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Analyzing of Production Data Using Combination of empirical Methods and Advanced Analytical Techniques

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Abstract

Various methods of analysis are available to analyze production data in order to estimate the intrinsic features of the well and the reservoir condition in the current state. The parameter estimated from all of these analyses when performed separately often demonstrate poor agreement because each of them was developed using different assumptions. This paper discusses the most common analysis methods that can be performed in combination on production data including empirical decline curve analyzing method, analytical type curves analysis, and the flowing material balancing technique that can actually be used for calculating reservoir or well properties including original oil in place (OOIP), ultimate oil recovery (EUR), drainage area (A), skin factor (S), and well permeability(K). These techniques applied on Mshrif formation/ Buzurgan oil field to estimate the above parameters by the three methods. These methods have the advantage of being able to predict and analyze using flow rate and well flowing pressure without needing to shut in the well to predict average pressure of reservoir that is essential in most estimations. The result showed that both analytical Blasingame type curve method and flowing material balance gave analogous estimations but didn't agree with Arp's empirical method estimation.

Keywords: *PDA; Type curve; Decline curve; Flowing material balance; RTA; Dynamic material balance.*

1. Introduction

Production data analysis techniques have advanced greatly in recent years. There are many methods accessible nowadays. However, not a single approach that consistently gives the most reliable results.

Arps [1] presented the first s method to analyze oil and gas production data in the 1950s. The fact that Arp's approach decline curve analysis is still prevalent today attests to its success. The simplicity of the Arp's technique is one of its most attractive characteristics. Since it is an experimental method, previous knowledge of well or reservoir parameters is not necessary. This method could be used to predict the future performance of well by employing an empirical curve match. As a result, it can be used in production using any reservoir driving mechanism [2].

One limitation of Arps decline analysis curve method it is unable to distinguish between production forecasts and operational restrictions. Thus, the Arp's decline should be determined by the implicit assumption that prior operational conditions will remain constant along the well life. Other limitation of Arp's method is that it is only applicable in the transient flow period. In fact, Arp's decline analysis is frequently misapplied to transient-dominated production. In such cases, this approach able to only predicting ultimate oil recovery (for example, Arp's method) has limited use. There are more methods that employ transitory solutions could be utilized instead [3].

Fetkovich demonstrated in 1980 that Arps decline curve method is invalid for the duration of transient flow. As a result, he constructed type curves consider transient flow period which combine with type curve of Arp's curves by use the well test measures and empirical formulae that Arps applied to his type curves [4-5].

The Arps and Fetkovich techniques are based on the assumption of constant pressure at the bottom of the hole and principally consider flow rate data while ignoring changes in bottomhole pressure. (Palacio and Blasingame) later proposed superposition time function which takes into account variable in rate and variable in pressure to show up as constant flow rate production, and what previously matched Fetkovich exponential decline curves would now fit harmonic decline form in Blasingame type curves. The name of this function is 'Material Balance Time' which represent the period of time required to achieve this volume of cumulative production using current flow rate recorded or tc = Np/q. when the flow reaches boundary dominated flow state the pressure wave reaches the boundary of reservoir. During this time the flow rate is entirely controlled by the expansion of the rock and fluid caused by the reservoir pressure decline. Agrawal and Blasingame [6-7] used the decline type curve to interpret production data by matching the constant rate & constant pressure solutions created by Fetkovich, Palacio, and Blasingame. Agarwal and Gardner's dimensionless variables did not depend on the definition established by Fetkovich and adopted by Blasingame, instead depending on a traditional well testing definition. They also included derivatives graphs, first derivative with inverse derivative that's to demonstrate some variations in decline analysis of transient and PSS flow. Furthermore, decline type curves of them were provided in two different formats; rate versus cumulative as well as cumulative versus time analyses [8].

Recently, petroleum engineering focused on flowing material balance methods. One of these methods is the 'flowing material balance method', which was presented as a modern Production Analysis approach as an alternate for classical material balance calculating. Since the classic material balance equation application requires static shut in pressure data, the more sophisticated technique known as "flowing material balance" (FMB) has gained popularity recently [9]. The flowing material balance approach, which uses bottom hole flowing pressures and constant flow rates to complete material balance calculations at flowing reservoir conditions, eliminates the restriction of shutting in wells [10].. Constant production rate over a longer time duration is the main limitation for using this method.

Therefore, researchers recently focused on using 'dynamic material balance' outputs. Mattar and Anderson [10-11] introduced dynamic material balancing equation as expansion of flowing material balance equation which is possible to apply in case of constant or variable rates, also this equation can be used for all reservoirs types since it does not require static shut in pressure measurements and can apply on oil or gas reservoirs. This technique analyzes flowing measurements at any location converting the measured flowing pressure into current reservoir average pressure. Original volume in place can then be determined using the computed average pressure with corresponding cumulative rate of production using the classic material balance approach [11].

This research focuses on the interpretation of measured flow rates and well flowing pressures using different production data analysis techniques which include (empirical decline curve analysis, analytical rate transient analysis for example Blasingame type curves and flowing material balance. The goal of this work is to provide good estimation for the reserve (OOIP=Oil Initially in Place) and ultimate oil recovery (EUR) of one of the currently producing oil fields of Iraq in the south region of the country (Buzurgan oil field- Mishrif formation).

Buzurgan oil field distance 40 km to the north east of Amara in Iraq's south-eastern area, close to the Iranian border. Mishrif formation is one of the large reservoirs in southern Iraq. Buzurgan Field is divided into two domes: north dome and south dome. Furthermore, the north dome's dimensions were 16 km x 6 km, while the south dome's dimensions were 23 km x 8 km [12].

The Mishirif Formation is forms from of bio-clastic, cavernous, and sometimes limestone interbeds as well as crystal to microcrystalline limestone, light to moderately hard limestone, recrystallized and chalky in certain places, and limestone (mudstone, whack-stone, pack-stone, grain-stone). The thickness range is 331 to 373 meters [13-14].

2. Methodology

Three methods of production data analysis we explained and applied in this research, these methods are (imperial Arp's decline curve, analytical Blasingame type curve and flowing material balance). the methodology and interpretation steps are listed below.

2.1 Diagnosis and preparation of production data

The analysis workflow begins with this stage. The goal of diagnostic data process is to ensure that high-quality data is used during production analyses. As a consequence, representative results are possible. In reality, the data diagnostic process involves identifying anomalous events which influence flowing conditions and may indicate a fluid flow violation concept assumptions upon which production data analysis tools are built.

Production data analysis, in contrast to pressure transient analysis, that offers accurate production and pressure information as part of a controlled operation, includes employing surveillance and monitoring data collected under changing operating scenarios, and it may be measured with uncertain accuracy. As a result, interpreters should be aware with the possible mistakes or misinterpretation produced by low reliability/low accurate production rates while analyzing production data. However, while most output rates are continually recorded—regardless of quality pressure history data that required for production analysis is often or never available in other cases [15].

PDA approaches need a lot of production data to be used, particularly when bottom hole readings of pressure are not available. Calculating the loss of pressure within the wellbore and completion structure and estimating sand face flowing pressures require the flowing head pressure readings, some fundamental fluid and reservoir properties and downhole flowing pressure measurements [16].

2.2. Preparing basic input data required

After checking consistency and quality of production data (production rate, well head flowing pressure (WHP)), other input data necessary in converting pressure step was prepared these data were, initial reservoir pressure, surface and bottom temperature, average formation and fluid properties (net pay, porosity, specific gravity, gas oil ratio, bubble point pressure, fluid saturations), PVT data, well bore schematic, basic measurement (MD and TVD) of vertical and horizontal wells, deviation survey data.

2.3. Decline Curve Analysis (Arp's time-rate analysis)

Using conventional Arp's decline analysis formulas that built on boundary dominated flow assumption (BDF) as the current flow regime, the ultimate recovery (EUR) of oil or gas reservoirs can be estimated in reliable way. The procedure of this type of DCA analysis technique is very simple and summarized in three steps [17].

1- First step is the determination of decline law by plotting the rate vs time curve and rate vs cumulative curve and based on the characteristics of these curves we can determine the type of decline weather its exponential or harmonic or hyperbolic decline type.

2- The second step is the estimation of decline exponent, from Straight-line equation, rate and cumulative production based on the current production rate (q_f) and the flowrate at the time of abandonment (Q_f) by equations (1 and 2) for exponential decline, equations (3and4) for harmonic decline and equations (5 and 6) for hyperbolic decline are used to calculate these parameters.

$$q = q_o * e^{(-Dt)} \tag{1}$$

$$Q = \frac{q_o}{D}[1 - e^{Dt}] \tag{2}$$

$$\mathrm{q} = \mathrm{q_o}(1 + \mathrm{bDi\ t})^{-1/\mathrm{b}} \tag{3}$$

$$Q = (q_\circ)/(1-b)Di\,[1-(1+\mathrm{b\,Dit})]^{\,1-(\frac{1}{\mathrm{b}})} \tag{4}$$

$$q = q_\circ(1+bDi\,t)^{-1/b} \tag{5}$$

$$Q = \frac{q_\circ}{(1-b)Di}[1-(1+b\,Dit)]^{\,1-(\frac{1}{b})} \tag{6}$$

3- The third step is calculation of ultimate recoverable volume using equation $EUR = N_\mathrm{p} + Q_\mathrm{f}$

2.4. Type curve analysis (Blasingame type curve)

The goal of type curve analysis is identifying a form of curve that corresponds to the actual response of the oil or gas wells and reservoirs during the test. The dimensionless variable that defines the type curve can be used for computing reservoir or well properties as permeability and skin factor. Graphically, this match can be done by overlaying the graph of testing data with an analogous graph of type curves and finding the type curve gives an optimum fit.

Type curves are obtained from flow equation solutions with specific initial and boundary flow conditions. Type curves are typically expressed in dimensionless terms for the purpose of generality, such as dimensionless pressure vs. dimensionless time. Depending on the model's complexity, a given interpretation model will generate a single type curve or one or more groups of type curves.

Three types of flow rate versus 'material balance time' curves can plot in dimension less form by the Blasingame type curves: normalized decline rate curve, normalize decline rate integral curve, and decline flow rate integral derivative curve in the trying of finding the match of field data and type curves, any of these curves or a combination of them can be utilized. The Blasingame method has the advantage of following to the idea of integration followed by derivation, that can filter the noise in field data and give production features.

Blasingame type curve analysis procedure in oil wells listed below:

1- Select suitable model (Radial, Fracture, Horizontal, water drive) that out fit with each well.
2- match plotted (*q/Δp vs. tc*) data to constant rate Blasingame type curve in dimensionless format ($q_{Dd}\ vs.\ t_{Dd}$) and chose transient (r_{eD}) stem.
3- Graph the rate integral and the rate integral derivative type curves on one graph and match complementary type curves [dimensionless flowrate integral (q_{Ddi}) and dimensionless flowrate integral derivative (q_{Ddid}) to rate integral (q_i) and rate integral derivative data (q_{id}) to try to fine-tune confirm match.

$$\left(\frac{q}{\Delta p}\right)_\mathrm{i} = \frac{1}{t_\mathrm{c}}\int_0^{t_\mathrm{c}} \frac{q}{p_\mathrm{i}-p_\mathrm{wf}}d\tau \tag{7}$$

$$\left(\frac{q}{\Delta p}\right)_\mathrm{id} = -\frac{d\left(\frac{q}{\Delta p}\right)_\mathrm{i}}{d\ln\ t_\mathrm{c}} = -t_\mathrm{c}\frac{d\left(\frac{q}{\Delta p}\right)_\mathrm{i}}{dt_\mathrm{c}} \tag{8}$$

The subscripts (i) and (d) represent integration and derivative respectively.

1- Select the real matching point $(t_c, \frac{q}{\Delta p})_M$ and the possible matching point $(t_{cDd}, q_{Dd})_M$. If we have the thickness of produced formation, compressibility, and the wellbore radius, we may compute the OOIP, drainage area, permeability, as well as skin factor, among other things.
2- Calculate reservoir permeability using the matching point by rate

$$K = \frac{(q/\Delta p)_M}{(q_{Dd})_M}\frac{\mu B}{2\pi h}\left(ln\ r_{eD} - \frac{1}{2}\right) \tag{9}$$

3 Calculate the wellbore radius rwa using the matching point by time and r_{eD} calculated.

$$t_{\mathrm{cDd}} = \frac{\frac{K}{\varphi C_{\mathrm{t}}\mu} t_{\mathrm{c}}}{\frac{1}{2} r_{\mathrm{wa}}^2 (r_{\mathrm{cD}}^2 - 1)\left(\ln\, r_{\mathrm{cD}} - \frac{1}{2}\right)} \tag{10}$$

$$r_{wa} = \sqrt{\frac{2K/\varphi\mu C_t}{(r_{cD}^2 - 1)\left(ln\; r_{cD} - \frac{1}{2}\right)} \left(\frac{t_c}{t_{cDd}}\right)_M} \tag{11}$$

4- Calculate the skin factor (s) by

$$S = \ln \frac{r_w}{r_{wa}} \tag{12}$$

5- Calculate the drainage radius & drainage area using

$$r_e = r_{wa}\, r_{eD} \tag{13}$$

$$A = \pi r_e^2 \tag{14}$$

6- Calculate the reserve (N) by

$$N = \frac{1}{C_{\mathrm{t}}} \left(\frac{t_{\mathrm{c}}}{t_{\mathrm{Dd}}}\right)_{\mathrm{M}} \left(\frac{q/\Delta p}{q_{\mathrm{Dd}}}\right)_{\mathrm{M}} (1 - S_{\mathrm{w}}) \tag{15}$$

2.5. Flowing material balance technique

The 'flowing material balance' and 'dynamic material balance' methods of material balance use flowing well pressures, p_{wf}, in the analysis rather than static pressures. The primary advantage of using the flowing material balance technique is that it eliminates the need to shut in wells and allows material balance calculations to be performed under dynamic reservoir circumstances [18].

Procedure of this method for oil wells (undersaturated) is very simple Summarize the following steps:

1- Calculate normalized cumulative rate of production

$$Q_n = \frac{Q}{C_t\, \Delta p} \tag{16}$$

2 Try to find the best fit straight line passing throw the data.
3 Extrapolate drown data to the x-axis and find the intercept point, the intercept number represent the value of initial oil in place value.
4 Determine a proper recovery factor (RF) for estimating the ultimate recovery of oil (EUR).

3. Results and discussions

The above three methods have been conducted on well BU-17. This well is an old production well drilled in 24 Oct. 1978, and located in the North of Buzurgan oil field. BU-17 was put into natural flow production in Feb. 1980, and the initial production is up to 2500 bbl/d. Currently the oil rate and WHP decreased to ~690 bbl/d and 18 kg/ cm^2 without water production. The Production data for ten years (2011-2021) were analyzed in this research. The objective is to calculate the original oil in place (OOIP), ultimate oil recovery (EUR), drainage area (A) and productivity index (PI) by the three methods. Table 1 shows the necessary reservoir and borehole parameters for this oil well. The production data required of this well are given in Figure 1**.** This figure showed simple data scattering, which may not have had an important effect on production forecasts; thus, the well data was considered as of high quality.

Table 1. Reservoir basic parameters

Property	Value	Property	Value
Reservoir temperature, °F	235	Bubble point pressure, psi	2660
Porosity, %	20	Oil gravity, API	24.85
Initial oil saturation, %	80	Initial formation volume factor, bbl/stb	1.349
Initial water saturation, %	20	Solution gas oil ratio, scf/bbl	634
Total compressibility, 1/psi	1.433369×10^{-05}	Oil compressibility, 1/psi	1.25783×10^{-5}
Wellbore radius, ft	0.583	Density @ pi & Ti, Ib/ft^3	46.0357
Net pay, ft	105	Oil viscosity @ pi & Ti, cP	1.0737

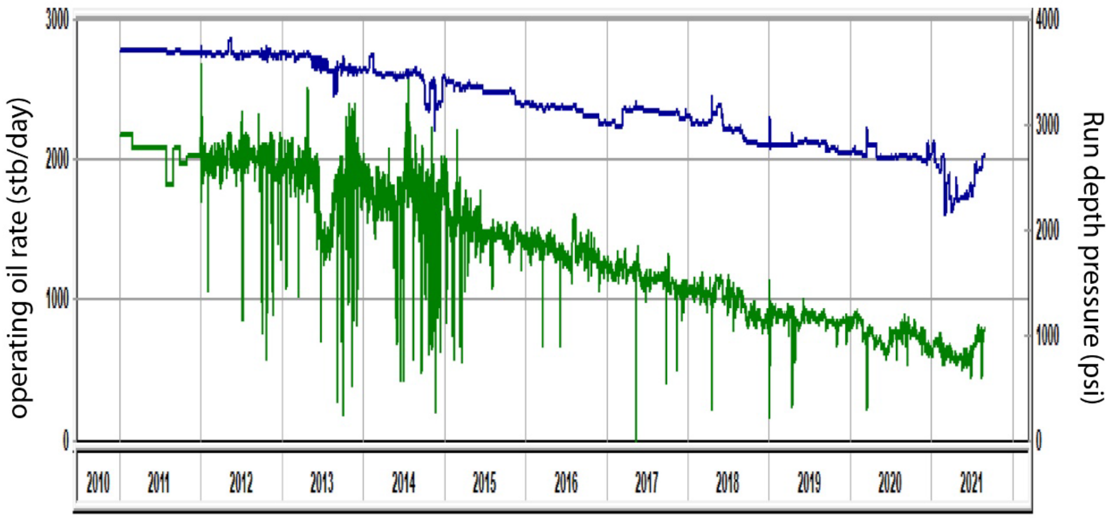

Figure 1. Rate & bottomhole flowing pressure of well BU-17

Arp's decline curve was the first method applied on this well. As previously stated, using conventional Arp's analysis equations that based on boundary dominated flow (BDF) regime, the ultimate oil recovery (EUR) of oil or gas reservoirs can be estimated in reliable way. Depending on the curve teachers it's found that the decline in this well matched by the exponential decline or by the harmonic decline. The exponential decline curve & harmonic decline curve results shown in Figure 2. From this figure we noticed that the EUR of the harmonic decline (EUR=5373.675) Mstb is obviously higher than that of exponential decline (EUR=7443.966 Mstb).

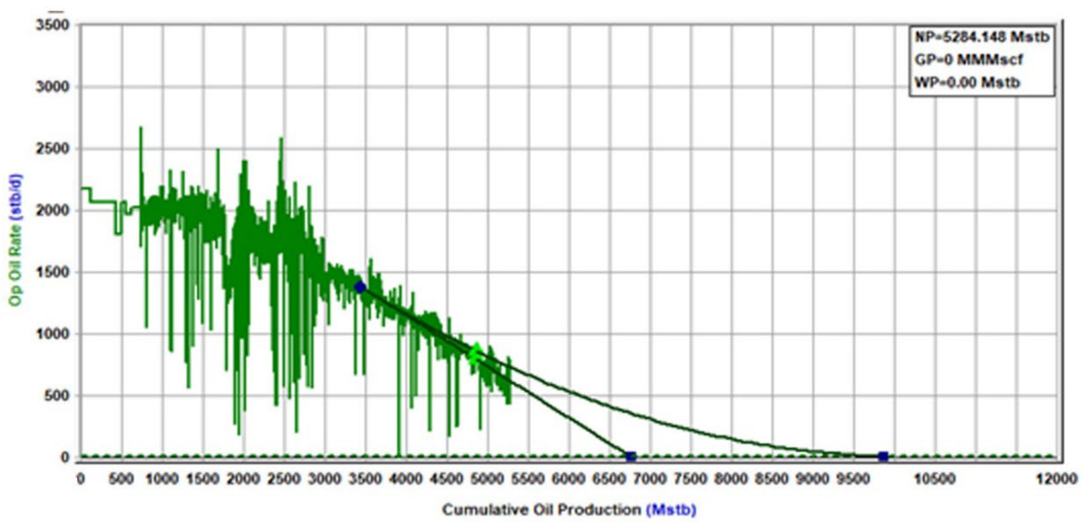

Figure 2. Cartesian rate–cumulative production plot of well BU-17

The second method applied was Blasingame type curve method. Three types of rates versus 'material balance time' curves in dimensionless form plotted in the Blasingame type curves; normalized decline of rate curve, normalized decline of rate integral curve, and decline of rate integral of derivative curve. Blasingame type curve method applied on well BU-17 in order to determine the dominated flow regime, estimate original oil in place (OOIP), ultimate oil recovery (EUR), average reservoir pressure and also obtain reservoir intrinsic properties which are productivity index, permeability, drainage area and skin. Blasingame type curve (figure 3), showed that each of flow rate data, rate integral and rate integral derivative trends gave a very good match with the dimensionless type curves. The well has started to show the response to the boundary at time (novembr-2012) which indicated by beginning of straight line. The Blasingame type curve analysis match showed by same figure resulted in finding of the OOIP and ultimate oil recovery 103346.7343 Mstb, 31004.0202 Mstb respectively. Well parameters that include drainage area, permeability, and skin factor of 1069.5281 acres, 11.8015 md, -2.15 respectively.

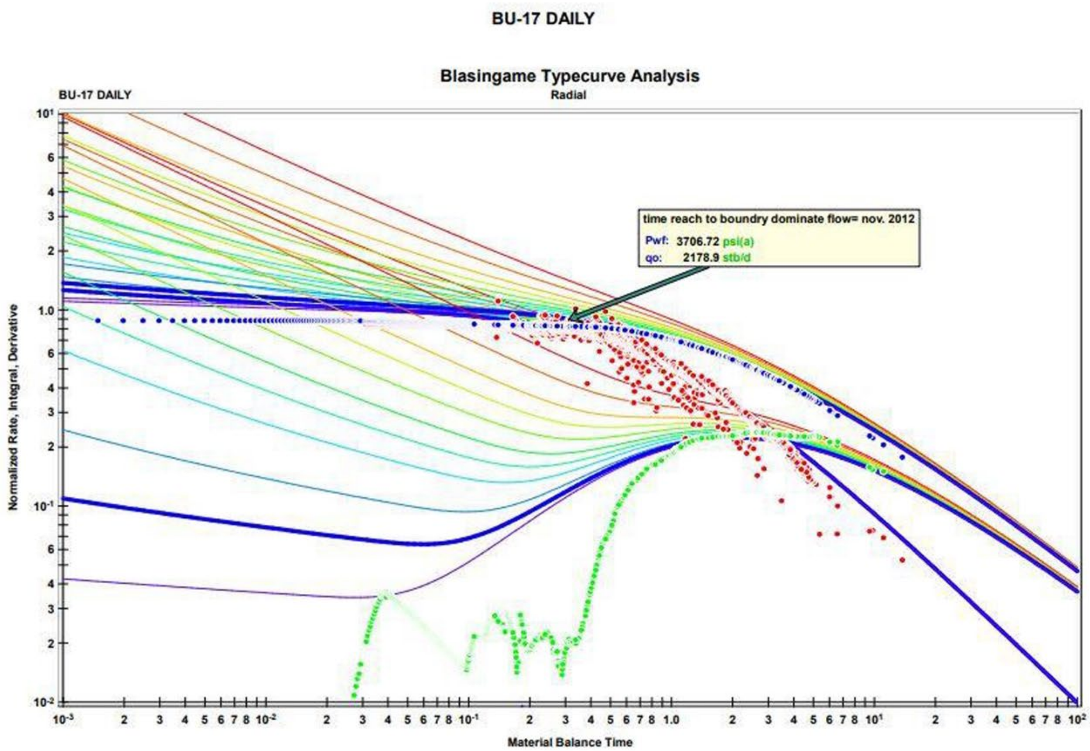

Figure 3. Blasingame type curve analysis of well BU-17

The third method was 'flowing material balance' technique. Flowing material balance technique was applied to the production data of well (BU-17) to estimate the volume of reserve (N), ultimate oil recovery (EUR), drainage area of well (A) and oil productivity index (PI) during the boundary dominated flow state. Since in this well most of data recorded during duration of boundary dominated flow, as Blasingame type curves show previously, and flowing material balance interpret the data during this period, the straight line that fit the data for this well was very clear, and obtained result was very analogous to that we get by Blasingame method. See Figures (3 and 4). Flowing material balance method resulted in estimates of original oil in place OOIP and expected ultimate recoverable of 106808.3573 Mstb and 32042.5072 Mstb. The derange area and productivity index of 1105.2930 acres and 1.2226 (bbl/d)/psi, respectively.

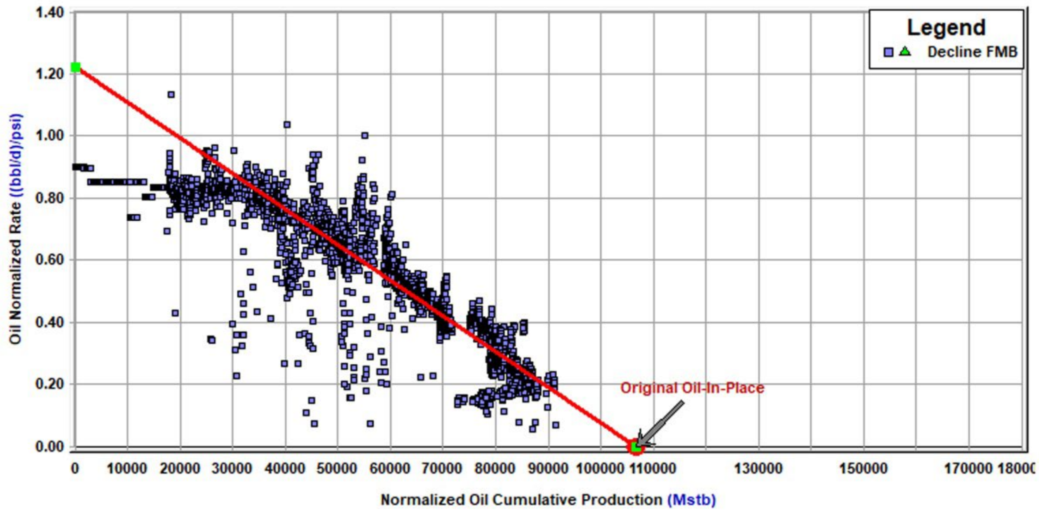

Figure 4. flowing material balance for well BU-17

Table 2 summarize the result obtained by the three method. As we noticed, original oil in place, ultimate oil recovery and drainage area estimated by Blasingame type curve analysis method compatible with the result found by the flowing material balance technique. But the ultimate oil recovery estimated by these two methods didn’t agree with the value estimated by empirical Arp's decline curve analysis method, the exponential analysis yields an EUR of about 5373.675 Mstb while Blasingame type curve and flowing material balance yields an EUR of about 31004.0202 Mstb and 32042.5072 Mstb respectively. When the effects of flowing pressures have been taken into account, the difference is clearly explained. Arp's analysis is based on production restrictions and its EUR determined by the extent of the drawdown if the drawdown along the forecasting duration was small the predicted EUR will be small. When the effect of magnitude and trend of flowing pressures is taken into account (as per the FMB and Blasingame), the EUR is found to be substantially larger than that suggested by Arps. The EUR recognized by Blasingame with flowing material balance is not constrained by the low percentage of drawdown, indicating the possibility of substantially higher reserves that recoverable.

Table 2. Summary of result

Parameters	Blasingame method	Flowing material balance method	Arp's method
EUR Mstb	31004.0202	32042.5072	5373.675
OOIP Mstb	103346.7343	106808.3573	
Drainage area A acre	1069.5281	1105.2930	
Permeability K Darcy	11.8015		
Skin factor S	-2.15		

5. Conclusions

A comprehensive production data analysis method was built and is currently being utilized to analyze field recorded production data in order to estimate well and reservoir parameters. There's no single technique for analyzing production data that can deal with all sorts of recorded data as well as reservoir types. The influence of flowing pressures on analysis quality is as important as the effect of production values. There is a high risk of misinterpretation when the flowing pressures were ignored. Using conventional Arps decline method of analyzing combined with both the 'Blasingame' & flowing 'material balance' techniques gives an excellent indication for determining if past or the immediate production characteristics are enough for well to achieve optimum fluids-in-place recovery. Flowing material balancing technique is explained, which provides a simple and straightforward method for calculating fluids-in-place without shutting down the well. This method handles boundary dominated period of flow more effectively than any other method of type curve analysis currently available.

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Nomenclatures:

A	*area in acres*
B_i	*initial formation factor in bbl/STB.*
b	*hyperbolic or harmonic exponent*
b_{pss}	*intercept with y axis of normalized PSS, in psi/bbl*
c_t	*total compressibility in psi invers*
Φ	*porosity in %*
h	*the net pay in foot*
k	*permeability in md*
μ	*viscosity in cP*
N	*Original Oil in Place in bbl*
p_D	*dimensionless of pressure*
p_{Di}	*dimensionless integral of pressure*
p_{Did}	*dimensionless integral derivative of pressure*
p_i	*initial value of pressure in psia*
PI	*normalized integral of pressure*
p_{id}	*normalized integral derivative of pressure*
p_{wf}	*flowing pressure at the bottom in psi*
Q	*rate of production in bbl/d*
q_D	*rate in dimensionless form*
Q	*cumulative rate of production in bbl*
r_e	*radius of reservoir in ft*
r_{eD}	*dimensionless radius*
r_{wa}	*apparent radius of well in ft*

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