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Dynamic Material Balance Study of Gas Reservoir Using Production Data: A Case Study of New Gas Sand of Kailashtila Gas Field

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Abstract: The material balance is one of the fundamental practice in reservoir engineering and is considered as a reliable estimation of hydrocarbons-in-place. A good knowledge of average reservoir pressure is essential to determine original gas-in-place. To have such reservoir pressure, the well needs to be shut-in for few days to months, resulting in loss of production. In the current economic environment, this production loss is often unexpected. In a previous study, Matter and McNeil showed that material balance calculation could be done without shut-in well, which uses flowing well pressure instead of static pressure and constant flow rates. However, a constant production rate for an extended period of time is very challenging production criterion for the majority gas fields. The dynamic material balance is an extension of the flowing material balance that allows either constant or variable flow rate. This study describes the practical application of a method known as Dynamic Material Balance for average reservoir pressure determination using flowing pressures and variable production rates and thus to estimate the original gas-in-place of new gas sand of Kailashtila Gas Field. The main purpose of this study is to apply the method in field cases and to make a comparison with other standard methods of reserve estimation such as volumetric, type curve analysis to see the result and validate the efficiency of its application. These comparisons show a fairly good agreement in gas in place obtained from the dynamic material balance method and that of type curve analysis in this field.

Keywords: Dynamic Material Balance, Flowing Pressure, Average Reservoir Pressure, Original Gas-in-Place, Kailashtila Gas Field

1. Introduction

Material balance has long been used as a simple yet powerful tool, which uses actual production performance data to determine the original-gas-in-place [1]. Correct estimation of original gas in place (OGIP) is very crucial for reservoir management and decision-making for field development [2-4]. Volumetric calculation, material balance, and decline curve analysis are the main techniques used for calculating reserves [5]. However, having enough and reliable information a numerical simulation model can be created to support also the OGIP estimation [3]. The volumetric and material balance estimate the original gas volume, while the production decline method estimates the recoverable gas. The accuracy of reserve calculation by the volumetric method depends on the data availability, especially the seismic and the log data. In a fluvio-deltaic sequence, as in Bangladesh, the likelihood of large errors in estimating rock volume is very high [4]. As a result, there may be gross errors in estimating the original gas-in-place. On the contrary, the accuracy of material balance depends on the production and pressure data. Its accuracy increases with time as more production and pressure data available.

The material balance is the application of mass balance to a producing reservoir [6]. The conventional material balance approach represents the relationship between the average reservoir pressure and the cumulative volumes of reservoir fluids produced. The widely used material balance equation for a volumetric depletion type reservoir is given by [7].

$$\frac{P}{z} = \frac{P_i}{z_i}\left(1 - \frac{G_P}{G}\right) = \frac{P_i}{z_i} - \frac{P_i}{z_i G} G_P$$

The conventional material balance for a gas reservoir relies on obtaining a straight line on P/z versus cumulative production graph to estimate original gas in place. This method requires average reservoir pressure, which is obtained from buildup test. A properly designed buildup test may take several days, which are usually associated with production loss expenses. In low to medium permeability reservoir, the loss of production opportunity as well as the cost of monitoring the shut-in pressure is often unacceptable. Besides, in critical demand-supply situations, like that Bangladesh, the buildup tests are not conducted on a regular basis [4]. As a result, reserves are not updated regularly.

In a previous publication, Mattar and McNeil (1998) introduced the flowing material balance concept, in which shut-in pressures are not required [8]. Instead of shut-in pressure, the flowing well pressure data along with the constant rate production are analyzed. In this method, a straight line is drawn through flowing pressure data and then a parallel line is drawn through initial reservoir pressure gives original gas in place. Unfortunately, most of the gas fields don't produce constant rate production. They incur significant variation in rate and flowing pressure over their production life. The dynamic material balance method is applicable for almost any type of reservoir because it is not limited by static pressure measurements and can be used for both oil and gas reservoirs [9]. In dynamic material balance, instead of pressure and time, the pseudo pressure and pseudo time are used to get more accuracy of the result. Because the pseudo pressure and pseudo time account the dependency of viscosity, compressibility and compressibility factor on pressure. The pseudo-variables (pseudo pressure and pseudo-time) can be defined as:

Pseudo Pressure [10]

$$P_P = 2\int_0^P \frac{P}{\mu Z} dp$$

Pseudo Time [11]

$$t_{ca} = \int_0^t \frac{dt}{\mu c_g}$$

Therefore, the main objective of this study is the application of dynamic material balance in field cases to calculate the average reservoir pressures and thus to estimate the original gas-in-place.

2. Methodology

The dynamic material balance is a graphical and very straightforward procedure. It can be used just like the conventional material balance after evaluating the average reservoir pressure at each pressure point. Knowing the flow rate and flowing sand face pressure at any given point in time, the average reservoir pressure can be calculated. The use of dynamic material balance is based on the assumption that the wells have produced long enough to achieve the pseudo steady state condition. Therefore, a good understanding of reservoir flow behavior is essential. As dynamic material balance is valid only when the flow has reached the boundary dominated condition, data obtaining during transient flow can't be used in the analysis. So, the first step is to verify the pseudo steady state (PSS) condition. There are different methods to validate the pseudo steady state (PSS) condition. One of this method is using production data analysis. In this method, a plot of cumulative gas production vs. time on the log-log scale is generated, which can be observed a deviation from the linear trend indicating PSS [12].

Once the PSS condition has been met, we proceed to apply the dynamic material balance. The working flow diagram for generating dynamic material balance plot for a gas well is given below:

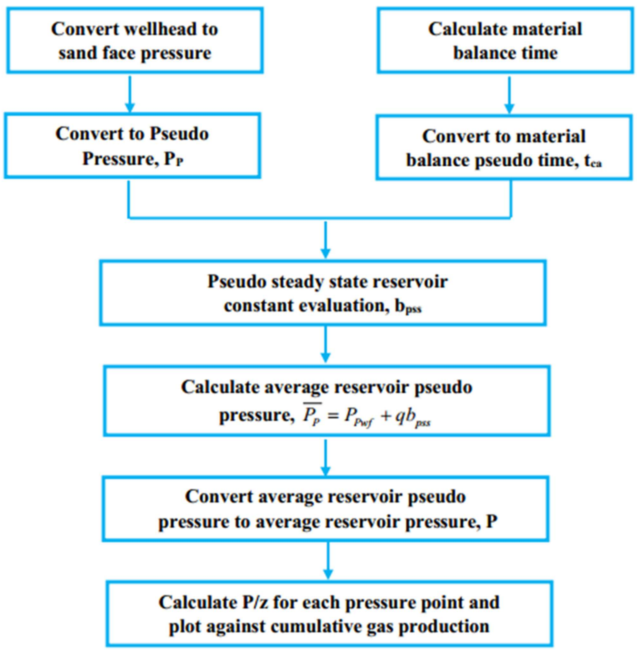

Figure 1. *Working flow chart for dynamic material balance plot.*

3. Kailashtila Gas Field

The Kailashtila Gas Field lies approximately 12 km southeast of Sylhet city, Bangladesh. It was discovered in 1960 and started its production from 27 March 1983. Kailashtila Gas Field can be considered as a medium permeability reservoir with the permeability values in the range of 100 to 500 md [13]. A total of 7 wells have been drilled in the five developed gas sands of this field. Presently, only five wells are producing from three sands with the total production of about 71 MMSCFD [14]. In this paper, dynamic material balance result of only new gas sand has been discussed. Three years of production data have been analyzed using dynamic material balance methods to estimate original gas-in-place. Some basic rock and fluid properties of new gas sand are listed in table-1.

Table 1. *Basic rock and fluid properties of new gas sand of Kailashtila Gas Field [15].*

Properties	Value
Initial Reservoir Pressure P_i (psia)	3870
Reservoir Temperature T_R (°F)	159.0
Porosity (fraction)	0.185
Permeability (md)	226.0
Gas Specific Gravity	0.628
Gas Saturation	0.650
Z factor	0.916

4. Result and Discussion

There is only one well (i.e. KTL-4) in the new gas sand zone of Kailashtila Gas Field. KTL-4 started its production from September 2012. Dynamic material balance study has been conducted on this well using the respective well and production data. Production data of KTL-4 appears in figure-2. From the figure, it can be observed that the well is producing at varying flow rates and decline trend of pressure.

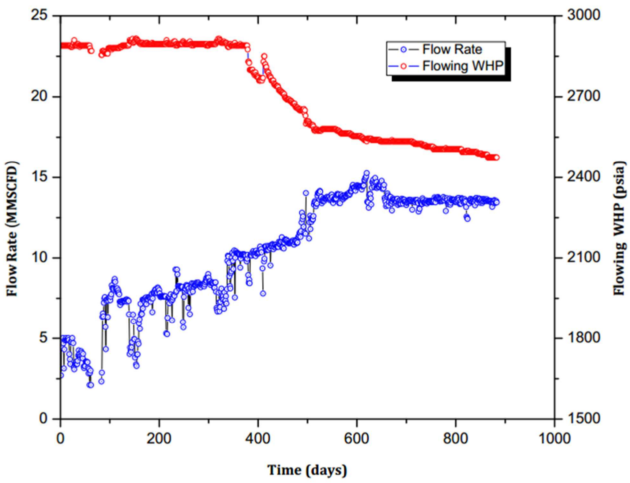

Figure 2. *Production Data of KTL-4.*

4.1. PSS Verification

As part of the analysis, the first step is to verify the pseudo steady state condition of the well. Figure-3 presents the log-log behavior of the cumulative production and time. It is found that a deviation from the linear trend which indicates the starting of the PSS condition of KTL-4. As dynamic material balance is only applicable in boundary pseudo steady state condition, production data on the transient condition are ignored for further calculations.

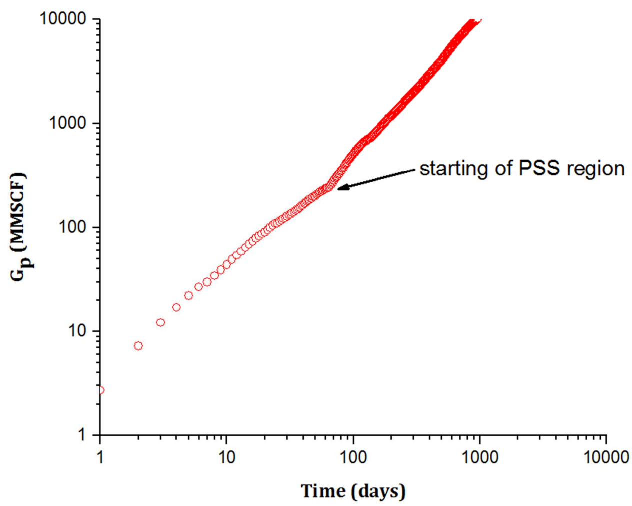

Figure 3. *Plot of log-log behavior of production cumulative vs time of KTL-4.*

4.2. Average Reservoir Pressure Calculation

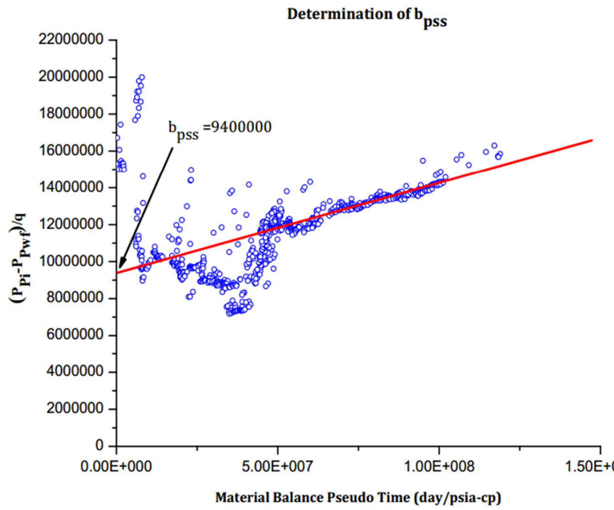

Figure 4. *Determination of b_{pss} for KTL-4.*

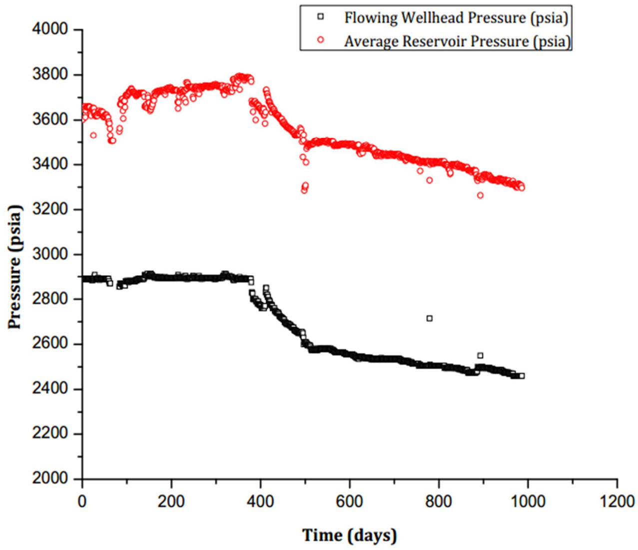

Figure 5. *Calculated Average Reservoir Pressure for each pressure point of KTL-4.*

The average reservoir pressure values have been calculated for each pressure point from wellhead pressure. The conversion of flowing pressure to average reservoir pressure is needed to take into account the varying flow rates of this well. To do this, $(P_{Pi} - P_{Pwf})/q$ vs material balance pseudo time t_{ca} is plotted, which appears in figure-4. From the figure, it can be seen that the intercept of y-axis gives a value of 9400000. This value is called the reservoir constant b_{pss}, which indicates the pressure loss corresponding to pseudo pressure due to steady-state inflow. The calculated results of averages pressure for each pressure point are shown in figure-5.

4.3. Dynamic Material Balance Plot

The material balance plot of the well (KTL-4) would yield the original-gas-in-place. The P/z corresponding to the average reservoir pressures versus cumulative production graph of well KTL-4 appears in figure 6. As from the straight-line nature of the data in figure 6, means that as the pressure declines, due to production, there is an insignificant amount of water influx into the reservoir from the adjoining aquifer. It can be safely assumed that the reservoir does not have any active water support. Gas in place values estimated from the plots of P/z versus cumulative gas production using the flowing pressure of well KTL-4 is 125.04 BCF. Thus, the total gas in place of new gas sand by the dynamic material balance method is 125.04 BCF.

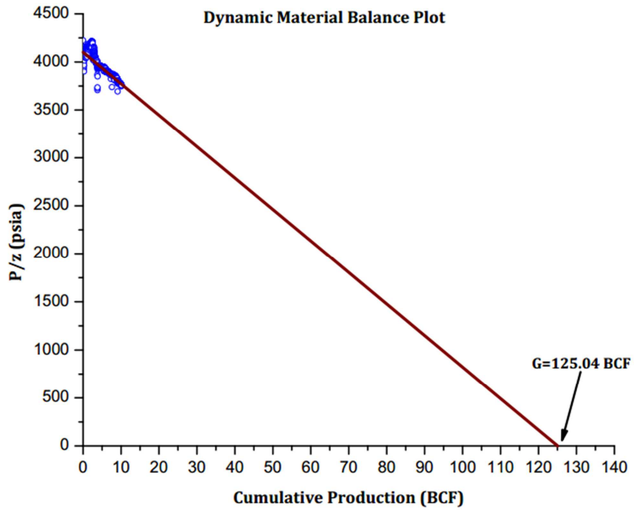

Figure 6. *Dynamic Material Balance of KTL-4.*

To validate the result of Dynamic Material Balance, Blasingame, Agarwal-Garden and Normalized pressure integral type curve methods are applied through FEKETE F. A. S. T. RTA™ software [16]. The type curve analysis graph of KTL-4 appears in figure 7 through figure 9. It can be observed that three type curves approaches yield a gas in place estimate of Blasingame, Agarwal-Garden and Normalized Pressure Integral 127.428 BCF, 127.174 BCF and 127.250 BCF respectively.

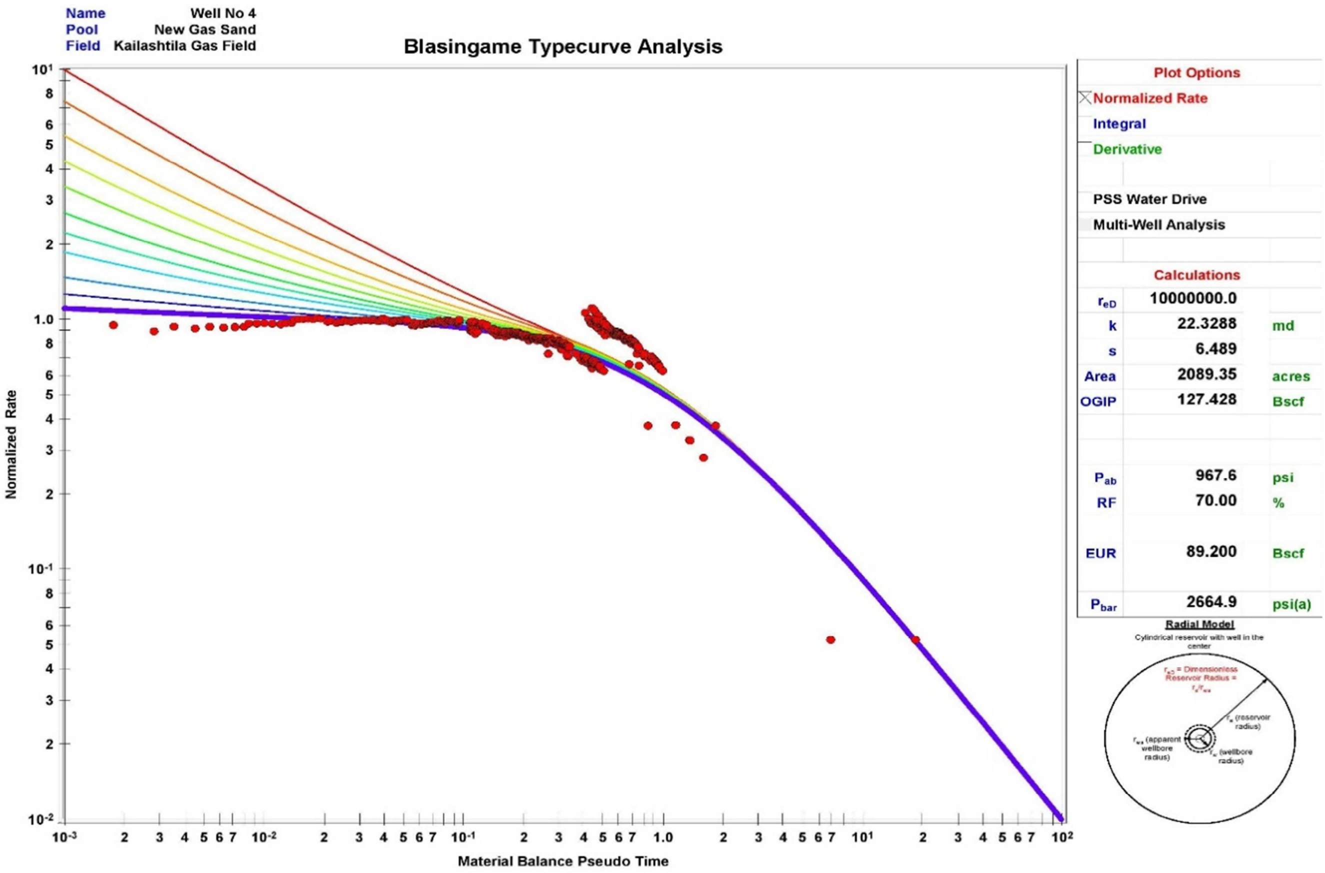

Figure 7. *Blasingame Type Curve Analysis of KTL-4.*

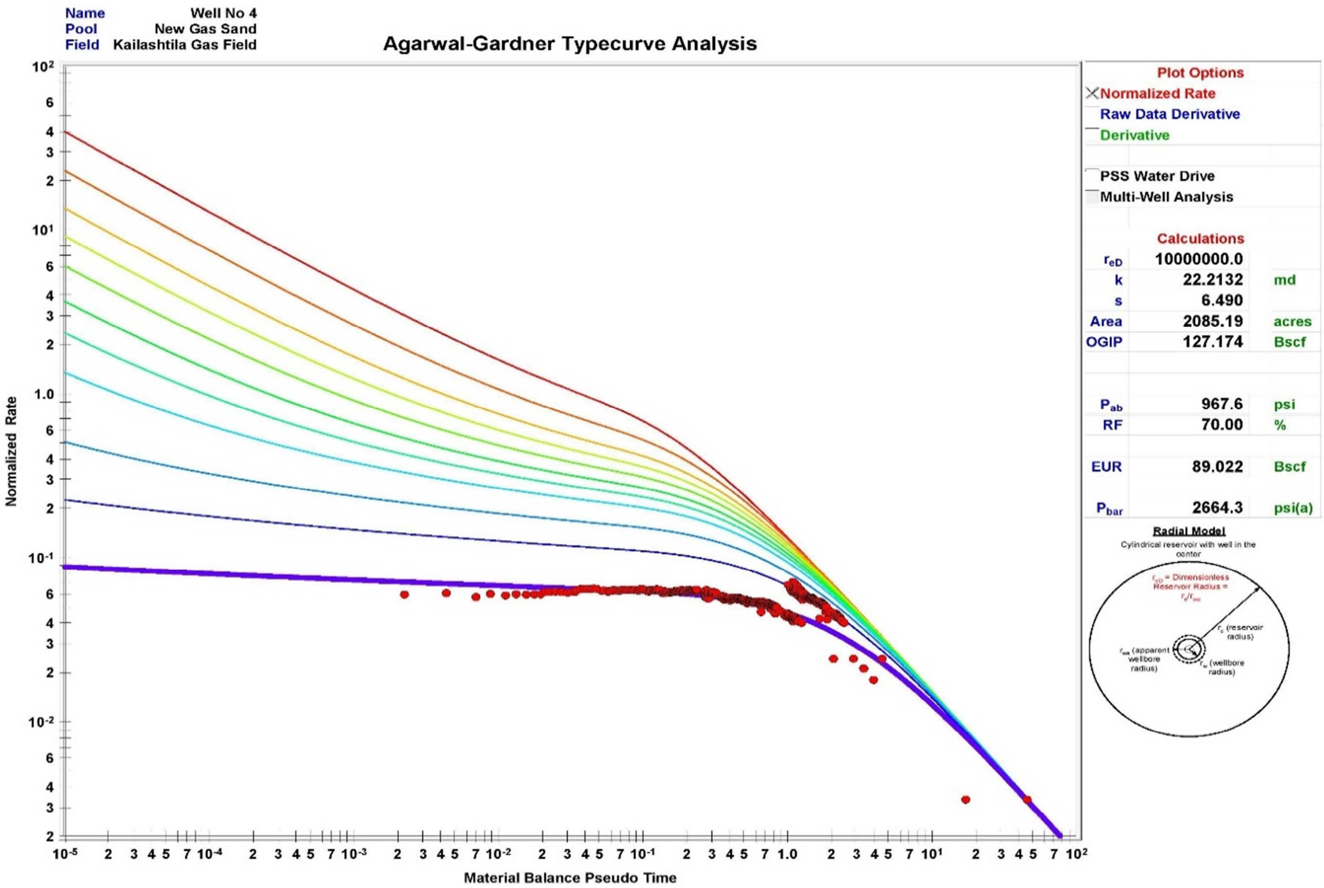

Figure 8. *Agarwal-Gardner Type Curve Analysis of KTL-4.*

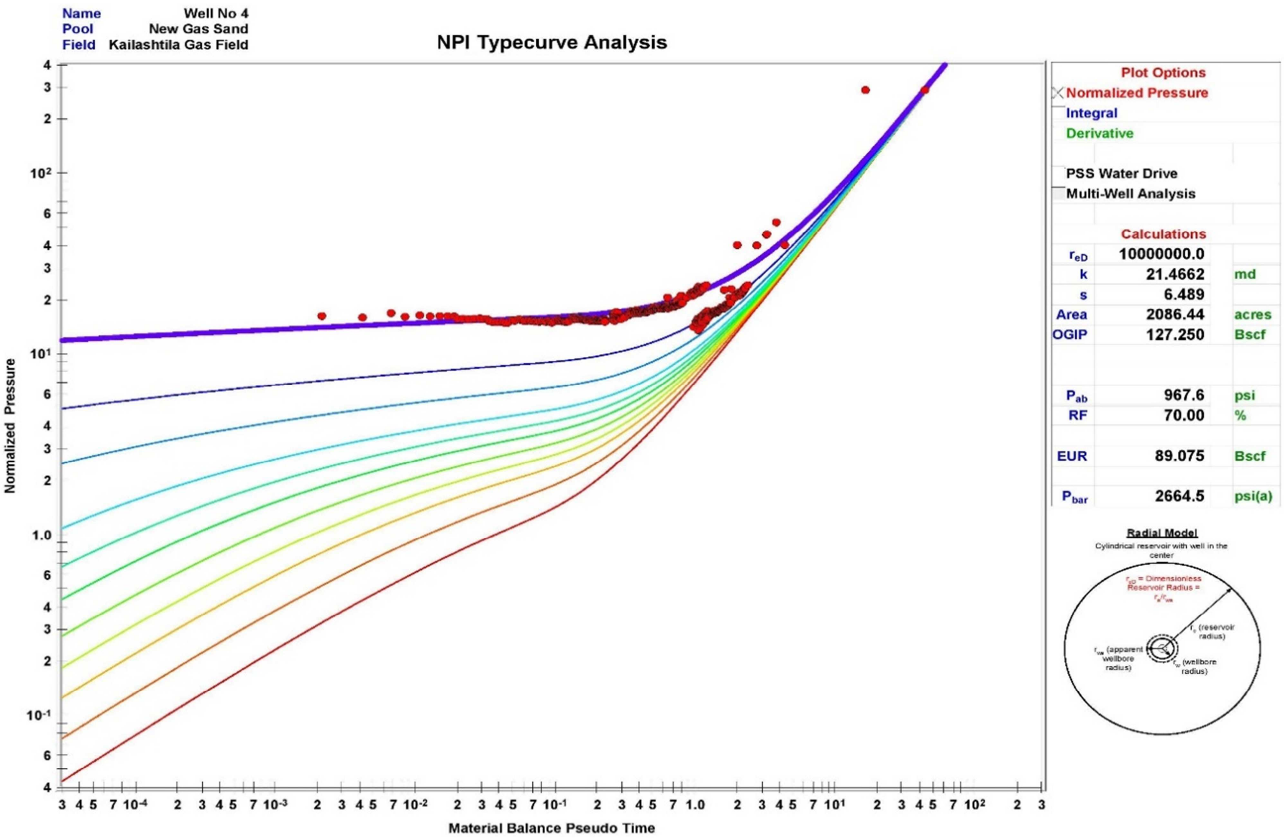

Figure 9. *Normalized Pressure Integral Type Curve Analysis of KTL-4.*

Table 2 compares the results of the present study with that of other studies. Gas in place estimates of HCU-NPD (2002) is based on the volumetric method [17]. From the comparison, it is evident that the result of DMB is very close to the three different type curve results and the estimation is little lower than the previously conducted volumetric estimation.

Table 2. *Comparison of the result of dynamic material balance with other different estimation methods.*

Sand	Analysis Method	OGIP (BCF)
New Sand (KTL-4)	Dynamic Material Balance	125.040
	Blasingame Type Curve	127.428
	Agarwal-Garden Type Curve	127.174
	Normalized Pressure Integral Type Curve	127.250
	Volumetric Estimation by HCU-NPD (2002) [17]	142.000

5. Conclusion

Dynamic material balance method, if properly applied having sufficient and available flowing data, is a very useful tool to calculate average reservoir pressure and to update the gas in place without interrupting the production. Gas in place estimates of this study based on flowing pressure and varying flow rate seems reliable with the type curve results. It is also shown that average reservoir pressure can be calculated without shut-in a well with a very simple and direct procedure. Though there is no need to shut in the well, the dynamic material balance should not be viewed as a replacement to build up test. It should be viewed as a very inexpensive supplement to them.

Nomenclature

b_{pss}: reservoir constant
c_g: gas compressibility, $psia^{-1}$
G: original gas in place, (MMSCF)
G_P: cumulative gas produced, (MMSCF)
P_i: initial reservoir pressure, (psia)
P_R: average reservoir pressure, (psia)
P_{wf}: flowing pressure, (psia)
P_P: pseudo pressure, ($psia^2$/cp)
P_{Pi}: pseudo pressure corresponding to initial reservoir pressure, ($psia^2$/cp)
P_{Pwf}: pseudo pressure corresponding to the sand face flowing pressure, ($psia^2$/cp)
$\overline{P}_p$: pseudo pressure corresponding to the average reservoir pressure, ($psia^2$/cp)
q: production rate, (MMSCFD)
t: time, (day)
t_c: material balance time for gas, (day)
t_{ca}: material balance pseudo time for gas, (day-psia/cp)
T: reservoir temperature, (°R)
z: gas compressibility factor
$\emptyset$: porosity (fraction)
μ: viscosity (cp)

Abbreviation

BCF: Billion Cubic Feet
DMB: Dynamic Material Balance
HCU: Hydrocarbon Unit
IKM: Intercom Kanata Management
KTL-4: Kailashtila Well No. 4
NGS: New Gas Sand
NPD: Norwegian Petroleum Directorate

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