International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

Material Balance and Decline Curve Analysis Used as Procedure for Estimating Reserves (A case study of D4 and W1 Fields)

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Abstract-Reserves are frequently estimated before drilling or any subsurface development, during the development drilling of the field, after some performance data are available and after performance trends are established1.Several techniques have been developed for estimating and evaluating reserves2.This study therefore aimed at comparing material balance and decline curve analysis using two fields as a case study. These are D4 Sand Guico field4 as D4 field, and Wedged Shaped field taken as W13.The material balance method was carried out using the PVT(Pressure, Volume, and Temperature), and production histories of the reservoirs to estimate the reserve. 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 produceable oil and consequently the stock tank oil initially in place (STOIIP) when the decline curve analysis was used.

Since the reserves used, that is, D4 Sand Guico field and the Wedged Shaped field 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.

Keywords-Reserves, Reservoir, Drilling,, Material Balance, Decline Curve Analysis, stock tank oil initially in place

1.0 INTRODUCTION

Reserve estimation is simply evaluating or assessing a particular reservoir. One major reason for the estimates of reserves is for management decisions which are seen in the formulation of policies for:

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

1.01 Material Balance Method

The material balance equation (MBE) has been used by reservoir engineers for a long time as the basic tool for interpreting and predicting performance. When properly applied, the MBE can be used to;

- Estimate initial hydrocarbon volumes in place
- Predict future reservoir performance
- Predict ultimate hydrocarbon recovery under various types of primary driving mechanisms.4

Schilthuis in 1941 was the first to present the general form of the material balance equation. The equation is derived as a volume balance which equates the cumulative observed production, expressed as an underground withdrawal to the expansion of the fluids in the reservoir resulting from a finite pressure drop5.

Evaluating the volume balance in reservoir barrels, he obtained;

Underground withdrawal (rb) = Expansion of oil + originally dissolved gas (rb) + Expansion of gascap gas (rb) + Reduction in HCPV due to connate water expansion and decrease in the pore volume (rb)

Mathematically,

$$N_P\left(B_O + (R_S - R_{SI})B_g\right) = NB_{OI}\left[\frac{\left(B_{O}-B_{OI}\right)+\left(R_{SI}-R_S\right)B_g}{B_{OI}} + m\left(\frac{B_g}{B_{gI}} - 1\right) + (1+m)\left(\frac{C_w S_{wc} + C_f}{1-S_{wc}}\right)\Delta P\right] + (W_e - W_P)B_w \quad (1)$$

Approximately two decades after the work of Schilthuis , Havlena and Odeh (1963-4) presented two papers describing MBE as a technique of interpreting the MBE as an equation of a straight line, the first paper describes the technique, and the second illustrates the application to reservoir case histories of various fields.5,6

1.01 Decline Curve Method

Decline curve analysis is one of the most extensively used forms of data analysis employed in evaluating oil and gas reserves and predicting future performance. The decline curve analysis is based on the assumption that past production trends and their controlling factors will continue in the future and, therefore can be extrapolated and described by a mathematical expression.7

Most of the existing decline curve analysis techniques are based on the empirical Arps equation: exponential, hyperbolic, and harmonic equation. In 1945, Arps proposed that the "curvature" in production-rate-versus-time can be expressed mathematically by a member of the hyperbolic family equations.7,8

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

When sufficient production data are available and production is declining, the past production curves of individual wells, lease or field can be extended to indicate future performance4 and estimate initial hydrocarbon in place.

METHODOLOGY

In this work, two reserves considered; The D4 Sand, Guico field as D4; and the Wedged Shaped field as W1; are all combination reservoir drive mechanism.

- Material Balance Equation Methodology

Different methodology approach was used for both the D4 and E1fields:

- MBE applied to D4 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 (2)
  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)
  $$Et = Eo + \frac{mBti}{Bgi}Eg$$
  This equation was summarized as;
  $$Et = \frac{mBti(Bg - Bgi)}{Bgi} + (Bt - Bti) \qquad (3)$$
  Equation 2 was then used for the calculation at different pressures levels.
  Now the combination drive mechanism formula is;
  $$F = N\left(Eo + \frac{mBti}{Bgi}Eg\right) + C\sum \Delta PQ(\Delta t_D) \qquad (4)$$
  Where Eo = Bt – Bti
  C = consistency test which is a function of real time.
  Dividing both sides of the equation 4 by
  $$\left[Eo + m\left(\frac{mBti}{Bt}\right)Eg\right]$$
  Would give a basis of the plot to obtain the stock tank oil initially in place, N
  $$\frac{F}{\left[Eo + \frac{mBti}{Bgi}Eg\right]} = N + \frac{C\sum \Delta PQ(\Delta tD)}{\left[Eo + \frac{mBti}{Bgi}Eg\right]} \qquad (5)$$
- the water influx We, was calculated using the formula;
  $$We = \left[\sum_{i=0}^{n-1} \Delta P_i Q(\Delta t_D)\right] / E_t \qquad (6)$$
  Assumption made:
  The value of Q(tD) was assumed for all the pressure levels.
  i. The pressure drop, ΔP was calculated using the formula;
  $$\Delta P = \frac{P_{i-1} - P_{i+1}}{2} \qquad (7)$$
  ii. With Q(tD) 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 intercept N, which is the stock tank oil initially in place.
  - MBE applied to W1 field

a) The underground withdrawal, F; oil and dissolved gas expansion, Eo; and gascap gas expansion, Eg were first calculated using the following formulae:

i. F = NP (BO + (RP - Rs) Bg) + WP BW (rb) which is the underground withdrawal (8)

ii. EO = (BO - BOI) + (RSI- RS)Bg (rb / stb) which is the expansion of oil and its originally dissolved gas (9)

iii. Eg = $Boi\left(\frac{Bg}{Bgi}\right) - 1$ (10)
which is the expansion of the gascap gas

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 B_W is 1
- m = 0.4 was assumed for E1 field.

With these assumptions in place, the general material balance equation
F= N (Eo + mEg +Ef,w) +WeBw (rb) (11)

Reduced to;
F = N(Eo+mEg)+We (12)

Where
$$\frac{F}{Eo + mEg} = N + \frac{We}{Eo + mEg} \qquad (13)$$

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
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This was gotten as a result of dividing both sides of equation (12) by (Eo + mEg).
The calculation for F,Eo and Eg were done for each plateau pressure level(see table 1.0) .

b) Secondly, the water influx calculation was made using the Hurst and Van Everdingen method.
   i. First the dimensionless time, tD for E1 was given by the formula

$$t_d = \frac{4.57x10^{-7} kt}{\Phi \mu C_t A} \quad (14)$$

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

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

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

   This was gotten for the different time levels.

   iii. With the tD and ΔP in place, the water influx, We was calculated using the equation(see table 2.0);

$$We = U \sum_{i=0}^{n-1} \Delta PiWd\left(td - Tdi\right) \quad (16)$$

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

c) 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.

DECLINE CURVE ANALYSIS METHODOLOGY

For the two fields, D4 and W1, the same approach was used in calculating the decline curve.

1. 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;

$$q_t = q_i e^{-D_i t} \quad (17)$$

   All such plots on the semi-log graph showed a linear relationship, so it was concluded that the resources follow the empirical exponential model.
2. 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.
3. To obtain the maximum produceable oil from the reservoir, Npmax, the formula was used;

   Npmax = $\frac{qi}{Di}$ (18)

   "qi" was gotten when the straight line from the semi-log plot of production rate vs. time was extrapolated to t = 0.
4. 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 = NPmax + Cumulative produced oil up to the last year. (19)

DISCUSSION OF RESULTS

This work has investigated the quantitative analysis of D4 Sand Guico Field and the wedged shaped field using decline curve analysis and the material balance methods of reserve estimation. The results obtained for the two methods differ because of the different assumptions made, level of accuracy, and the diferent methods of approach.

The MBE treats a areservoir 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.

Unlike the MBE method, the DCA gives a higher confidence estimates of ultimate recovery. This is justified because one of the basic assumption upon which decline curve is used is that factors that influenced the curve in the past remain effective throughout the production life.

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

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.

SIGNIFICANCE OF THE RESULTS

The values of STOIIP obtained from both DCA and MBE are of paramount importance to the reservoir engineer, production engineer as well as to the operating company.

For instance, the wedged shaped reservoir has a higher value of STOIIP of 197.23 MMstb and 200.5 MMstb for both DCA and MBE, and a lower decline rate of 2.293 x 10-4.Thus, exploitation of W1 field will be justifiable when compared with D4. This is due its lower decline rate coupled with the fact that it has a higher volume of reserve.

This can be compared with D4 field with 28.675 MMstb and 29 MMstb from DCA and MBE, and the higher decline rate of 4.8443 x 10-4. By implication, its volume does not justify exploitation.

From the foregoing, based on the results, the wedged shaped reservoir is favourably disposed to be exploited and will yield greater profit than the D4 reservoir. This objectivity in results is highly needed by the operating company whose major aim is to maximize profit at minimum cost.

CONCLUSION

Decline curve analysis and material balance have been used in estimating two different reservoirs: that is the D4 Sand Guico Field and the wedged shaped 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 Wedged Shaped reservoir and D4 Sand, Guico field were gotten as: 2.293 x 10-4 day-1 and 4.8443 x 10-4 day-1 respectively. Their corresponding values of STOIIP for each using decline curve method were: 197.23MMstb and 28.675MMstb respectively.

Using the material balance method, the STOIIP of the Wedged Shaped reservoir was gotten by plotting the variables F/ (Eo + mEg) against We/ (Eo + mEg) on a cartesian graph to obtain 200.5MMstb. For the D4 Sand, Guico field, plotting the variables F/ Et against [∑ΔPQ(ΔtD)]/ 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.

RECOMMENDATION

After a quantitative analysis of the D4 Sand Guico Field and the wedged shaped field, the following recommendations are made:

1.The operating companies are required to pay more attention to the accuracy of reserve estimation and are adviced to re-evaluate reservoir at frequent intervals of years to update the result with the production performance of the reservoir. This will ensure the companies' profitability, effective reservoir management, sound/effective decision making.

2.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.

3.It's one thing to have a good data, it's yet another to have competent hands for the estimation. Operating companies should pay close attention to whoever does the estimation for them.

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

5.The Monte Carlo simulation model can still be run for three reservoirs to help decision makers to obtain the probability distribution and other statistics. Eleke field offers a high degree of certainty.

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

The D4 Sand Guico field, D4

Table 1.0: The water influx table of values:

ΔP (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 104 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 2.0: Material balance table of values:

Pressure (psig)	Et (rb / stb)	F MMbbl	F / Et MMstb	$\left[\sum \Delta PQ(\Delta t_D)\right] / E_t$ X 104
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

The slope, U = 667.0 rb / psi

The stock tank oil initially in place, N = 29MMstb.

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

Table 3.0: Values of water influx for the Wedged Shaped field, W1

Td	Wd(td)	Pressure drop ΔP (psi)	We (Mrb)
0	0	120	0
5.67	4.88	225	0.586
11.34	7.46	195.5	2.00
17.01	9.10	170.5	3.723
22.68	10.09	145.5	5.549
28.35	10.83	123.5	7.331
34.09	11.27	105	9.001
36.69	11.52	33.5	10.514
45.36	11.69	64.0	11.583
51.03	11.81	97.5	12.561
56.70	11.89		13.628

Table 4.0: Values for the MBE equation for the W1

Pressure (psia)	F MMrb	Eo Rb/stb	Eg Rb/stb	mEg	Eo + mEg	We Mrb	F/ (Eo + mEg) MMrb	We/ (Eo + mEg) Mrb
2740 (pi)	-	-	-	-	-	-	-	-
2500	12.124	0.0268	0.07548	0.03019	0.0570	0.586	212.70	10.281
2590	30.761	0.0574	0.2114	0.0846	0.1420	2.000	216.69	14.088
2109	52.826	0.0923	0.3623	0.1450	0.2370	3.372	222.69	14.23
1949	79.791	0.1411	0.5284	0.2114	0.3525	5.549	226.40	15.74
1818	105.964	0.1881	0.6499	0.2600	0.4481	7.331	236.47	16.36
1702	132.292	0.2380	0.8605	0.3442	0.5822	9.001	227.23	15.46
1608	157.080	0.2862	1.0115	0.4046	0.6908	10.514	227.39	15.21
1635	179.177	0.3299	1.1625	0.4650	0.7949	11.583	225.41	14.57
1480	196.654	0.3630	1.2530	0.5012	0.8642	12.561	227.56	14.53
1440	210.743	0.3895	1.3436	0.5374	0.9269	13.628	227.36	14.70

The slope, U = 6453.2 rb/psi

The intercept, N = 200.5 MMstb.

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
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RESULTS FOR DECLINE CURVE ANALYSIS

1. Table 5.0: Values for the D4 Sand, Guico

Time (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

1. Table 6.0: Values for the Wedged Shaped field, W1

Date	Production rate (stb/d)	Cumulative Oil Production (Np) Mstb
0	0	0
365	21.59	7.88
730	25.23	18.42
1095	26.62	29.15
1460	27.87	40.69
1825	27.47	50.14
2190	26.68	58.42
2555	25.59	65.39
2920	24.23	70.74
3285	22.69	74.54
3600	21.21	77.43

Table 7.0: A table showing the values of D, Npmax andd STOIIP for the two fields is shown below.

	D (Day-1)	Npmax (MMstb)	STOIIP (MMstb)
D4 Sand field	4.8443 x 10-4	13.583	28.675
Wedged Shaped field	2.293 x 10-4	119.8	197.23

Table 8.0: Comparing the results of DCA and MBE STOIIP values of the two fields

	DCA (MMstb)	MBE (MMstb)
D4 Sand field	28.675	29.0
Wedged Shaped field	197.23	200.5

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

Results

Table 9.0: Results for the three fields

	Decline Rate (Day-1)	Decline Curve Value of STOIIP (N)	Material Balance Value of STOIIP (N)
D4 Sand Guico Field Reservoir	4.8443 x 10-4	28.675 MMstb	29 MMstb
Wedged Shaped Reservoir	2.293 x 10-4	197.23 MMstb	200.5 MMstb

3. Material Balance Plot of the Wedged Shaped Reservoir

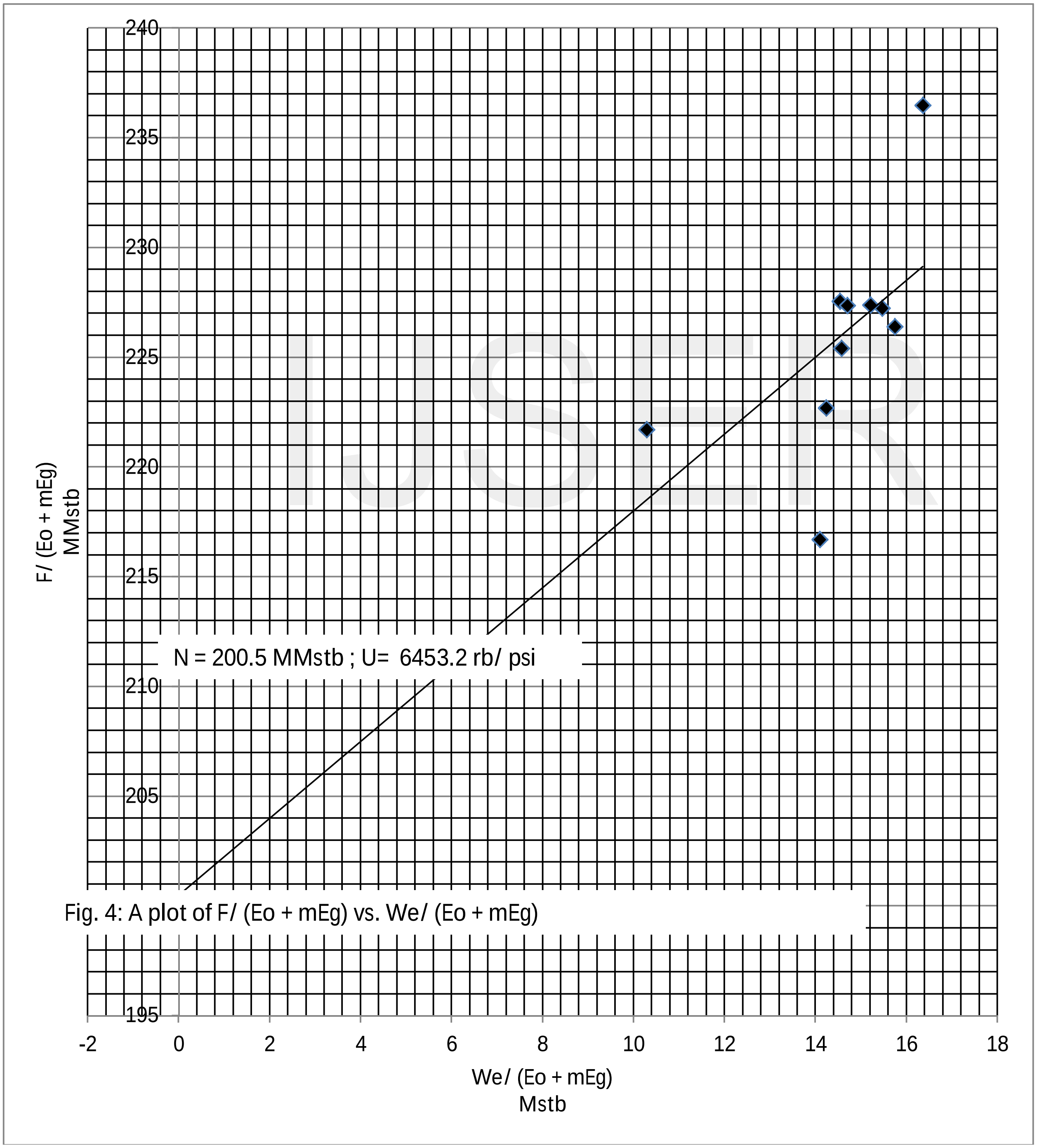

Fig. 4: A plot of F/ (Eo + mEg) vs. We/ (Eo + mEg)

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

4. Decline Curve Analysis graphs for Wedged Shaped Field.

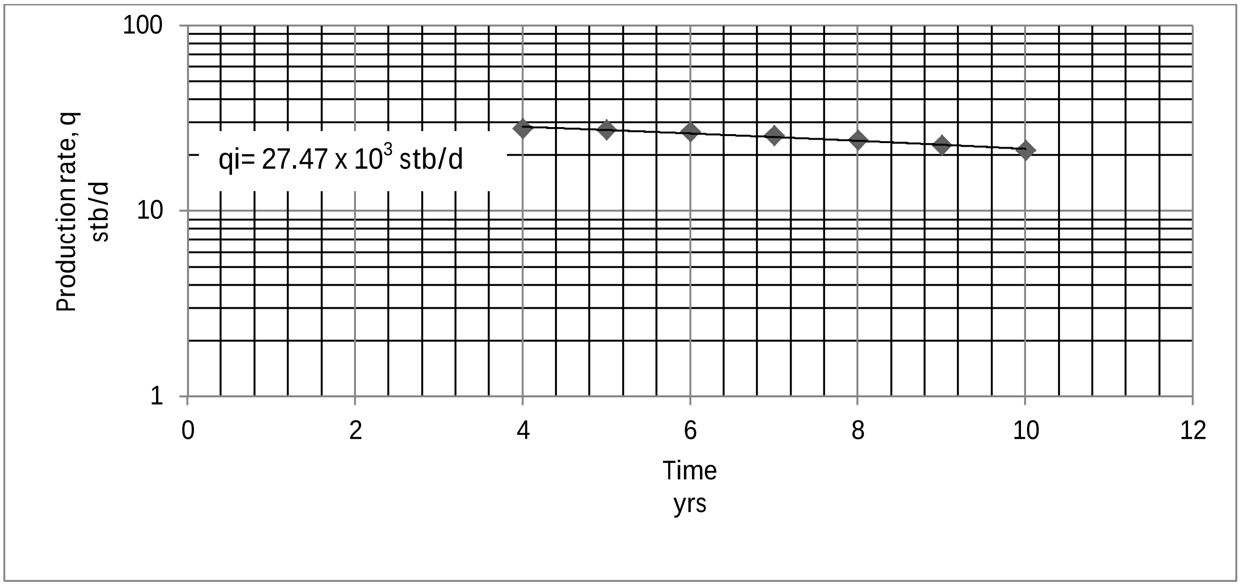

Fig. 5: Semi-log plot of production rate, q vs. time, yrs

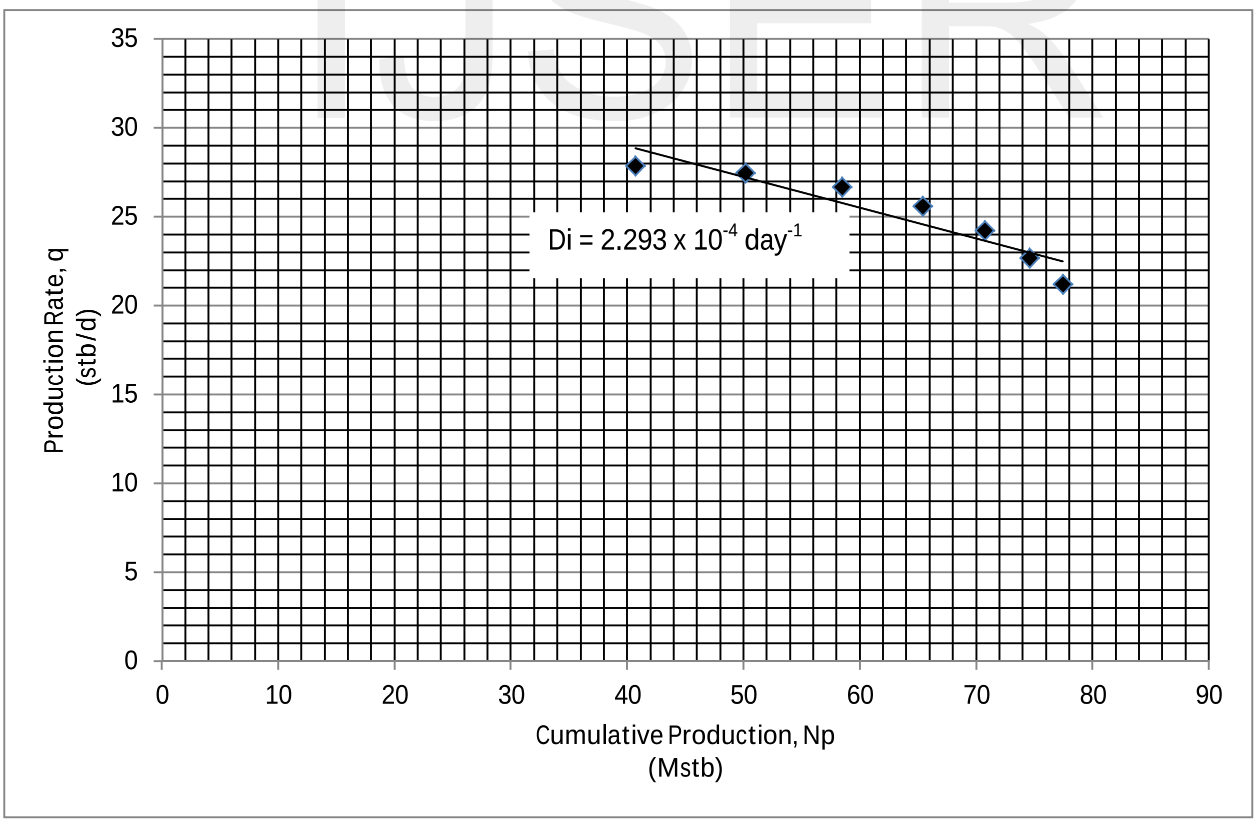

Fig. 6: Plot of production rate, q vs. cumulative production, Np

International Journal of Scientific & Engineering Research, Volume 5, Issue 12, December-2014
ISSN 2229-5518

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