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Material Balance and Decline Curve Analysis Used as a Means for Estimating Reserves: A Case Study of E1 and W1 Fields

O.A.Omoniyi and S.Adeolu

Department of Petroleum Engineering
Abubakar Tafawa Balewa University Bauchi, Bauchi State, Nigeria

ABSTRACT

The lifestyle of the 20th century man has been influenced more by oil and gas than any other natural resource and indications are that oil and gas reserve will increase in importance the remainder of this century. Based on the foregoing, many petroleum engineers spend a major part of their professional capabilities, along with new methods and techniques for improving these estimates.[1]
Reserve estimation is just what they are called-estimates. As with any estimate, they can be no better than the available data on which they are based, and are subject to the experience of the estimator[7].
Estimation of reserves using material balance and decline curve analysis seek to answer the question of reserve evaluation based on performance trend. Though there are several reservoir estimation techniques, only these two were used in this work.
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 approach was used. Since the reserves used, that is, the Eleke field taken as E1[2], and Wedged Shaped field[3] taken as W1 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.

INTRODUCTION

Reservoir estimation is a very crucial part of reserve management, exploitation, exploration and production. In reserve estimation, the goal is to principally evaluate a reservoir so as to be able to estimate, assess, the stock oil initially in place (STOIIP) as well as analyze past and present performance of the reservoir.

To improve the clarity of these estimations, several reserve estimation techniques are employed and the techniques implemented by the petroleum engineer depend on the quality and maturity of the data available. There's just one reason for doing that: estimation of oil and gas reserves are inherently uncertain. More so, the extent and nature of the commercially recoverable hydrocarbons from the subsurface cannot be determined with a high degree of precision because recoveries from subsurface reservoirs depend largely on the heterogeneities of the reservoir rock and the type of reservoir drive mechanism.

One man that did an extensive work in oil and gas reserves classification, estimation and evaluation is Forest, A. G.[1]. According to him, reserve estimation methods are:

1. Analogy
2. Volumetric Methods
3. Performance Techniques

i. Numerical Simulation Models
ii. Material Balance Method
iii. 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 that can provide useful information. Actually, before a reservoir is drilled, prospective reserves are usually estimated on this basis.

In the volumetric method of estimating 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 by this formula;

$$N = \frac{7758 A h \phi S_{oi}}{B_{oi}}$$

Where;

$$7758 = \frac{43560\, ft^2 / AC}{5.614\, ft^3 / bbl}$$

N = original oil in place, OOIP, stb; A = area, acre; h = average thickness, ft; ϕ = average porosity fraction, fraction; S_{Oi} = initial oil saturation, fraction; B_{Oi} = initial oil formation volume factor, rb/stb; rb = reservoir barrel; stb = stock tank barrel.

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 that 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.

METHODOLOGY

In this study, two reserves were considered; The Eleke field which is termed E1; and the Wedged Shaped field as W1 are all combination reservoir drive mechanism.

- **Material Balance Equation Methodology**

The same methodology approach was used for E1 and W1 fields.

For E1 and W1 fields:

a) The underground withdrawal, F; oil and dissolved gas expansion, E_O; and gascap gas expansion, E_g were first calculated for both fields using the following formulae:

i. $F = N_P (B_O + (R_P - R_S) B_g) + W_P B_W$(rb)

which is the underground withdrawal (1)

ii. $E_O = (B_O - B_{Oi}) + (R_{Si} - R_S)B_g$ (rb/ stb)

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

iii. $E_g = Boi\left(\frac{Bg}{Bgi}\right) - 1$

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, was assumed different for both; i.e. m = 0.7 for E1 field and m = 0.4 for W1 field.

With these assumptions in place, the general material balance equation

$F = N(Eo + mEg + Ef,w) + We\ Bw$ (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 $(E_O + mE_g)$.

The calculation for F, E_O and E_g 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, t_D for E1 was given by the formula

$$t_d = \frac{4.57 \times 10^{-7} kt}{\Phi \mu C_t A} \quad (7)$$

the reason being that the aquifer oil leg area A was given, but for W1 field t_D was

$$t_d = \frac{6.34 \times 10^{-3} kt}{\Phi \mu C_t r_o^2} \quad (8)$$

ii. The pressure drop, ΔP was then calculated for both using the formula(see table

2.0);

$$\Delta Pi = \frac{P_{i-1} - P_{i+1}}{2} \quad (9)$$

This was gotten for the different time levels.

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

$$We = U \sum_{i=0}^{n-1} \Delta PiWd\left(td - Tdi\right) \quad (10)$$

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.

c) Lastly, a table was incorporated which was principally done on Excel spreadsheet to calculate (E_O + mE_g) for the different pressures and the consequent fractions of F/ (E_O + mE_g) and We/ (E_O + mE_g)

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

A graph of F/ (E_O + mE_g) vs. We/ (E_O + mE_g) 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.

RESULTS OF THE MATERIAL BALANCE METHOD

Material balance method table of values.

Table 1.0: MBE values for Eleke field, E1

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 2.0: Values for water influx of the Eleke field

Td	Wd(td)	Pressure drop ΔP (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

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

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.

DECLINE CURVE ANALYSIS METHODOLOGY

For the two fields, E1, 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;

$$q_t = q_i e^{-D_i t} \quad (11)$$

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, Np_{max}, the formula was used;

$$Np_{max} = \frac{qi}{Di} \quad (12)$$

"qi" was gotten when the straight line from the semi-log plot of production rate vs. time was extrapolated to t = 0.

4. The stock tank oil initially in place (STOIIP) was gotten by adding the cumulative production up to the last year and the maximum produceable oil. The formula is given by;

STOIIP = Np_{max} + Cumulative produced oil up to the last year. (13)

RESULTS FOR DECLINE CURVE ANALYSIS

Table 5.0: Values for Eleke field

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

	D (Day^{-1})	Np_{max} (MMstb)	STOIIP (MMstb)
Eleke field	2.059 x 10^{-2}	311.36	327.93
Wedged Shaped field	2.293 x 10^{-4}	119.8	197.23

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

	DCA (MMstb)	MBE (MMstb)
Eleke field	327.93	330
Wedged Shaped field	197.23	200.5

Results

Table 9:Results for the two fields

	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
Wedged Shaped Reservoir	2.293 x 10^{-4}	197.23 MMstb	200.5 MMstb

1. Material Balance Graph of Eleke Field

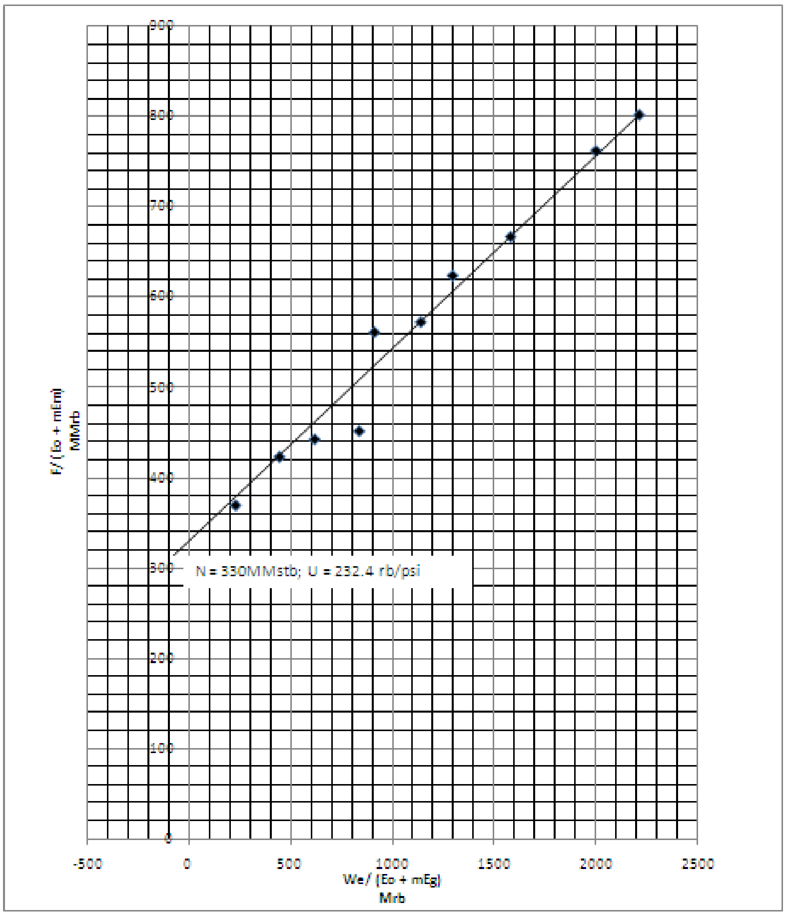

Fig. 1: A plot F/ (Eo + m Eg) vs We/ (Eo + mEg)

2. Decline Curve Graphs of the Eleke Field.

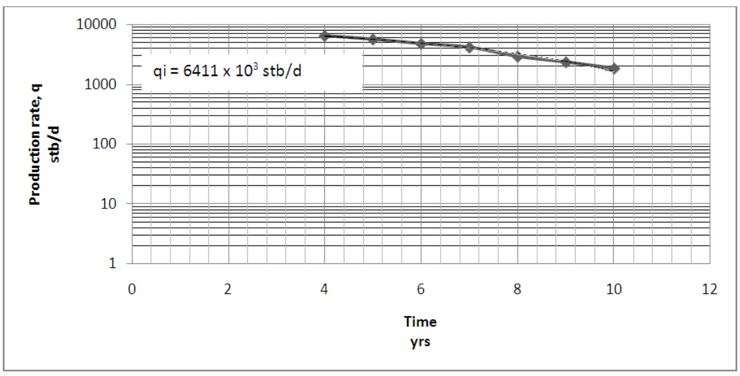

Fig. 2: Semi-log plot of production rate, q vs. time, yrs

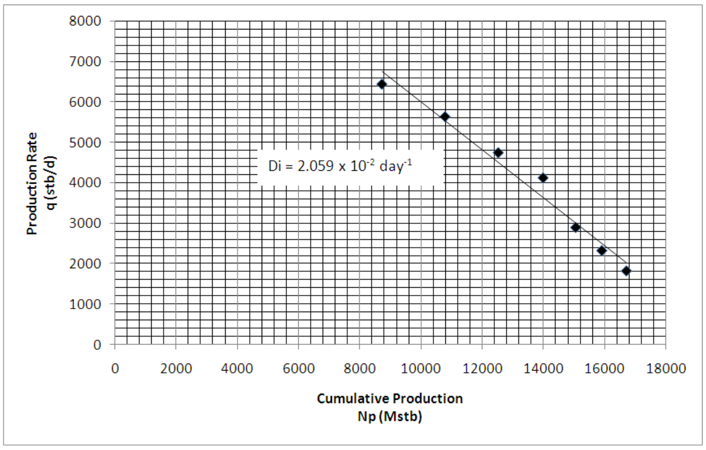

Fig. 3: Plot of production rate, q vs. cumulative production rate, Np

3. Material Balance Plot of the Wedged Shaped Reservoir.

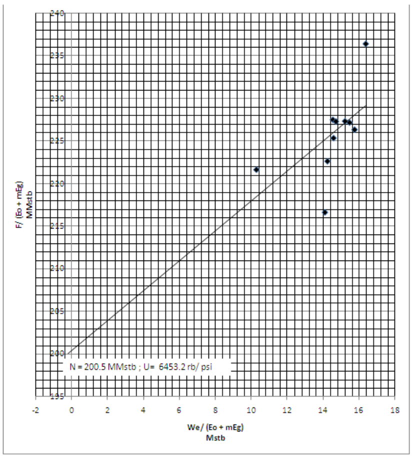

Fig. 4: A plot of F/ (Eo + mEg) vs. We/ (Eo + mEg)

4. Decline Curve Analysis graphs for Wedged Shaped Field.

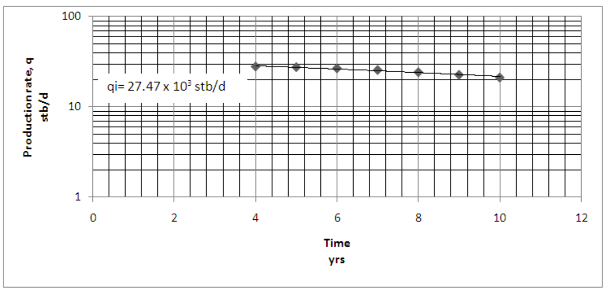

Fig. 5: Semi-log plot of production rate, q vs. time, yrs

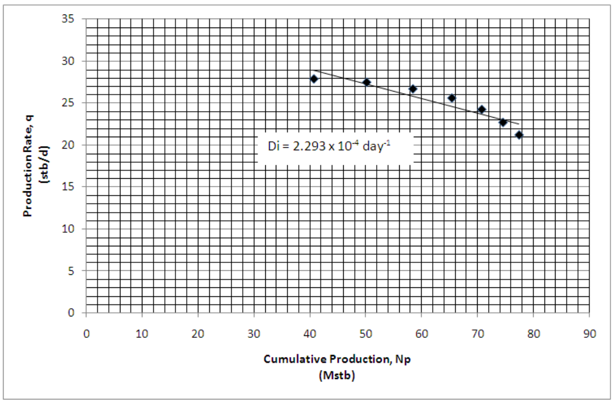

Fig. 6: Plot of production rate, q vs. cumulative production, Np

DISCUSSION OF RESULTS

Decline curve analysis (DCA) and the material balance equation (MBE) were used in this work to estimate the stock tank oil initially in place (STOIIP) of two different reservoirs, that is, Eleke field, and the Wedged Shaped reservoir..

The closeness to which the several values of the STOIIP gotten from each method shows a very important 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.

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.

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.

Therefore, 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.Therefore 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 the other two.

SIGNIFICANCE OF THE RESULTS

The values of STOIIP 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 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 implies greater profit for the owners of the well.

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

CONCLUSION

In this work, the decline curve analysis (DCA) and material balance (MBE) method were used in estimating two different reserves, that is; Eleke field, and the Wedged Shaped reservoir 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 the Wedged Shaped reservoir were gotten as: 2.059 x 10^{-2} day^{-1},and 2.293 x 10^{-4} day^{-1}respectively. Their corresponding values of STOIIP for each using decline curve method were: 327.93MMstb and 197.23MMstb respectively.

Using the mterial balance method, the STOIIP of Eleke and Wedged Shaped reservoir were gotten by plotting the variables F/ (Eo + mEg) against We/ (Eo + mEg) on a cartesian graph to obtain; 330MMstb and 200.5MMstb respectively.

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

1. For both material balance and decline curve analysis, the production data to be used should be carefully obtained.
2. 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.
3. It is also recommended that, 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.

4. Eleke field has a higher value of STOIIP. To maximise profit, operating companies can exploit it first because it would offset cost of production.
5. 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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