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Enhancing Shale Gas Production Forecasting and EUR Estimation: A New Approach for Decline Curve Analysis

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Abstract

Accurate prediction of production levels and estimated ultimate recovery (EUR) is crucial for the development of shale gas reservoirs. Empirical decline methods are widely used in the oil and gas industry due to their simplicity and effectiveness. However, these methods often fail to provide accurate predictions for wells experiencing fluctuating production or transient flow (TF). To address this pressing issue, three empirical methods, namely Arps' decline method, stretched exponential production-decline method, and Duong method are compared based on their principles and characteristics.

The findings demonstrate that the Duong method exhibits the highest reliability. However, to overcome the impact of production fluctuations associated with wells exhibiting boundary-dominated flow (BDF), enhancements are proposed for Duong method. To illustrate, a new approach is suggested by combining Arps' method with the decline exponent of Duong method. This new approach aims to achieve reasonable production and EUR forecasts for wells experiencing a rapid and unstable decline in TF production.

To evaluate the accuracy and applicability of the new approach, field cases from the Haynesville Shale, Marcellus Shale, and Marcellus-Upper Shale in the United States of America are utilized. The comparative analysis between the new approach and the three aforementioned methods reveals a successful reduction in the error percentage during the transient flow period by 6 to 9% and the BDF period by 9 to 14%. These findings highlight the improved accuracy and applicability of the proposed approach, demonstrating its potential for predicting production and EUR in shale gas reservoirs characterized by fluctuating production and transient flow conditions.

Introduction

Shale gas development plays a significant role in meeting the growing global energy demand. One of the key challenges in this domain is the accurate evaluation of production levels and estimated ultimate recovery (EUR) in shale-gas wells. The ability to predict these parameters with high accuracy is essential for effective reservoir management and decision-making processes. In the oil and gas industry, empirical decline methods have been widely employed due to their simplicity and effectiveness [33]. However, their reliability in predicting results for wells with fluctuating production or transient flow (TF) remains questionable.

There are lots of empirical methods that can be used with unconventional reservoirs, these methods were discussed and compared with their characteristics and limitations which can be found in recent review papers [3,22,25,31,33.34]

One of the most used decline methods is Arps' method [4]. However, researchers suggested that Arps' decline curves are not suitable for tight/shale-gas wells [36]. This is because the decline exponent, b, varies with time and becomes greater than 1 as the transient flow (TF) progresses. Further, it varies between 0 and 1 during boundary-dominated flow (BDF), whereas in a shale-gas well, BDF is not often achieved.

To address this urgent issue, this study focuses on comparing and evaluating three empirical decline methods commonly used in the industry from different empirical methods [2,4,5,6,7,8,12,13,14,23, 29,30,32,37,38]. These three methods include Arps' decline method [4], Stretched Exponential Production Decline (SEPD) method[29,30], and Duong's method [6,7]. By examining the principles and characteristics of these methods, we aim to identify the most reliable approach for accurate production and EUR forecasting. However, these three methods don't give accurate production predictions when using short-production historical data [33].

The results of our analysis demonstrate that the traditional Duong method outperforms the other methods in terms of reliability. However, it is susceptible to the influence of production fluctuations and multiple solutions when dealing with wells that have achieved boundary-dominated flow (BDF) [19]. To overcome these limitations, improvements are proposed in the form of a new approach. This new approach aims to provide more robust predictions with only short production historical data in the presence of production fluctuations and BDF conditions. It combines Arps' method with the decline exponent of Duong's method, aiming to achieve reasonable production and EUR forecasting.

To evaluate the accuracy and universality of the new approach, field examples from the Haynesville Shale (Lorikeet Field), Marcellus Shale (Duck Field), and Marcellus-Upper Shale (Albatross Field) are employed.

Challenges Related to Analysing the Producing Shale Gas Wells

In the production of shale gas reservoirs, the extraction process involves drilling horizontal wells and implementing multiple stages of fracture stimulation, leading to the creation of a stimulated reservoir volume (SRV). The extent of the SRV is determined by factors such as the length of the horizontal well and the number of stimulation stages. However, this process gives rise to a complex system comprising interconnected natural fractures, hydraulic fractures, and an ultra-low permeability matrix. Consequently, a variety of flow regimes emerge, influencing the decline patterns observed in shale gas wells, as illustrated in Figure 1.

The decline trends in shale gas wells can be significantly influenced by various flow regimes [1]. These flow regimes are described as follows:

- Linear flow: This flow regime, occurring perpendicular to the hydraulic fractures from the matrix, can dominate throughout the well's lifespan. It is characterized by transient linear flow, which can be identified by plotting flow rate versus time on a Log-Log plot. In the absence of natural fractures, this plot exhibits a slope of -1/2.

- Linear-BDF flow: represents a combination of two distinct flow regimes observed in shale gas wells. It begins with a transient linear flow, followed by a transition to boundary-dominated flow (BDF). This transition typically occurs when the boundaries of the stimulated reservoir volume (SRV) are reached. On a Log-Log plot, the linear-BDF flow regime can be identified by a deviation from the -1/2 slope observed in the transient linear flow regime.

- Bilinear-Linear flow: In this flow regime, the initial assumption is bilinear flow, which is subsequently followed by linear flow. Bilinear-linear flow is commonly associated with the presence of natural fractures and typically occurs during the early stages of production for a limited duration. It is characterized by fluid movement linearly from the fractures to the well and simultaneously from the matrix linearly to the fractures. On a Log-Log plot, this flow regime is recognized by a slope of -1/4, followed by a slope of -1/2, indicating the presence of linear flow.

- Bilinear-Linear-BDF flow: This flow regime is identified on a Log-Log plot by a deviation from the -1/2 slope once again when the flow reaches the boundaries of the stimulated reservoir volume (SRV). It begins with the bilinear flow, followed by linear flow, and eventually transitions to boundary-dominated flow (BDF) as the SRV becomes depleted.

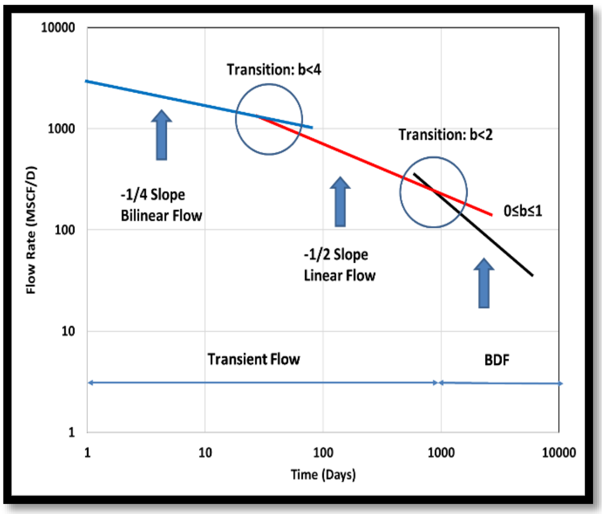

Figure 1 Identifying the Different Flow Regimes Based on the Slope Value on the Log-Log Plots.

Materials and Methods

Arps [4], Duong [6], and SEPD [29] are commonly used methods. These methods are extensively utilized due to their simplicity and effectiveness in predicting production trends and estimating the ultimate recovery of shale gas reservoirs. However, these three methods still suffer from the following challenges when using short-production historical data, as shown in Table 1.

Arps Method

The Arps' decline curve analysis (DCA) method [4], a widely employed technique in the petroleum industry, is commonly utilized for predicting future well performance and estimating the well's ultimate recovery (EUR).

The Arps model encompasses three methods: exponential, hyperbolic, and harmonic, which are characterized by the decline exponent. Equation 1 through Equation 3 demonstrates the mathematical formulations associated with each method.

Table 1 Correlation Formulae and Application Steps of the Three Most Widely Used Empirical Methods.

Method	Correlation formulae	Application steps	Characteristics
Arps' exponential Arps' hyperbolic Arps' harmonic	$q_t = q_i exp(-D_i t)$ $q_t = \frac{q_i}{(1+bD_i t)^{1/b}}$ $q_t = \frac{q_i}{(1+D_i t)}$	(1) The values of the initial rate qi, initial decline rate Di, and the decline exponent b are assumed (2) Regression is done on the three parameters to get the best matching and forecasting	(1) One of the main conditions is that the well should be in a boundary-dominated flow **Error! Reference source not found.** (2) The well is produced at a constant bottom-hole-flowing pressure **Error! Reference source not found.**. (3) Past production trends will continue in the future and, therefore, the trend can be extrapolated**Error! Reference source not found.**. (4) Not suitable for shale or tight gas ls**Error! Reference source not found.**]
SEPD	$q = q_i \cdot \exp[-(t/\tau_{\mathrm{SEDP}})^{n_{\mathrm{SEDP}}}]$	(1) Draw on log-log plot ln(−ln(q/qi)) = A + n·lnt (A is the curve intercept and n is the slope). (2) Obtain τ = $e^{-A/n}$ (3) Use the obtained parameters in the fitting calculation.	(1) The main condition that the well should be in BDF**Error! Reference source not found.**. (2) May leads to underestimate EUR **Error! Reference source not found.** (3) Needs at least 36 months of production data **Error! Reference source not found.**
Duong	$q = q_i \cdot t^{-m_D} \exp\left[\frac{a_D}{1-m_D}(t^{1-m_D}-1)\right]$	(1) Draw a log-log plot of q/Gp on the y-axis and time on the x-axis. (2) Draw a straight line through the values (3) Calculate the slope which equals m (4) Calculate the intercept which is the qi (5) Calculate the (a) value from the chart (6) Use the obtained parameters in the fitting calculation.	(1) Applicable on shale gas, consider the flow behavior and fit data from various shale plays very well. (2) May overestimate the reserve

The applicability of this model is primarily observed when the well is in a boundary-dominated flow (BDF) state and physical properties and bottom-hole pressure remain relatively constant. However, in the case of shale gas reservoirs, the decline exponent (b) is consistently greater than 1, necessitating the use of the super-hyperbolic model. The super-hyperbolic model employs the same expression as Equation 2 but introduces different ranges for the decline exponent (b).

Exponential Decline:

$$q_t = q_i exp(-D_i t) \quad (1)$$

Hyperbolic Decline:

$$q_t = \frac{q_i}{(1+bD_i t)^{1/b}} \quad (2)$$

Harmonic Decline:

$$q_t = \frac{q_i}{(1+D_i t)} \quad (3)$$

where; qt = gas flow rate at time t (Mscf/day), qi = initial gas flow rate (Mscf/day), t = time (Day), Di = initial decline rate (Day-1), b = Arps' decline-curve exponent.

Stretched Exponential Decline Production Method (SEDP)

In 1993, Kisslinger employed the stretched exponential function to model the decay rates of aftershocks [17]. This stretched decay can be conceptualized as a combination of pure exponential decay [15], as discussed by Johnston (2006). Building upon this concept, Valkó and Lee developed a novel model for predicting decline rates in production data from unconventional reservoirs, as outlined in their work [20,29,30]. This approach does not rely on a single parameter interpretation but instead incorporates gamma functions. The parameters (n) and (τ) represent summations of multiple exponential declines rather than singular parameters. Additionally, the estimated ultimate recovery (EUR) is no longer an infinite value but instead bounded and independent of time or rate [38]. This empirical model can fit both transient and boundary-dominated flow (BDF) scenarios, and it was derived by analyzing production data from over 12,800 wells in the Barnett Shale Play. The mathematical methods derived from this model are demonstrated in Equations 4 to 6.

$$\boldsymbol{q = q_i \cdot \exp[-(t/\tau_{SEDP})^{n_{SEDP}}]} \quad (4)$$

$$G_P = q_i\left(\frac{\tau_{SEDP}}{n_{SEDP}}\right)\left\{\Gamma\left(\frac{1}{n_{SEDP}}\right) - \Gamma\left[\frac{1}{n_{SEDP}}, \left(\frac{t}{\tau_{SEDP}}\right)^{n_{SEDP}}\right]\right\} \quad (5)$$

$$EUR = \frac{qi^{\tau_{SEDP}}}{n_{SEDP}}\tau_{SEDP}\left[\frac{1}{n_{SEDP}}\right], \quad (6)$$

where; n_{SEDP} is the model parameter (dimensionless), τ_{SEDP} = model parameter (day), $\Gamma\left(\frac{1}{n}\right)$ is gamma function and $\Gamma\left[\frac{1}{n}, \left(\frac{t}{\tau}\right)^n\right]$ is the incomplete gamma function.

It was found that the SEPD approach could significantly underestimate future production and estimated ultimate recoveries (EURs) for wells with short production histories, particularly in reservoirs with permeability ranging from 0.0001 to 0.1 millidarcy (md).

It is worth noting that the model takes into account reservoir heterogeneity [10]. Accurately estimating the parameters (n) and (τ) requires a significant amount of production data, typically over 36 months [24].

Duong Method

Tight or shale gas reservoirs exhibit remarkably low permeability, resulting in an extended production duration characterized by transient flow that can span several years. In these reservoirs, the contribution of the fracture system to production is significant, while the matrix contribution is negligible. To effectively capture the decline behavior of shale gas wells, Duong proposed an approach that is independent of fracture type (finite conductivity, infinite conductivity, natural or artificial), well type (vertical or horizontal), or completion type (single or multi-stage) [6,7]. This model was developed based on the assumption of constant bottom-hole flowing pressure [22], and its mathematical representation can be found in Equations 7 and 8, as demonstrated in the works of Lee and Hu [11,21]

$$\frac{q_g}{G_P} = at^{-m} \quad (7)$$

$$q = q_i \cdot t^{-m_D}\exp\left[\frac{a_D}{1-m_D}\left(t^{1-m_D} - 1\right)\right] \quad (8)$$

Where; a_D is an intercept constant (d^{-1}), and m_D is the slope.

It is important to note that the exponent "m" is always a positive number in all calculations. However, Paryani et al. (2018) highlighted two issues related to this model [26]: extended shut-in periods and water breakthrough. To accurately determine the (a) and (m) parameters, a log-log plot of q/Gp versus time is drawn where the (a) value is the intersection of the straight line with the y-axis and the (m) value is the slope

Decline Rate and Decline Exponent

Johnson and Bollens introduced the concept of the loss ratio**Error! Reference source not found.**, which characterizes the declining behavior of production rates. For reference, Equations 9 through 11 provide the definitions of the loss ratio and its second derivative, the decline exponent (b).

Decline parameter

$$D(t) = -\frac{1}{q(t)}\frac{dq(t)}{dt} \quad (9)$$

Loss Ratio

$$\frac{1}{D(t)} = -\frac{q(t)}{dq(t)/dt} \quad (10)$$

Decline exponent

$$b(t) \equiv \frac{d}{dt}\left[\frac{1}{D(t)}\right] = -\frac{d}{dt}\left[\frac{q(t)}{dq(t)/dt}\right] \quad (11)$$

Where qt = gas flow rate at time t, (Mscf/day), t = time (Day), b = Arps' decline-curve exponent.

While obtaining these parameters directly from the definition or through regression may seem straightforward, it is important to note that analyzing them thoroughly provides significant valuable information. This analysis helps in characterizing the reservoir, as these parameters govern the variations in production rate over time. Consequently, they have an impact on various aspects, including reservoir boundaries, driving mechanisms, wellbore, production conduit, and wellhead operation conditions. The decline rate and decline exponent of the three mentioned methods are driven by the above three equations and are described in Table 2.

A New Approach for Shale Gas Wells

One of the main challenges when predicting the production decline of shale gas reservoirs is to accurately estimate the ultimate recovery during both periods transient and BDF. Also, it's so difficult to make accurate predictions during the first six months to the first year as the available history data are not enough to give an accurate prediction.

To address this issue, a new decline approach is developed to overcome this drawback and to give an accurate forecast after 150 days of production.

This new technique is a combination of the decline exponent of Duong's method and Arps' decline equation.

Methodology

1. Draw q/Gp versus time on a log-log plot and fit the data by drawing a straight line through the data as shown in Figure 2.
2. Calculate the intercept value (a) and the slope value m.

3. Choose the highest value of production rate for qi.

Table 2 Decline Rate and Decline Exponent of the Three Different Methods

Model	Decline rate (Dt)	Decline exponent (b)
Exponential Arps' (1945)	$D(t)= D\mathrm{i}$	b=0
Hyperbolic Arps' (1945)	$D(t) = \frac{D_i}{1 + D_i * b * t}$	0<b<1
Harmonic Arps' (1945)	$D(t) = \frac{D_i}{1 + D_i * t}$	b=1
Duong(2010,2011)	$D(t)=\frac{m}{t}-\frac{a}{t^m}$	$b=\frac{m\,t^m(t^m-at)}{(at-mt^m)^2}$
SEPD (2010)	$D(t) = \frac{n_{SEDP}\, t^{n_{SEDP}-1}}{t^{n_{SEDP}}}$	$b = \frac{(-n_{SEDP}+1)t^{n_{SEDP}}t^{-n_{SEDP}}}{n_{SEDP}}$

4. History matches 150 days of data and predicts the rest of the days.
5. Regression is done on the three assumed parameters (qi, a, m) to match the first 150 days.
6. Calculate the decline exponent of the Duong method at each time step through Equation 12

$$b=\frac{m\,t^m(t^m-at)}{(at-mt^m)^2} \quad (12)$$

7. Calculate the production rate using Arps' equation by substituting the b value of Arps' with the calculated b value of Duong's method.
8. Define the time at which the TF end and the BDF start.
9. Calculate the mean absolute error percent during the TF and BDF periods.

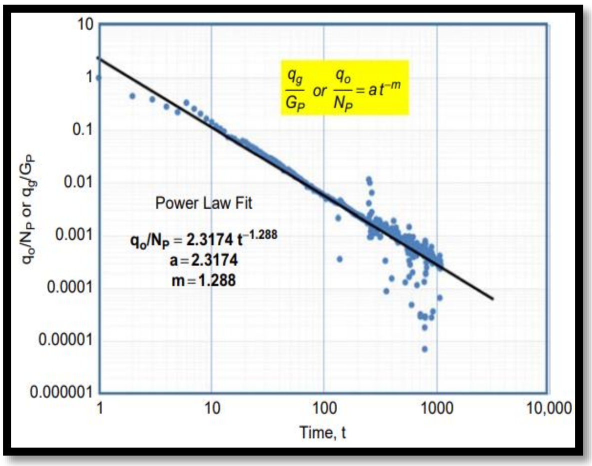

Figure 2 Duong's Power Law Concept [1]

Cases Study

This study is based on actual data that was released in 2021 on the SPE official website. The

data consists of more than forty wells of dry gas in shale gas reservoirs. Three wells were selected. The selection was based on choosing wells from different fields, different reservoirs, and different flow regime times. The reservoirs are the Haynesville Shale (Lorikeet Field), Marcellus Shale (Duck Field), and Marcellus-Upper Shale (Albatross Field).

Calculation and Matching Procedure

This is a description of the calculation and matching procedure for each model,

1. A log-log plot of rate versus time is done for each well to know their flow behavior and the time at which the flow reached the boundary.
2. All methods were programmed using the visual basic in Excel (VBA).
3. The matching procedure for each case was performed using a semi-log basis (log q vs. t).
4. In each of the data cases, history matching is done using 150 days.
5. To determine the best fit for each case, the mean absolute error percent was employed between the actual values and the calculated values of the field data.
6. Comparison and analysis are done for all three cases to see the effect of using the new decline approach for Duong, SEPD, and Arps'.

Results and Discussion

Case 1_Bilinear-Linear-Boundary Dominated Flow

Well_1 is a dry gas well that is located in the US and produces from Haynesville shale with an initial rate of 11,900 MSCFD. A log-log plot of rate versus time indicates the presence of all the different flow regimes together as shown in Figure 3. A bilinear -1/4 slope is observed during the early time followed by linear flow regimes of the -1/2 slope. Also, I is's shown that the fluid reaches the boundary at an early time (200 days) during the first year of production.

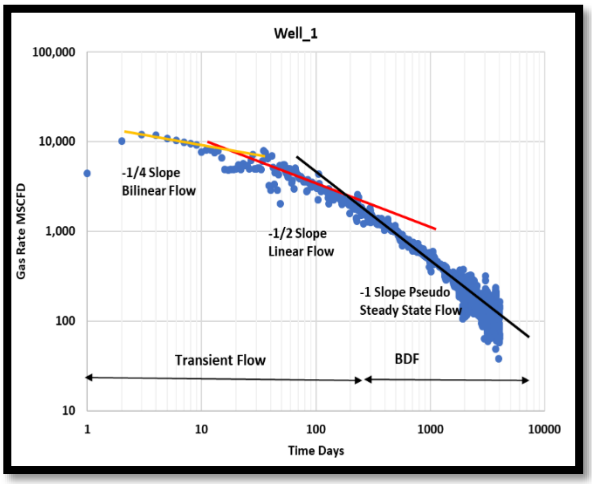

Figure 3 Identifying The Different Flow Regimes of Well_1 Based on The Slope Value on The Log-Log Plots**.**

To perform Duong's method, a log-log plot of q/Gp versus time is done to calculate the intercept of the line (a) and the slope (m) as shown in Figure 4. Then, regression is done on the calculated variables (a,m) as shown in Table 3 to have the least mean absolute error percent between the calculated and the actual production rate during the first 150 days.

A semi-log plot of rate versus time was plotted and 150 days of the data are matched and the 3850 days are predicted using the four different methods (Arps', Duong, SEPD, New Approach) as shown in Figure 5. The mean absolute error percent of every method during both the transient and BDF is calculated as indicated in Table 6.

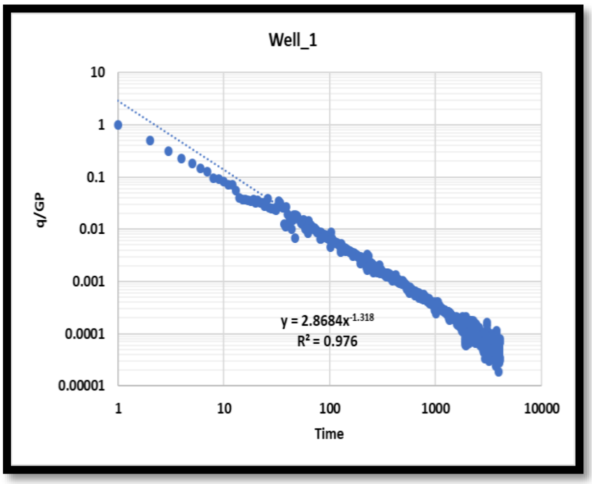

Figure 4 Duong's Power Law Plot for Well_1

Table 3 The Results of The Assumed Values From The Log-log of q/Gp Vs.Time and The Adjusted Values After The Regression

Parameters	Assumed values	Adjusted values
qi Mscfd	3000	2999
a	2.8684	2.0836
m	1.318	1.2437

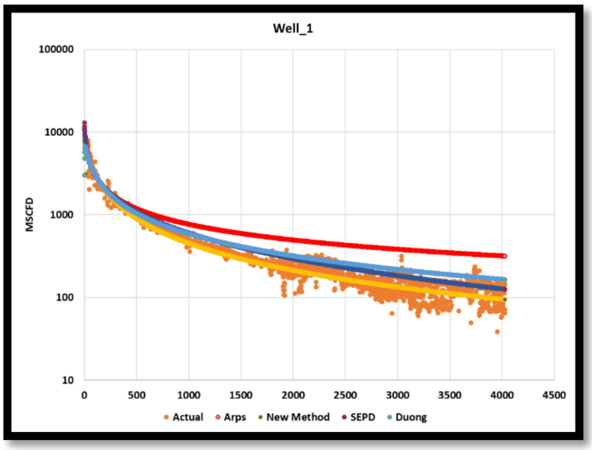

Figure 5 Fitting 150 Days of Data Length and Prediction 3850 Days During Transient and BDF Using Arps', Duong, SEPD, and The New Approach.

Case 2_ Bilinear-Linear-Boundary Dominated Flow

Well_2 is a dry gas well that is located in the US and produced from Marcellus shale with an initial rate of 6,800 MSCFD. A log-log plot of rate versus time indicates the presence of the three types of flow regimes as shown in Figure 6. A bilinear -1/4 slope is observed during the early time followed by linear flow regimes of the -1/2 slope. Also, it's shown that the fluid reaches the boundary after 500 days of production.

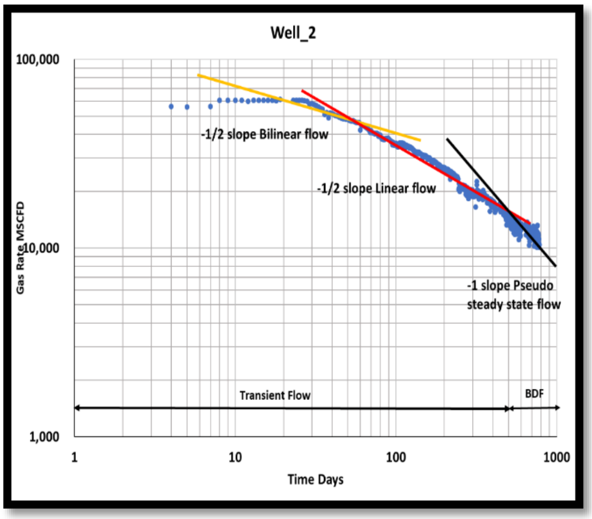

Figure 6 Identifying The Different Flow Regimes of Well_2 Based on The Slope Value on The Log-Log Plots.

To apply Duong's method, a log-log plot of production rate (q) divided by cumulative production (Gp) versus time is utilized. This plot allows for the determination of the line's intercept (a) and slope (m), as illustrated in Figure 7. Subsequently, regression analysis is conducted on these calculated variables (a and m), as presented in Table 4, aiming to minimize the mean absolute error percentage between the predicted and actual production rates within the initial 150 days.

For the purpose of comparison, a semi-log plot of production rate versus time is generated, focusing on 150-days. This data is matched with the observed values, while the subsequent 625-day period is predicted using four different methods: Arps', Duong, SEPD, and the new approach. The results of this comparison are visualized in Figure 8. To assess the accuracy of each method, the mean absolute error percentage is calculated for both the transient flow and boundary-dominated flow periods, as shown in Table 6.

Table 4 The Results of The Assumed Values From The Log-log of q/Gp Vs.Time and The Adjusted Values After The Regression

Parameters	Assumed values	Adjusted values
qi Mscfd	**3000**	**3001**
a	2.6291	3.5258
m	1.245	1.315

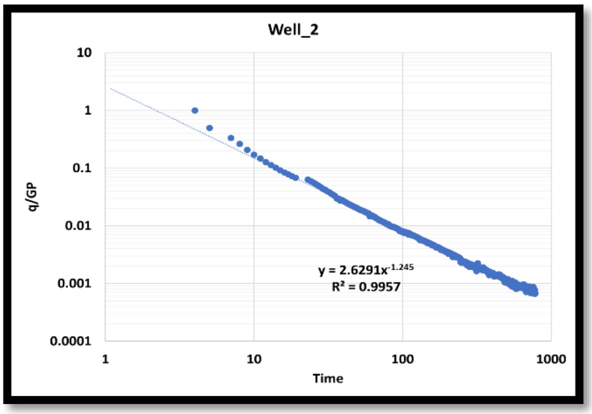

Figure 7 Duong’s Power Law Plot for Well_2

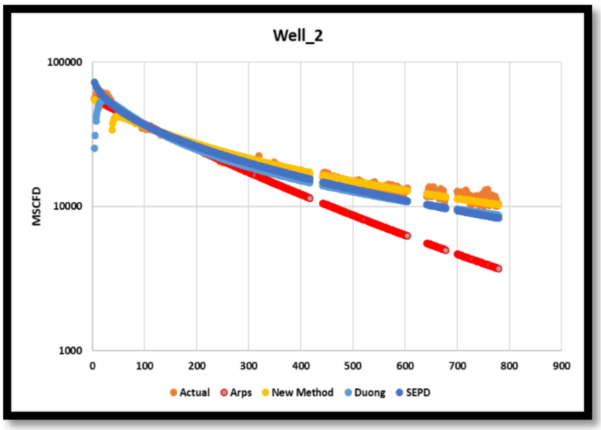

Figure 8 Fitting 150 Days of Data Length and Prediction 625 Days During Transient and BDF Using Arps’, Duong, SEPD, and The New Approach.

Case 3_ Bilinear-Linear Flow

Well_3, located in the United States, is a dry gas well produced from the Marcellus-Upper shale formation. It has an initial production rate of 9,200 thousand standard cubic feet per day (MSCFD). Analyzing the log-log plot of production rate versus time, it can be observed from Figure 9 that the well is still experiencing transient flow and has not yet reached the boundary condition.

During the early time period, the plot exhibits a bilinear flow behavior with a slope of -1/4, followed by linear flow regimes with a slope of -1/2. To apply Duong's method, a log-log plot of production rate divided by cumulative production (q/Gp) versus time is utilized. This plot allows for the calculation of the intercept (a) and slope (m), as depicted in Figure 10. Regression analysis is then performed on these calculated variables (a and m), as presented in Table 5, aiming to minimize the mean absolute error percentage between the predicted and actual production rates during the first 150 days.

In order to assess the performance of different methods, a semi-log plot of production rate versus time is generated. The observed data for a 150-day period is matched, and predictions for the subsequent 630 days are made using four different methods: Arps', Duong, SEPD, and the new approach. The results of this comparison are visualized in Figure 11. To quantify the accuracy of each method, the mean absolute error percentage is calculated for the transient flow period, as presented in Table 6.

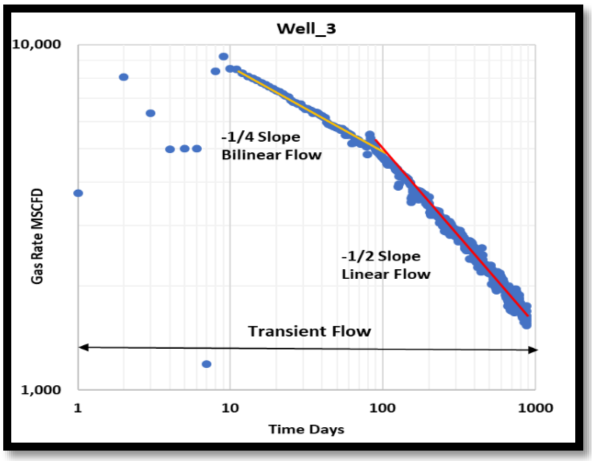

Figure 9 Identifying The Different Flow Regimes of Well_3 Based on The Slope Value on The Log-Log Plots.

Table 5 The Results of The Assumed Values From The Log-log of q/Gp Vs.Time and The Adjusted Values After The Regression

Parameters	Assumed values	Adjusted values
qi Mscfd	**3000**	**3001**
a	1.2857	3.5258
m	1.117	1.315

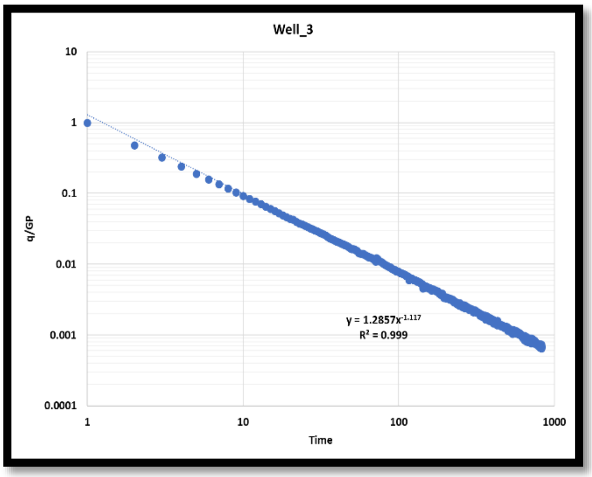

Figure 10 Duong’s Power Law Plot for Well_3

Table 6 Results Estimated for 5 Wells by Duong, Arps', and The New Developed Approach Using the Historical Production Data in TF and BDF

Well name	Number of production days	BDF beginning time, days	Data prediction in TF				Data prediction in BDF			
			Duong Error%	Arps Error%	SEPD Error%	New Approach Error%	Duong Error%	Arps Error%	SEPD Error%	New Approach Error%
Well_1	4027	200	2%	3%	4%	2%	42%	124%	29%	16%
Well_2	780	500	8%	18%	5%	5%	16%	53%	16%	5%
Well_3	830	Not yet	10%	20%	13%	4%	Didn't reach the boundary			

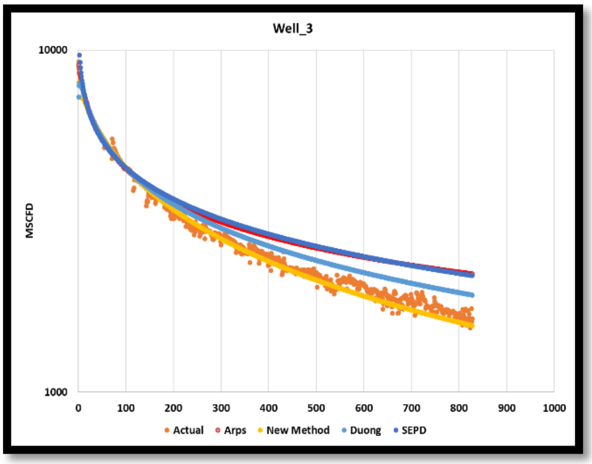

Figure 11 Fitting 150 Days of Data Length and Prediction 630 Days During Transient and BDF Using Arps', Duong, SEPD, and The New Approach.

Conclusions

This study examines the fundamental characteristics and suitability of the commonly used empirical methods for shale gas wells. It investigates the limitations and challenges associated with these methods and offers potential solutions to address them. The key findings of this research can be summarized as follows:

1. The proposed New Approach can be obtained by substituting the decline exponent of Duong's method in Arps' equation to overcome the drawback of Arps' method when using with shale gas reservoirs; as the New Approach states that the b exponent is changing with time instead of constant value as mentioned in Arps' method.
2. For the case study of the Haynesville shale, when the BDF is reached at an early time (in the first year), the New Approach succeeded in reducing the error percent during the BDF period by 14 % compared to the best-matched method SEPD and this is a huge improvement in prediction.
3. For the case study of the Marcellus shale, when the BDF is reached at a later time, the New Approach succeeded in reducing the error percent during the BDF period by 11 % compared to the best-matched methods Duong and SEPD.
4. For the case study of Marcellus-Upper when the flow is still in the transient regime. the New Approach succeeded in reducing the error percent during the TF period by 6 % and 9% compared to the best-matched method Duong and SEPD.
5. From all three cases, it can be concluded that the New Approach succeeded in reducing the error percent during the transient flow period by 6 to 9 % and during BDF by 11 to 14 % compared to the best-matched method.

List of Abbreviations

BDF	=	Boundary Dominated Flow
BHP	=	Bottom Hole Pressure
DCA	=	Decline Curve Analysis
EUR	=	Estimated Ultimate Recovery
SEPD	=	Stretched Exponential Decline Model
SRV	=	Stimulated Reservoir Volume
TF	=	Transient Flow
VBA	=	Visual Basic in Excel

Nomenclature

a	=	Intercept of Duong's Method
b	=	Decline-Curve Exponent
D	=	Decline Rate (Day-1)
Di	=	Initial Decline Rate (Day-1)
Gp	=	Gas Cumulative Production (Mscf)
m	=	Slope of Duong's Method
nSEDP	=	Model Parameter (dimensionless),
q	=	Gas Flow Rate (Mscf/D)
q_t	=	Gas Flow Rate at Time t (Mscf/D)
qi	=	Initial Gas Flow Rate (Mscf/D)
t	=	Time (day)
τSEDP	=	Model Parameter (day)

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Conflicts of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest

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