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Application of dynamic material balance to evaluate oil wells in Buzurgan oil field

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Abstract

The Material Balance Equation is a crucial tool utilized in reservoir studies to evaluate fluids and rock properties at static pressures. The Flowing and Dynamic Material Balance methods offer a significant advantage by avoiding the requirement to shut down wells, as they use flowing pressure instead of static pressure under constant or variable flow rates. The concept of "Dynamic Material Balance" involves converting the bottom hole flowing pressure at any point at any given time to the average reservoir pressure at that point. This allows for the use of classical material balance calculations and the development of classical material balance plots. In this study, the Dynamic Material Balance and Agrawal Type Curve techniques were used to estimate average reservoir pressures, initial hydrocarbon in place, and ultimate oil recovery for a well in the Mishrif reservoir, the main reservoir in the Buzurgan oil field. Many wells in this field experience problems such as high-pressure decline or continuous water production, necessitating ongoing evaluation. While the Dynamic Material Balance method focuses on boundary-dominated flow data, the Agrawal-type curve technique analyzes data from both transient and boundary flow periods. Agarwal decline curves were constructed using relationships of pseudo pressure normalized production, material balance pseudo time, and dimensionless variables in well-test analysis. The results from both methods showed comparable results with an absolute percentage error of (0.738) %, (3.07) %, and 5.7% for oil-in-place, drainage area, and average reservoir pressure, respectively. This strong correlation between the Dynamic Material Balance and Type Curve results indicates their accuracy and reliability.

Keywords: *flowing material balance; dynamic material balance; type curves; Agrawal type curve.*

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1- Introduction

Estimating hydrocarbons in place in oil or gas reservoirs is required from the point of discovery until drilling further wells for development. These estimations are essential in determining the economic sustainability of a development project and recording regulatory reserves. The major techniques for calculating and estimating hydrocarbon-in-place include the volumetric method, the material balance technique, decline curves analysis methods, and the use of numerical simulation. Material balance has been applied as a simple yet powerful approach for determining the original oil or gas in place using actual production performance data. Correct assessment of the original oil or gas in place is critical for reservoir management or field development decision-making [1].

Mattar and McNeil [2] proposed a flowing material balance approach, which removes the constraint of shutting in wells and enables material balance computations to be done under dynamic reservoir conditions making use of flowing pressures & rates that remain constant. A constant rate of production over an extended period is one of the most challenging production requirements for most producing fields.

Mattar et al. [3] provide the Dynamic Material Balance approach, and there has recently been an increased focus on this method and its expected outcomes. The dynamic material balance is an alternative to 'flowing material balance' that can be used for both constant and variable rates. Because it is not constrained by static pressure in the reservoir, the 'dynamic material balance' approach can be applied to both gas and oil reservoirs [4].

Sun [5] stated that there are other similar methods for evaluating wells, but they are more advanced, such as the method of 'Type Curve Analysis. This method is a more advanced method for calculating the original hydrocarbon in place. The purpose of 'type curve analysis' is to identify a type curve that corresponds to the real reaction of the wells & reservoirs during the test. The dimensionless parameters that define that type of curve can then be utilized to calculate reservoirs and wells parameters like permeability and skin [6].

Agarwal et al. [7] formed decline-type curves for analyzing the production data of the field. Their methods are based on the findings of Fetkovich [8], and Blasingame et al. [9], who used the concept of equivalents of constant flow & constant pressure solutions to develop their methods. Agarwal and Gardner, give dimensionless

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type curves based on standard well tests. They provide charts for both the primary and semi-log pressure derivatives. Furthermore, their decline curves are presented in forms other than the standard normalization rates versus the time plot. The rate vs. cumulative or cumulative vs. time analysis curves are examples of these. A semi-log integral derivative curve is supplied along with the semi-log derivative.

This study investigates the use of dynamic material balance as a technique for estimating reserves and ultimate oil recovery (UOR) in one of Iraq's currently producing oil fields in the country's south- the Buzurgan oil field, Mishrif formation (a major reservoir in southern Iraq). The Buzurgan field is located 40 kilometers north of Amara in southern Iraq, near the Iranian border. The Buzurgan Field is composed of two domes: the north and the south dome. The north dome measures 16 km × 6 km, while the south dome measures 23 km x 8 km [10]. The Mishirif formation consists of bio-clastic, cavernous, and occasionally limestone interbeds, along with crystalline to micron-sized limestone, lightweight to medium-hard limestone, recrystallized and chalky in parts, with limestone. The thickness ranges between 331 and 373 meters [11].

2- Methodology

2.1. Flowing material balance

Al-Fatlawi et al. [12] detailed a gas material balance approach for determining gas in place during constant rate production without shut-in. The study assumes that pressure decreases uniformly throughout the reservoir under constant rate boundary-dominated flow, as illustrated in Fig. 1. This means that the pressure drop observed in the wellbore is similar to the pressure decline recorded across the reservoir. The researcher then shifted the negative slope straight line shown by drawing a sand face or the wellhead pressure (p_{wf}/z, p_{wh}/z) versus the accumulative rate of production with respect to the initial pressure in the reservoir or the initial pressure at the wellhead (p_{ri}/z_i, p_{whi}/z_i) to get gas in place on the x-axis intercept Fig. 2.

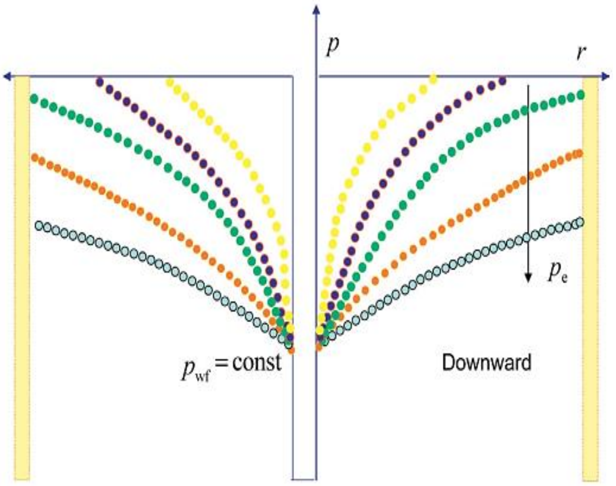

Fig. 1. Pressure drop during the boundary-dominated flow

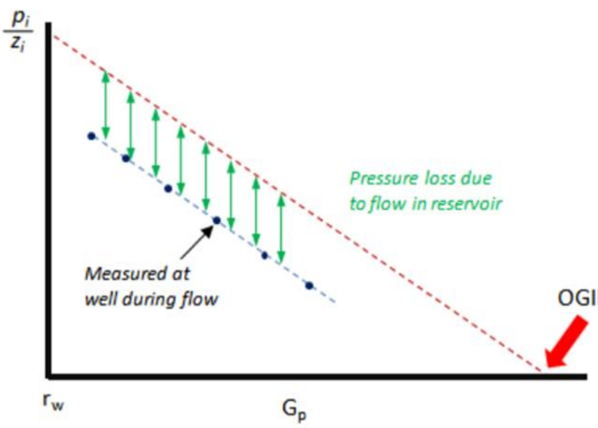

Fig. 2. P/zi graph for pseudo steady state condition, the flowing material balance Method runs parallel to the Pwf/z line

2.2. Dynamic material balance

The "Dynamic Material Balance" technique converts flowing pressure in any location in time to the reservoir's average pressure at that instant. Following that, a classical material balance plot can be created using the procedure of traditional material balance calculations [13].

a- Mattar et al. oil dynamic material balance method

Hago [14] explained the method of Mattar et al. [3], which proposed a mathematical theory called 'dynamic material balance' which begins with a well-known formula for pseudo-steady-state flow for oil wells above bubble point pressure and flowing with a constant rate.

$$p_D = \frac{2t_D}{r_{eD}^2} + \left(\ln r_{cD} - \frac{3}{4}\right) \tag{1}$$

Where: $P_D = \frac{(P_i - P)kh}{141.2qB_o\mu_o}$, $t_D = \frac{2.637\times10^{-4}kt\times24}{\phi\mu_o c r_w^2}$, $r_{eD} = \frac{r_e}{r_w}$

$$(P_i - P_{wf}) = \frac{141.2B_o\mu_o q}{kh}\frac{2r_w^2}{r_e^2}\frac{2.637\times10^{-4}kt\times24}{\phi\mu c r_w^2} + (141.2Bo\ \mu o\ q)/kh\ (ln(re/rw\ ) - 3/4) \tag{2}$$

$$p_i - p_{wf} = \frac{qt}{c_t N} + \frac{141.2qB\mu}{kh}\left[\left(\ln\frac{r_e}{r_{wa}}\right) - \frac{3}{4}\right] \tag{3}$$

Let:

$$b_{pss} = \frac{141.2B_o\mu_o}{kh}\left(\ln\left(\frac{r_e}{r_w}\right) - \frac{3}{4}\right) \tag{4}$$

bpss corresponds PSS constant and represents the reciprocal of the productivity index.

$$p_i - p_{wf} = \frac{qt}{c_t N} + b_{pss} \times q \tag{5}$$

Recognize that qt in Eq.5 corresponds to cumulative production (Np)

$$p_i - \bar{p}_R = \frac{N_p}{c_t N} = \frac{qt}{c_t N} \tag{6}$$

Combining Eqs. 5 and 6:

$$\bar{p}_R - p_{wf} = b_{pss} \times q$$
$$\bar{p}_R = p_{wf} + b_{pss} \times q \qquad (7)$$

If b_{pss} known, then the average pressure in the reservoir can determined at any time by determining the flowing pressure and then adding the value of $b_{pss} \times q$, that q is the current flow rate.

By modifying the Eq. 3 into the following form, b_{pss} might be calculated:

$$\frac{(p_i - p_{wf})}{q} = \frac{qt}{c_t N q} + b_{pss} = \frac{Np}{c_t N q} + b_{pss} \qquad (8)$$

The terms (Pi -p_{wf})/q and (Np/q) of Eq. 8 can then be drawn on the y- and x-axes of a cartesian plotting respectively. This plot's outputs are 1/ Nct from the slope of the curve and bpss from the point of intersection, which give an estimated OOIP and the productivity index for every well, respectively (Fig. 3).

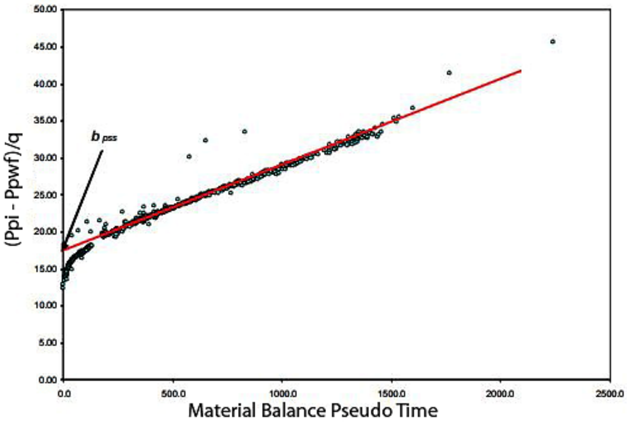

Fig. 3. Ideal case for dynamic material balance (Mattar and Anderson 2005)

b- Agarwal et al. dynamic material balance method

By replacing the time of flow with material balance time (tc), the previous approach of (b_{pss}) remains valid for a variable rate of production.
For an oil well, Eq. 8 can be expressed as:

$$p_i - p_{wf} = \frac{qtc}{c_t N} + b_{pss} \times q \qquad (9)$$

Multiplying $\frac{q}{(p_i - p_{wf}) \times b_{pss}}$ at both sides of Eq. 9

$$\frac{q}{\Delta p} = -\frac{N_p}{b_{pss}\, N \Delta P C_t} + \frac{1}{b_{pss}} \qquad (10)$$

Plot the $\frac{q}{\Delta p}$ vs. $\frac{N_p}{\Delta P C_t}$ curve as in (Fig. 4) and use the regression results to get the reserves N.

The dynamic material balance approach can be applied to all types of reservoirs since it is not restricted by constant pressure measurements.

The procedure for this technique in the oil wells seems quite simple. The following steps describe this procedure:

1- Determine the normalized cumulative production.
2-

$$Q_n = \frac{Q}{C_t\,\Delta p} \qquad (11)$$

3- Plot $\frac{q}{\Delta p}$ versus Q_n
4- Try to find the best possible straight-line fit to the data.
5- Extrapolate the data to the X-axis and identify the intercept point; the intercept number is the original oil-in-place value.
6- Determine a proper recovery factor (RF) for estimating the ultimate recovery of oil (EUR).

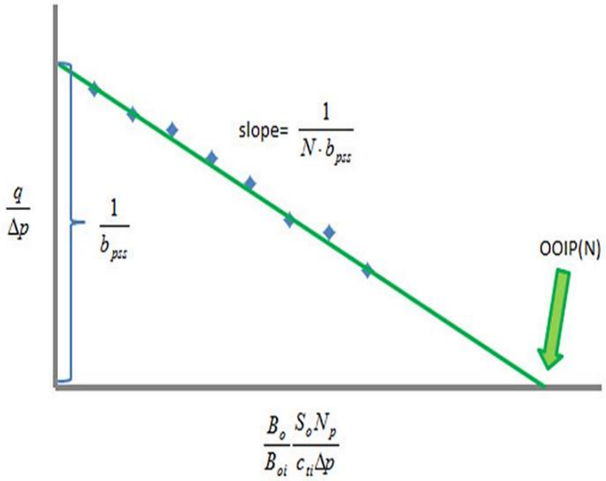

Fig. 4. Agarwal-Gardner plot of normalized rate versus normalized cumulative

3- Results and discussions

The 'dynamic material balance' technique was used to analyze the production data from well BU-46. This is a horizontal production well drilled in 2014 in the Buzurgan oil field. BU- 46 began with natural production in May of 2015, with an initial capacity of 3000 bbl/d [15]. The oil rate and WHP have currently fallen to 1800 bbl/d and 23 kg/cm^2, respectively, without water production. In this study, production data from the years 2015 through 2019 was analyzed. During the boundary-dominated flow period, it is objective to determine the initial oil in place, ultimate recovery of oil (EUR), and productivity index (PI). Table 1 provides the necessary reservoir and oil well information. Fig. 5 shows the well's production data. The slightly scatter data in this figure may not have significant effects on production forecasts, hence it is still considered to be high-quality data.

Table 1. Reservoir basic parameters

Property	**Value**
Reservoir temperature, °F	235
Porosity, %	20
Initial oil saturation, %	80
Initial water saturation, %	20
Total compressibility, 1/psi	1.433369×10^{-5}
Wellbore radius, ft	0.583
Net pay, ft	105
Bubble point pressure, psi	2660
Oil gravity, API	24.85
Initial formation volume factor, bbl/stb	1.349
Solution gas oil ratio, scf/bbl	634
Oil compressibility, 1/psi	1.25783×10^{-5}
Density @ pi & Ti, Ib/ft^3	46.0357
Oil viscosity @ pi & Ti, cp	1.0737

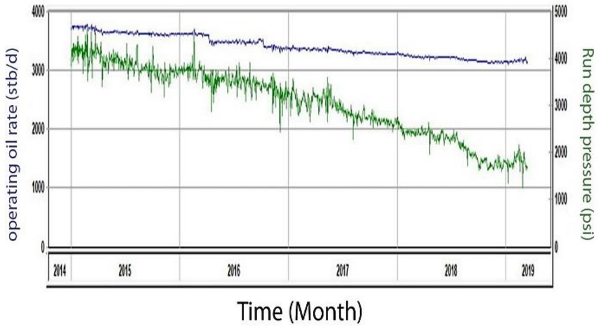

Fig. 5. Production rate and bottom hole flowing pressure of well BU-46

3.1. Dynamic material balance plot

The production data from well BU-46 during the boundary-dominated flow period has been analyzed using the dynamic material balance technique. Fig. 6 shows the BU-46 well's oil production normalized rate vs. normalized cumulative production. Since most of the data in this well were collected during the boundary-dominated flow period and dynamic material balance was used to interpret the data at this time, a straight line that fit the data of these wells was quite clear as shown in Fig. 6. The intercept of this straight line with the x-axis gives the value of original oil in place in stb/day and from the slope of this straight line, we can get that the value of b_{pss} corresponds PSS constant represents the reciprocal of the productivity index. Also, if b_{pss} known, then the average pressure in the reservoir can determined at any time by determining the flowing pressure and then adding the value of b_{pss} × q, that q is the current flow rate.

The dynamic material balancing technique estimates the original oil in place (OOIP) and the ultimate recoverable of 128242.0749 Mstb and 38472.6224 Mstb. The drainage area and Productivity index of 1327.097 acres and 2.9369 (bbl/d)/psi, respectively.

The average pressure in the reservoir is determined for every flowing pressure point. Converting average pressure to flowing pressure requires taking into account variations in flow rate in this well [16].

$$PI = \frac{1}{b_{pss}} \tag{12}$$

$$p^{-} = p_{wf} + qb_{pss} \tag{13}$$

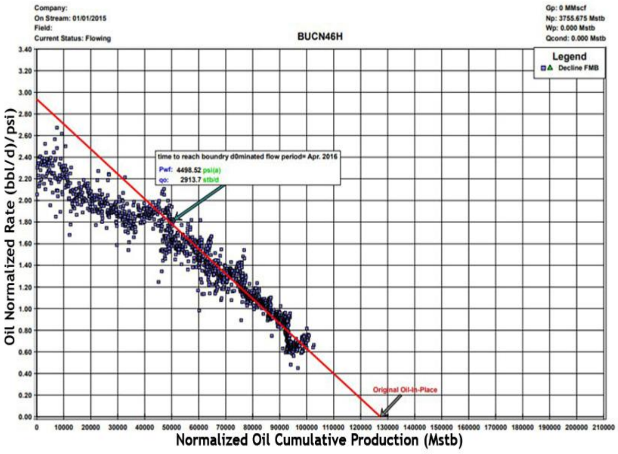

Fig. 6. Dynamic material balance for well BUH-46

Fig. 7 is a graph of calculated average pressure with respect to time. This figure showed that during the four years of production, the average reservoir pressure dropped from initial pressure which equals (6000 psi) to reach about (4200 psi) after 1460 days.

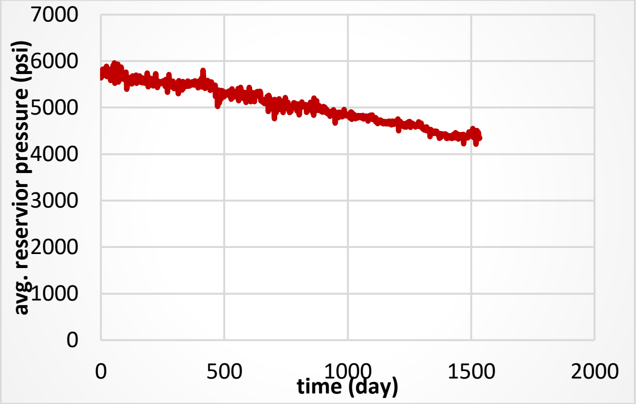

Fig. 7. Calculated average reservoir pressure of well BU-46

3.2. Agrawal type curve analysis

Agarwal type curves analysis approach was also used in this work to confirm the results obtained by the dynamic material method. Three type curves in the Agrawal method were plotted which are rate normalize ($\frac{q}{\Delta p}$ $VS.t_c$), the inverse normalized derivative of pressure ($\frac{1}{\text{DER}}$ $VS.t_c$) and inverse normalized integral derivate of pressure ($\frac{1}{\text{DERI}}$ $VS.t_c$) curves vs material balance time on the log coordinates. As shown in Fig. 8, BUH-46 exhibited good type curves matching for the rate normalize and inverse-pressure-derivative curve, and the response to the boundary of well BUH-46 was started at (April-2016). Agarwal type curves analysis match, shown in the same figure, yielded the initial oil in place with ultimate oil recovery 127302.4775 Mstb, and 38190.7432 Mstb respectively. The drainage area is 1287.551 acre. These results match the dynamic material balance estimate.

The average reservoir pressure calculated using this method at the end of the duration forecasting is 4453.4216 psi, which is extremely close to the dynamic material balance estimate.

The above result proves the applicability of the new suggested method in this field and we can evaluate the performance of each well using production data without needing to shut in the well and lose production. Table 2 shows the comparison of results we got by applying the flowing material balance and Agrawal-type curve methods. The close results of the two methods can be revealed with the absolute percentage error of 0.738% for oil-in-place and EUR, 3.07% for drainage area, and 5.7% for average reservoir pressure.

Table 2. Compassion of well/ reservoir parameters as estimated by Flowing Material balance and Agrawal-type curve methods

Method	OOIP (Mstb)	EUR (Mstb)	Drainage area (acre)	Avg. pressure (psi)
Flowing material balance	128242.075	38,472.622	1327.097	4200
Agrawal type curve	127302.4775	38,190.743	1287.551	4453.4

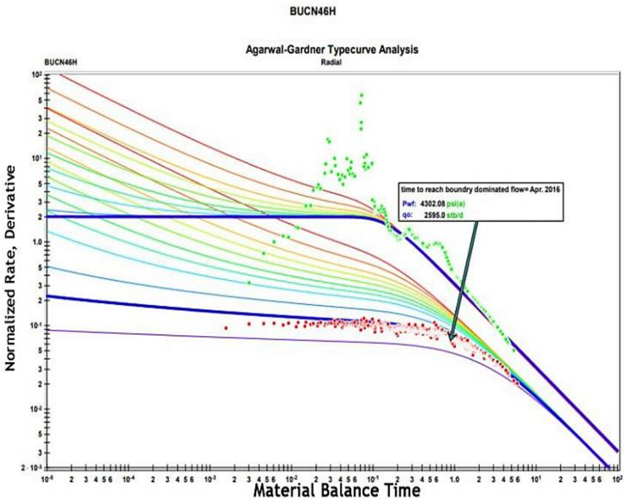

Fig. 8. Agarwal type curve analysis of well BUH-46

4- Conclusions

1. The dynamic material balance approach, when applied correctly with enough and reliable production information, is a very valuable method for determining average pressures in reservoirs and maintaining the amount of oil in place without affecting production.
2. The average pressure of the reservoir obtained from the "Dynamic Material Balance" approach can be used anywhere it is needed.
3. The influence of flowing pressures on analysis quality is as important as the effect of production values. There is a high risk of misinterpretation whether the flowing pressure is ignored.
4. The initial volume of oil in place & ultimate recovery of oil estimations in this research on the basis of dynamic material balance seemed to be reliable with the results obtained using the Agrawal-type curve.

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تطبيق نظرية توازن المواد الديناميكي لتقييم آبار النفط في حقل بزركان النفطي

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الخلاصة

تعتبر طريقة استخدام معادلة توازن المواد اساسية في هندسة المكامن والتي يمكن من خلالها تقدير كمية الهيدروكربونات الموجودة في المكمن بصورة دقيقة. ان تقدير هذه الكمية يتطلب معرفة او تحديد معدل الضغط المكمني بصورة دقيقة. وللحصول على هذا الضغط لابد من غلق البئر لعدة ايام الى عدة شهور مما يؤدي الى خسارة في الانتاج وان خسارة الانتاج هذه غالبا ما تكون غير مقبولة من الناحية الاقتصادية. سابقا، Mattar و McNeil بينوا ان حسابات توازن المواد ممكن اجرائها دون الحاجة الى غلق البئر وذلك باستخدام بيانات الانتاج (ضغط الجريان بدلا من الضغط الساكن ومعدل الانتاج الثابت) بطرقة اسموها توازن المواد المتدفقة مع ذلك، فأن الحفاظ على معدل الجريان ثابتا لفترة زمنية طويلة هو مطلب صعب للغاية في اغلب حقول النفط. حديثا، Mattar و Anderson قدموا طريقة توازن المواد الديناميكي وهي امتداد لطرقة توازن المواد المتدفقة والتي ممكن ان تطبق في حالة الجريان الثابت والمتغير. يصف هذا البحث التطبيق العملي لطريقة توازن المواد الديناميكية باستخدام ضغط الجريان ومعدل التدفق المتغير لتقدير كمية الاحتياطي المكمني وتحديد معدل الضغط للمكمن لواحد من الابار المنتجة في حقل بزركان النفطي . الهدف الاساسي لهذه الدراسة هو تطبيق طريقة التوازن الديناميكي على مثال حقلي ومقارنة النتائج مع طريقة اساسية اخرى وهي طريقة Agrawal type curve او منحني النوع من اجل تقييم دقة النتائج المتحصلة. تشير المقارنات الى ان هنالك تقارب ممتاز نسبيا في كمية الاحتياطي النفطي ومعدل الانتاج المسموح ومعدل الضغط المكني المحسوبة بطريقة توازن المواد الديناميكية وتلك المحسوبة بطريقة معدل النوع.

الكلمات الدالة: توازن المواد المتدفقة، توازن المواد الديناميكي، تحليلات منحني النوع، معدل الضغط المكمني.