along with new methods and techniques for improving these estimates. To understand the confidence level and risks of the estimates, a clear and consistent set of reserve classification must be used. The confidence level and the techniques implemented by the petroleum engineer depend on the quantity and the maturity of the data available. The data quality, therefore establishes the classification assigned to the reserve estimates and indicates the confidence one should have in the reserve estimates. Reserve estimation is simply evaluating or assessing a particular reservoir[3]

One major reason for the estimates of reserves is for management decisions which are seen in the formation of policies for:

- Exploration and development of oil and gas properties.
- Design and construction of plants, gathering systems and other surface facilities.
- Determining and construction of ownership in unitized projects.
- Establishing sales contracts.

An extensive work in oil and gas reserves classification, estimation and evaluation was done by Forest, A.G[4].

According to him, reserve estimation methods are:

- Analogy
- Volumetric Methods
- Performance Techniques
  - Numerical Simulation Models
  - Material Balance Method
  - Production Decline Curves

In the analogy method, geologic provinces where production from target formation in other entrapments exists, statistical analysis of the older wells are used to determine the mean or median reserves can provide useful information. Actually, before a reservoir is drilled, prospective reserves are usually estimated on this basis.

In the volumetric method of estimation recoverable reserves, the original oil in place (OIIP) and the estimated recovery efficiency factor are multiplied. In this way, stock tank oil in place can be calculated.
For material balance to be used to estimate the reserve, five percent of its volume must have been recovered. In simple volumetric terms, the material balance can be expressed as:
Initial volume = volume remaining + volume recovered [3]
Decline curves are plotted to show a graphical representation of production data available. They show that production decreases with time and since the graphical representation of production data eventually shows production curves decrease with time, the curves are known as 'decline curves'. Analysis of such curves is what decline curve analysis is all about.
Mathematical simulation approach reserve estimation by making a model of the reservoir.

**2. Methodology**
Two reserves were considered in this work; The $D_4$ Sand, Guico field as $D_4$ and Eleke field which is termed E1; are all combination reservoir drive mechanism.

*2.1. Material Balance Equation Methodology*
Different methodology approach was used for both the $D_4$field and E1fields:
MBE applied to E1 field

- The underground withdrawal, F; oil and dissolved gas expansion, Eo; and gascap gas expansion, Eg were first calculated for E1 field using the following formulae:
  - $F = N_P (B_O + (R_P - Rs) B_g) + W_P B_W$ (rb)

which is the underground withdrawal (1)

  - $E_O = (B_O - B_{OI}) + (R_{SI} - R_S)B_g$ (rb/ stb)

which is the expansion of oil and its originally dissolved gas (2)

  - Eg = $Boi\left(\frac{Bg}{Bgi}\right)-1$

which is the expansion of the gascap gas (3)
The following assumptions were made;
- The reservoir is producing under combination drive.
- Change in hydrocarbon pore volume (HCPV) due to connate water expansion was neglected.
- The water formation volume factor Bw is 1
- m = 0.7 was assumed for E1 field.

With these assumptions in place, the general material balance equation
F = N (Eo + mEg +Ef,w) +WeBw (rb) (4)
Reduced to;
F = N (Eo + mEg) +We (5)
Where

$$\frac{F}{Eo+mEg} = N + \frac{We}{Eo+mEg} \quad (6)$$

This was gotten as a result of dividing both sides of equation 5 by (Eo + mEg).

The calculation for F,Eo and Eg were done for each plateau pressure level(see table 1.0) .

- Secondly, the water influx calculation was made using the Hurst and Van Everdingen method.

- First the dimensionless time, $t_D$ for E1 was given by the formula

$$t_d = \frac{4.57x10^{-7}\,kt}{\Phi\mu C_t A} \quad (7)$$

the reason being that the aquifer oil leg area A was given

- The pressure drop, ΔP was then calculated using the formula(see table 2.0);

$$\Delta Pi = \frac{P_{i-1} - P_{i+1}}{2} \quad (8)$$

This was gotten for the different time levels.

➢ With the $t_D$ and ΔP in place, the water influx, We was calculated using the equation(see table 2.0);

$$We = U\sum_{i=0}^{n-1} \Delta PiWd\left(td - Tdi\right) \qquad (9)$$

Where U = water influx constant, rb/psi; $W_D$ ($t_D$) = the dimensionless water influx read from the Van Everdingen and Hurst water influx chart.

- Lastly, a table was incorporated which was principally done on Excel spreadsheet to calculated for (Eo + mEg) for the different pressures and the consequent fractions of F/ (Eo + mEg) and We/ (Eo + mEg)

From equation 6; $\frac{F}{Eo + mEg} = N + \frac{We}{Eo + mEg}$

A graph of F/ (Eo + mEg) vs. We/ (Eo + mEg) will result in a straight line graph with slope U which is the water influx constant in rb/psi and the stock tank oil initially in place, N which is the intercept.

- MBE applied to $D_4$ field

Though similar procedure was used, only the configuration of the terms changed.

➢ F, which is the underground withdrawal was calculated using the formula;

F = (Np [Bt + (Rp-Rsi) Bg] + Wp – Wj (10)

Where Bt = Bo + (Rsi -Rp) Bg; Boi = Bti and Bt which is the total two-phase formation volume factor. Et which looks like a variant combining (Eo + mEg)

$$\mathrm{Et} = \mathrm{Eo} + \frac{\mathrm{mBti}}{\mathrm{Bgi}}\mathrm{Eg}$$

➢ This equation was summarized as;

$$\mathrm{Et} = \frac{\mathrm{mBti}\left(\mathrm{Bg} - \mathrm{Bgi}\right)}{\mathrm{Bgi}} + \left(\mathrm{Bt} - \mathrm{Bti}\right) \qquad (11)$$

Equation 12 was used then used for the calculation at different pressures levels.

➢ Now the combination drive mechanism formula is;

$$\mathrm{F} = \mathrm{N}\left(\mathrm{Eo} + \frac{\mathrm{mBti}}{\mathrm{Bgi}}\mathrm{Eg}\right) + \mathrm{C}\sum \Delta \mathrm{PQ}\left(\Delta \mathrm{t}_{\mathrm{D}}\right) \qquad (12)$$

Where Eo = Bt – Bti

C = consistency test which is a function of real time.

Dividing both sides of the equation 13 by

$$\left[\mathrm{Eo} + \mathrm{m}\left(\frac{\mathrm{mBti}}{\mathrm{Bt}}\right)\mathrm{Eg}\right]$$

➢ Would give a basis of the plot to obtain the stock tank oil initially in place, N

$$\frac{F}{\left[Eo + \frac{mBti}{Bgi} Eg\right]} = N + \frac{C\sum \Delta PQ(\Delta tD)}{\left[Eo + \frac{mBti}{Bgi} Eg\right]} \qquad (13)$$

- the water influx We, was calculated using the formula;

$$We = \left[\sum_{i=0}^{n-1} \Delta P_i Q(\Delta t_D)\right] / E_t \qquad (14)$$

- Assumption made:

The value of Q(tD) was assumed for all the pressure levels.

- The pressure drop, ΔP was calculated using the formula;

$$\Delta P = \frac{P_{i-1} - P_{i+1}}{2} \qquad (15)$$

- With $Q(t_D)$ assumed , the water influx We, was calculated.

- Lastly, a table was incoporated on Microsoft Excel spreadsheet to calculate F/Et and $\left[\sum \Delta PQ(\Delta t_D)\right] / E_t$.

A plot of F/ Et vs. $\left[\sum \Delta PQ(\Delta t_D)\right] / E_t$ will gice a slope C in rb/psi and an interceptN, which is the stock tank oil initially in place.

## 3. Results of the Material Balance Method

| Pressure (psia) | F MMrb | Eo Rb/stb | Eg Rb/stb | mEg | Eo + mEg | We Mrb | F/ (Eo + mEg) MMrb | We/ (Eo + mEg) Mrb |
|---|---|---|---|---|---|---|---|---|
| 4487 | | | | | | | | |
| 4444 | 2.5464 | 0.00073 | 0.102 | 0.006834 | 0.006907 | 1.590 | 368.67 | 230.20 |
| 4416 | 5.3569 | 0.00165 | 0.0164 | 0.010988 | 0.012638 | 5.64 | 422.30 | 446.27 |
| 4370 | 8.4056 | 0.003950 | 0.0225 | 0.015075 | 0.019025 | 11.79 | 441.82 | 619.71 |
| 4332 | 12.3895 | .002004 | 0.0300 | 0.0201 | 0.022104 | 20.19 | 560.51 | 913.41 |
| 4298 | 16.1938 | 0.003088 | 0.0490 | 0.03283 | 0.035918 | 30.11 | 450.86 | 838.29 |
| 4260 | 20.8213 | 0.003531 | 0.0491 | 0.032897 | 0.036428 | 41.56 | 571.57 | 1140.88 |
| 4228 | 26.1943 | 0.004972 | 0.0553 | 0.037051 | 0.042023 | 54.51 | 623.33 | 1297.15 |
| 4230 | 28.2560 | 0.0040100 | 0.0573 | 0.038391 | 0.042401 | 67.12 | 666.40 | 1582.98 |
| 4259 | 29.3895 | 0.002945 | 0.0532 | 0.035644 | 0.038589 | 77.27 | 761.60 | 2002.38 |
| 4282 | 30.6539 | 0.002600 | 0.0532 | 0.035644 | 0.0382244 | 84.27 | 801.54 | 2215.25 |

*Table 1: Material balance method table of values.*
*MBE values for Eleke field, E1*

| Td | Wd(td) | Pressure drop $\Delta P$ (psi) | We (Mstb) |
|---|---|---|---|
| 0 | 0 | 21.5 | 0 |
| 205.9 | 74 | 35.5 | 1.590 |
| 411.7 | 140 | 37.0 | 5.64 |
| 617.6 | 190 | 42.0 | 11.79 |
| 823.4 | 240 | 36.0 | 20.19 |
| 1029.3 | 280 | 36.0 | 30.11 |
| 1235.3 | 328 | 35.0 | 41.56 |
| 1441.0 | 370 | 15.0 | 54.51 |
| 1646.9 | 400 | -15.0 | 67.12 |
| 1852.7 | 430 | -25.0 | 77.27 |
| 2058.6 | 465 | | 84.27 |

*Table 2 :Values for water influx of the Eleke field*

*The slope U = 232.4 rb/psi and the intercept N was; N = 330MMstb*

*The $D_4$ Sand Guico field, $D_4$*

| $\Delta$P (psig) | Q (tD) reD | Et (rb/ stb) | $We = \left[\sum_{i=0}^{n-1} \Delta P_i Q(\Delta t_D)\right] / E_t$ x $10^4$ Bbl |
|---|---|---|---|
| 23.5 | 220.15 | 0.1104 | 4.6861 |
| 16.5 | 222.45 | 0.1188 | 7.4579 |
| 10.5 | 225.42 | 0.1293 | 8.7234 |
| 10.5 | 226.45 | 0.1311 | 10.4411 |
| 14.0 | 227.89 | 0.1417 | 11.9100 |
| 11.0 | 228.56 | 0.1478 | 13.1340 |
| 7 | 229.89 | 0.1551 | 13.5964 |
| -13.0 | 230.45 | 0.1563 | 11.7380 |
| 1 | 231.06 | 0.1391 | 13.3960 |
| 17.5 | 234.12 | 0.1576 | 14.3301 |
| 15 | 235.68 | 0.14609 | 16.1913 |
| 5 | 236.98 | 0.1771 | 15.4395 |
| -21.5 | 237.06 | 0.1674 | 13.6038 |
| -1.5 | 238.45 | 0.1498 | 15.0530 |
| 1 | 246.0 | 0.1654 | 13.9114 |

*Table 3:The water influx table of values:*

| Pressure (psig) | Et (rb/ stb) | F MMbbl | F / Et MMstb | $\left[\sum \Delta PQ(\Delta t_D)\right] / E_t$ X $10^4$ |
|---|---|---|---|---|
| 1814 | 0.1104 | 8.499 | 76.98 | 4.6861 |
| 1799 | 0.1188 | 8.987 | 75.65 | 7.4579 |
| 1781 | 0.1293 | 9.747 | 75.38 | 8.7234 |
| 1778 | 0.1311 | 12.782 | 97.50 | 10.4411 |
| 1760 | 0.1417 | 14.200 | 100.21 | 11.9100 |
| 1750 | 0.1478 | 15.340 | 103.79 | 13.1340 |
| 1738 | 0.1551 | 16.801 | 108.32 | 13.5964 |
| 1736 | 0.1563 | 18.397 | 117.70 | 11.7380 |
| 1764 | 0.1391 | 19.001 | 136.61 | 13.3959 |
| 1734 | 0.1576 | 20.113 | 127.62 | 14.3301 |

| | | | | |
|---|---|---|---|---|
| 1729 | 0.1609 | 20.615 | 128.12 | 16.1913 |
| 1704 | 0.1771 | 21.716 | 122.62 | 15.4395 |
| 1719 | 0.1674 | 22.573 | 134.84 | 13.6038 |
| 1747 | 0.1498 | 22.937 | 153.12 | 15.0530 |
| 1722 | 0.1654 | 23.644 | 142.95 | 13.9114 |

*Table 4: Material balance table of values:*
*The slope, U = 667.0 rb/psi*
*The stock tank oil initially in place, N = 29MMstb.*

**4. Decline Curve Analysis Methodology**
For the two fields, E1 and $D_4$, the same approach was used in calculating the decline curve.
The graph of production rate versus time was plotted on the semi-log graph (see fig.2). A straight line relationship on the semi-log graph shows that the data undergoes the empirical model of Arps, J.J.[6] , i.e;

$$q_t = q_i e^{-D_i t} \quad (16)$$

All such plots on the semi-log graph showed a linear relationship, so it was concluded that the resources follow the empirical exponential model.
Then a graph of production rate vs. cumulative production was plotted on the Cartesian graph for the two reserves(see fig.3) . From these, the several decline rates, D, were gotten from the slope of each graph of the different field.
To obtain the maximum produceable oil from the reservoir, $Np_{max}$, the formula was used;

$$Np_{max} = \frac{qi}{Di} \quad (17)$$

"qi" was gotten when the straight line from the semi-log plot of production rate vs. time was extrapolated to t = 0.
To obtain the stock tank oil initially in place (STOIIP), the cumulative production up to the last year and the maximum produceable oil were added. The formula is given by;
STOIIP = $NP_{max}$ + Cumulative produced oil up to the last year. (18)

**5. Results for Decline Curve Analysis**

| Date | Production rate (stb/d) | Cumulative Oil Production (Np) Mstb |
|---|---|---|
| 01/01/86 | 0 | 0 |
| 01/01/87 | 5507 | 2010 |
| 01/01/88 | 6123 | 4245 |
| 01/01/89 | 6123 | 6393 |
| 01/01/90 | 6441 | 8733 |
| 01/01/91 | 5641 | 10792 |
| 01/01/92 | 4751 | 12526 |
| 01/01/93 | 4131 | 13986 |
| 01/01/94 | 2907 | 15047 |
| 01/01/95 | 2337 | 15900 |
| 01/01/96 | 1836 | 16700 |

*Table 5: Values for Eleke field*

| xTime (days) | Production Rate Mbbl/ day | Cum. Oil Produced, Np MMbbl |
|---|---|---|
| 1056 | 4.930 | 5.2030 |
| 1058 | 5.190 | 5.4940 |
| 1061 | 5.600 | 5.9440 |
| 1211 | 6.580 | 7.9670 |
| 1607 | 5.540 | 8.9070 |
| 1757 | 5.440 | 9.5550 |

| | | |
|---|---|---|
| 1997 | 5.274 | 10.520 |
| 2237 | 5.210 | 11.655 |
| 2357 | 5.170 | 12.188 |
| 2507 | 5.140 | 12.790 |
| 2567 | 5.070 | 13.022 |
| 26.87 | 5.010 | 13.463 |
| 2867 | 4.910 | 14.081 |
| 3077 | 4.760 | 14.651 |
| 3227 | 4.680 | 15.092 |

*Table 6: Vs for the $D_4$ Sand, Guico*

| | **D ($Day^{-1}$)** | **$Np_{max}$ (MMstb)** | **STOIIP (MMstb)** |
|---|---|---|---|
| Eleke field | 2.059 x $10^{-2}$ | 311.36 | 327.93 |
| $D_4$ Sand field | 4.8443 x $10^{-4}$ | 13.583 | 28.675 |

*Table 7: Aable showing the values of D, Npmax andd STOIIP for the two fields is shown below*

| | **DCA (MMstb)** | **MBE (MMstb)** |
|---|---|---|
| Eleke field | 327.93 | 330 |
| $D_4$ Sand field | 28.675 | 29.0 |

*Table 8: Comparing the results of DCA and MBE STOIIP values of the two fields*

*5.1. Results*

| | **Decline Rate ($Day^{-1}$)** | **Decline Curve Value of STOIIP (N)** | **Material Balance Value of STOIIP (N)** |
|---|---|---|---|
| Eleke Field Reservoir | 2.059 x $10^{-2}$ | 327.93 MMstb | 330 MMstb |
| $D_4$ Sand Guico Field Reservoir | 4.8443 x $10^{-4}$ | 28.675 MMstb | 29 MMstb |

*Table 9:Results for the two fields*

**6. Discussion of Results**

In this study, decline curve analysis (DCA) and the material balance equation (MBE) were used to estimate the stock tank oil initially in place (STOIIP) of two different reservoirs, that is, Eleke field, and the $D_4$ Sand, Guico field.

The closeness to which the several values of the STOIIP gotten from each method shows a very imporatant value for scrutiny and reasoning.

The MBE treats a reservoir as a single homogenous tank with no areal or vertical distribution of reservoir rock of fluid. Normally, before the MBE is applied, the reservoir's volume must have been exploited to some degree. This implies that it's accuracy is hindered by the fact that most calculations assume gas released to be distributed homogenously. This is a weakness in the material balance method as it tends to over-estimate the reservoir regardless of the tact and experience of the estimator.

Decline curve is applied only when production is noticed to have been stable over a period of time and when this time is compared with the time in which material balance data are gotten is shorter in range.

From the foregoing, it can be inferred that the data quality therefore, establishes the classification assigned to the reserve estimates and indicates the confidence one should have in the estimates of the reserve. This is one major factor why the values of STOIIP gotten from the MBE is higher as compared to those from DCA.

Though, this criticism is to build a healthy thought as to considering a run of both methods together so as to compare the analysis of one over the other. So we cannot relegate the MBE to the background. The reason is obvious; the extrapolation of the decline curve method is based on the assumption that the near future trend of the reservoir will be governed by the empirical mathematical function of it's past performance thus making decline curve analysis at times inferior to material balance.

The Eleke field has a larger value of STOIIP. So it's more economically viable to exploit when compared to $D_4$ field

**7. Significance of the Results**

STOIIP values gotten from both DCA and MBE is of utmost importance to the reservoir engineer, production engineer and the operating company at large.

For instance, the Eleke field has a higher value of STOIIP of of 327.93 MMstb from DCA and 330 MMstb from the MBE and also a higher decline rate of 2.059 x $10^{-2}$ $day^{-1}$. Though decline rate of the reservoir is high, the volume of the reserve present offsets the rate at which the decline occur, by implication the well will produce for a longer period of time. This maens greater profit for the owners of the well.

Therefore, based on the results, Eleke field is favourably disposed to be exploited and will yield greater profit than either the other reservoir. This objectivity in results is highly needed by the operating company whose major aim is to maximize profit at minimum cost.

**8. Conclusion**

In this study, the decline curve analysis (DCA) and material balance (MBE) method were used in estimating two different reserves, that is; Eleke field, and the $D_4$ Sand, Guico field to obtain their decline rates and corresponding stock tank oil initially in place (STOIIP). The two reservoirs were of the combintaion drive mechanism type.

Plotting a graph of production rate against cumulative production for each field, the following decline rates of Eleke field and $D_4$ Sand, Guico field were gotten as: 2.059 x $10^{-2}$ $day^{-1}$and 4.8443 x $10^{-4}$ $day^{-1}$ respectively. Their corresponding values of STOIIP for each using decline curve method were: 327.93MMstb and 28.675MMstb respectively.

Using the material balance method, the STOIIP of Eleke reservoir was gotten by plotting the variables F/ (Eo + mEg) against We/ (Eo + mEg) on a cartesian graph to obtain; 330MMstb. For the D4 Sand, Guico field, plotting the variables F/ Et against $[\sum\Delta PQ(\Delta t_D)]$/ Et resulted in an STOIIP value of 29MMstb.

The evaluation of these reserves using either of the two methods depend principally on the qualtiy of the data, the experience of the estimator and the interval of estimation.

**9. Recommendation**

Production data to be used for both material balance and decline curve analysis should be carefully obtained.

Since the extent and nature of commercially recoverable hydrocarbon from the subsurface cannot be determined with a high degree of precision, several estimation methods should be run together to compare the result of one with the other.

Even after several methods have been employed, operating companies can still carry out estimation methods to further reassure confidence after somoe years from the first estimation done.

Its one thing to have a good data, its yet another to have competent hands for the estimation. Operating companies should pay close attention to whoever does the estimation for them.

Eleke field has a higher value of STOIIP. To maximise profit, operating companies can exploit it first because it would offset cost of production.

After all these methods have been employed, enhanced oil recovery can still be run for each reservoir to recover the interstitial oil.

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## Annexure

### 1. Material Balance Graph of Eleke Field

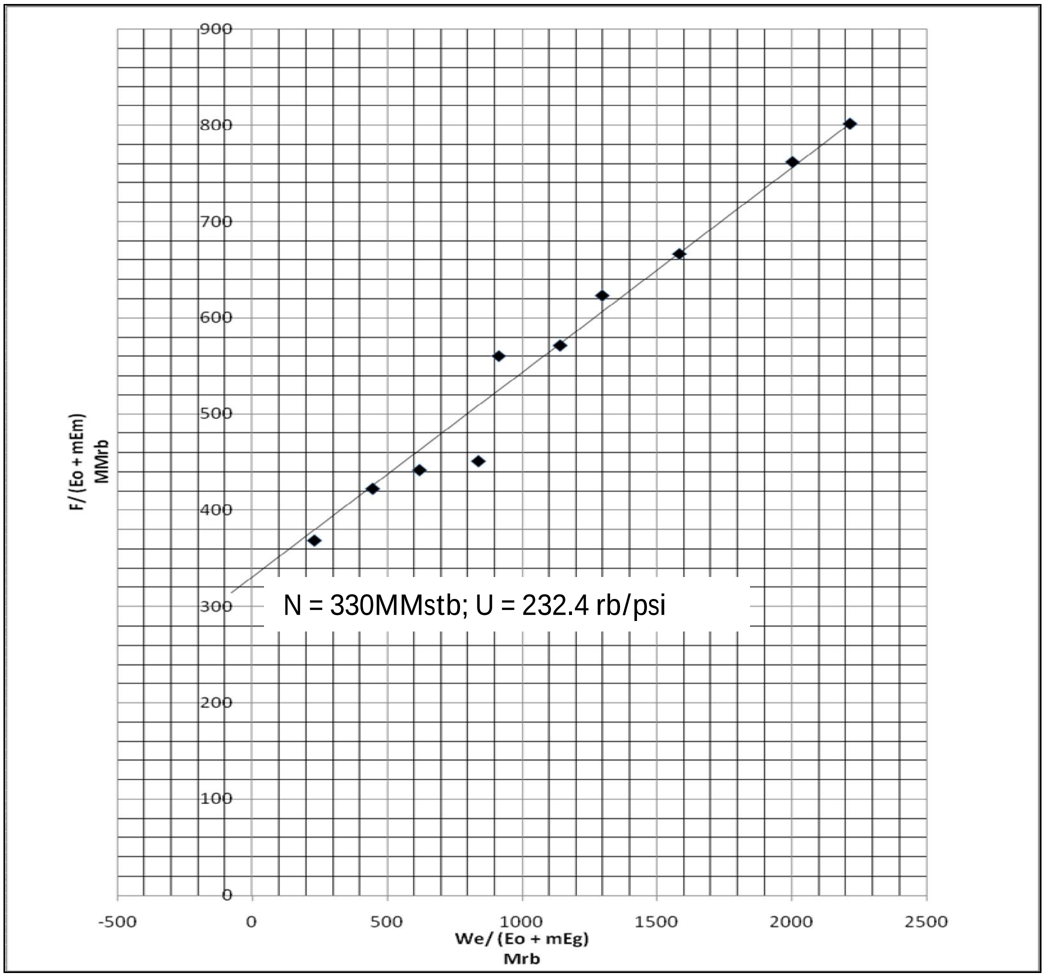


*Figure 1: A plot F/ (Eo + m Eg) vs We/ (Eo + mEg)*

### 2. Decline Curve Graphs of the Eleke Field

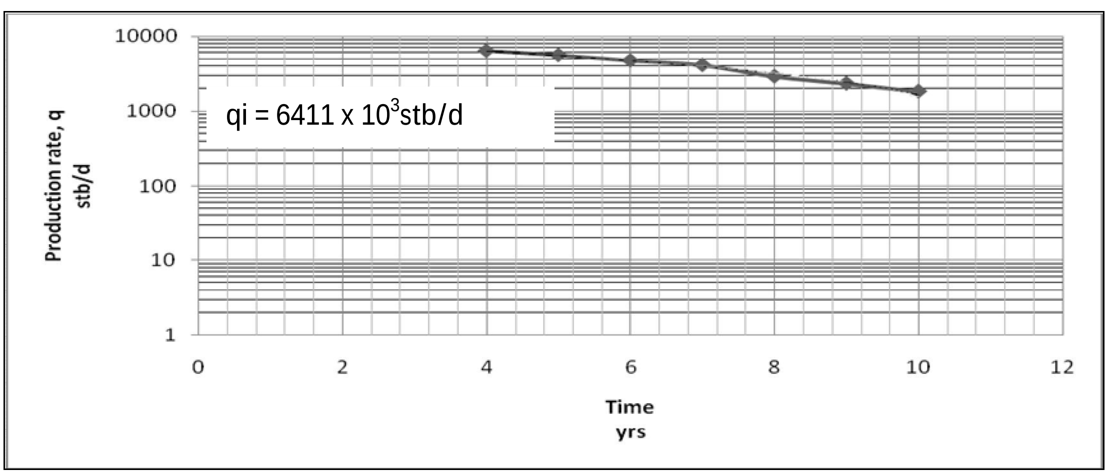


*Figure 2: Semi-log plot of production rate, q vs. time, yrs*

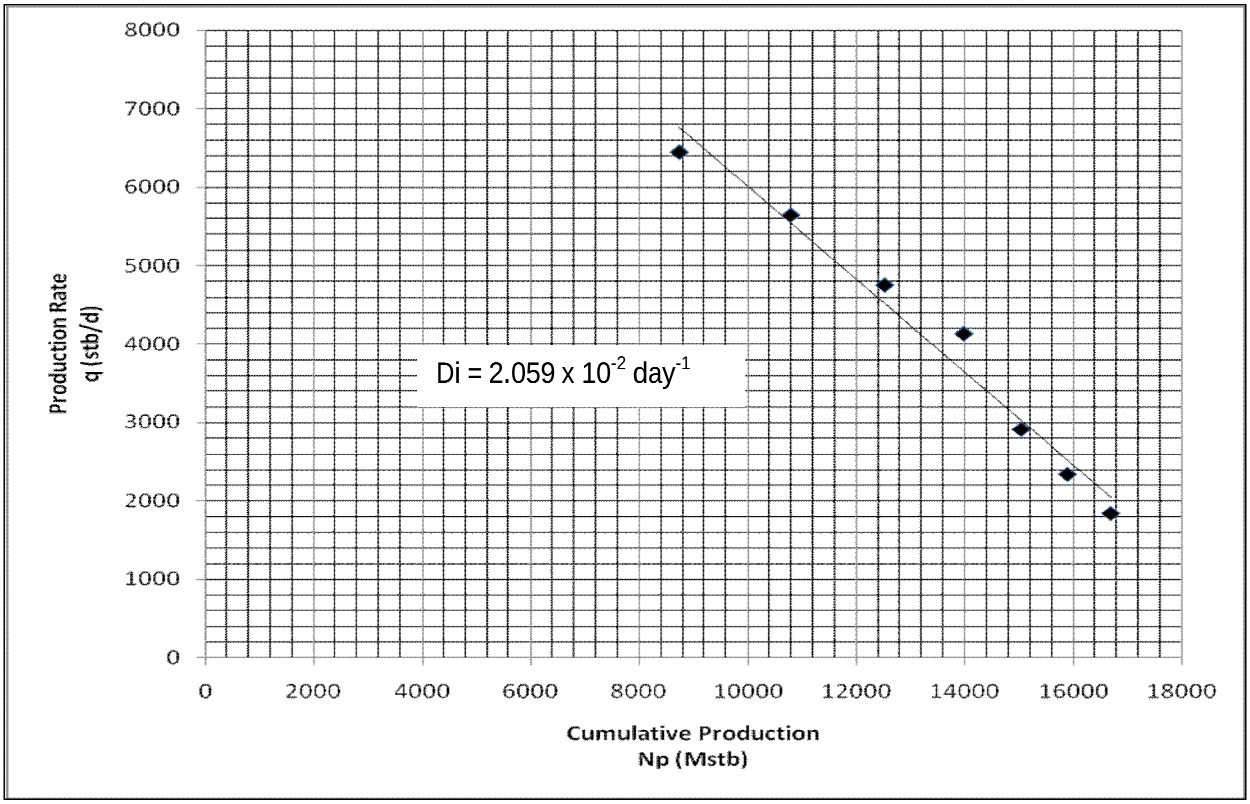


*Figure 3: Plot of production rate, q vs. cumulative production rate, Np*

**3. Material Balance Plots for Guico Field**

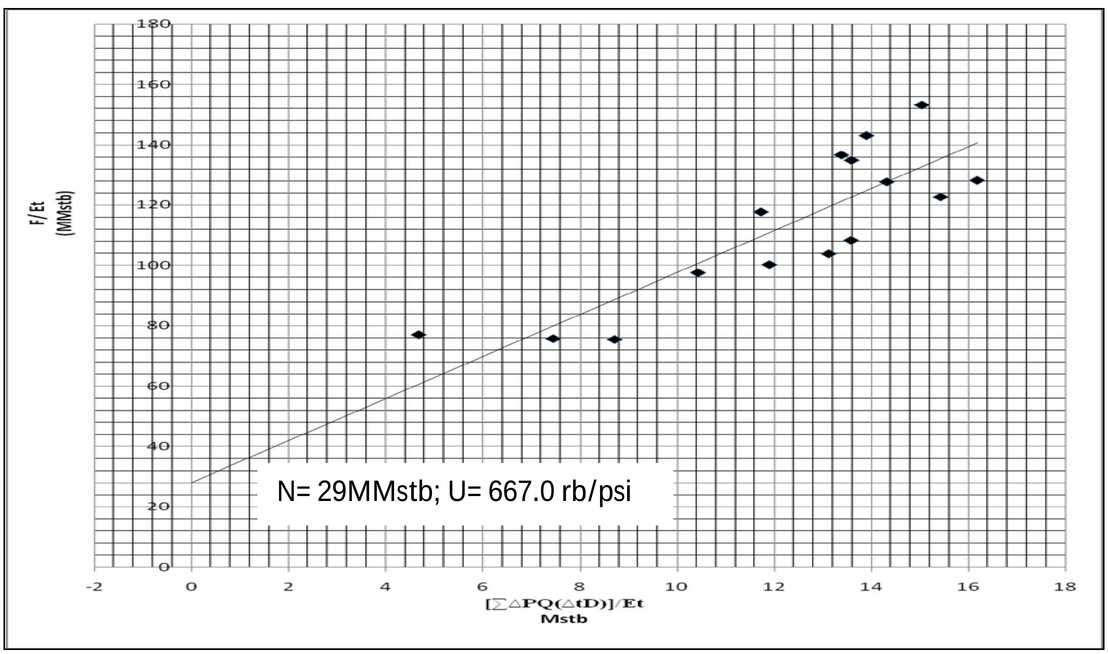


*Figure 4: a plot of F*

**4. Decline Curve Analysis plots of the Guico Field.**

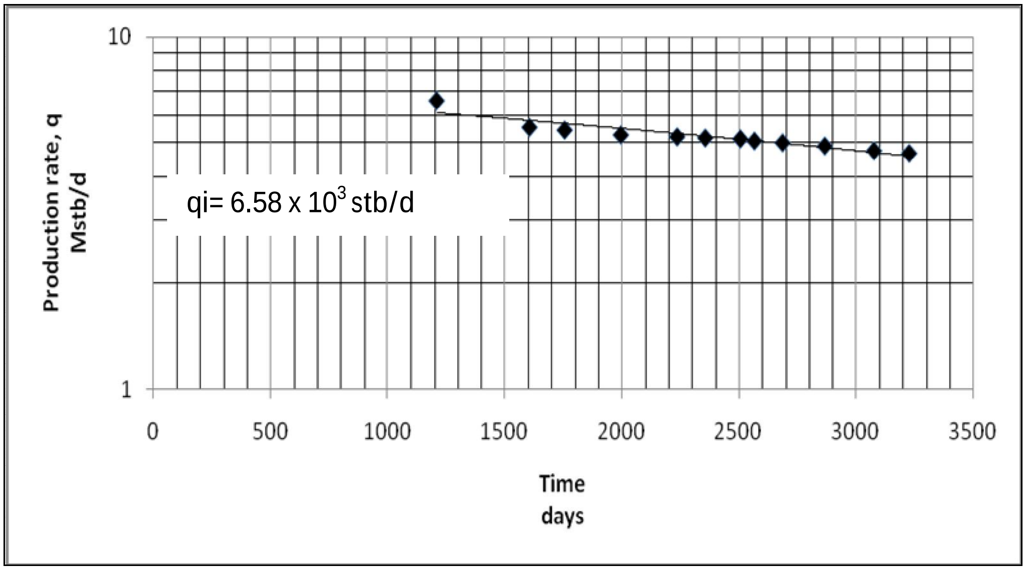


*Figure 5: Semi-log plot of production rate, q vs. time, days*

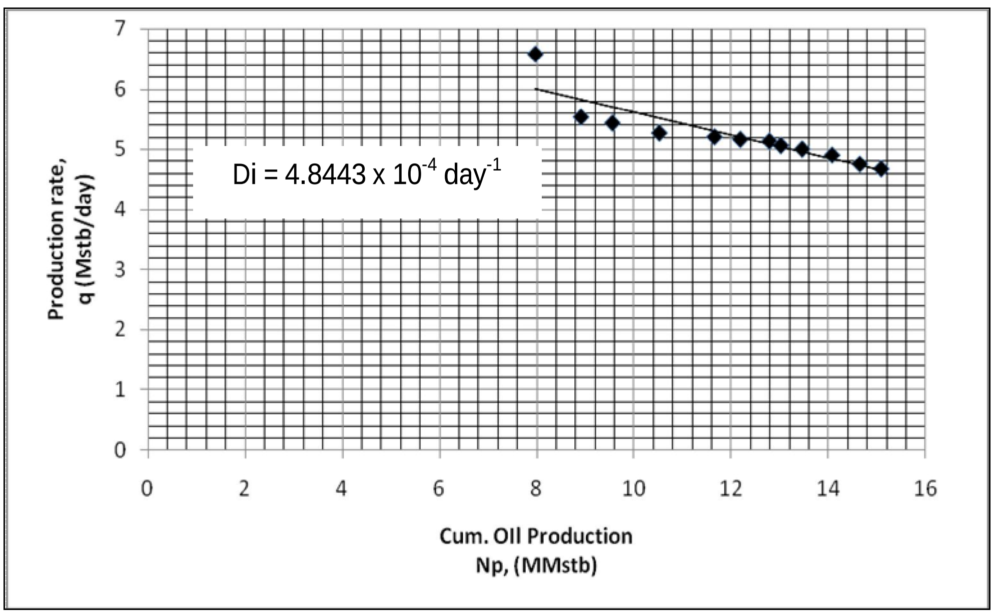


*Figure 6: Plot of production rate, q vs. cumulative production, Np*