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Maximizing Estimated Ultimate Recovery from Unconventional Gas Reservoirs: A Decline Curve Analysis Approach

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INFORMATION

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ABSTRACT

This research investigates the application of decline curve analysis to estimate ultimate recovery and production life of unconventional gas wells. By analyzing production data from 14 wells, including both primary and refractured wells, we aim to quantify the impact of hydraulic fracturing on well performance and reservoir productivity. The study employs the Arps decline curve model to characterize production trends and predict future production rates. The results demonstrate that refractured wells exhibit significantly higher recovery factors compared to primary wells. This finding underscores the importance of hydraulic fracturing as a stimulation technique to enhance production from unconventional gas reservoirs. The insights gained from this study can aid in optimizing field development strategies, maximizing economic returns, and mitigating production decline.

1. Introduction

Decline Curve Analysis (DCA) is a fundamental tool in reservoir engineering, employed to predict future production rates and estimate ultimate recovery from oil and gas wells. Arps' equations, a set of empirical models, are widely used in DCA to characterize production decline trends. These models, including exponential, hyperbolic, and harmonic decline, are fitted to historical production data to forecast future performance (Alagoz et al., 2023; Alagoz and Dundar, 2023; Alagoz and Dundar, 2024).

Accurate estimation of ultimate recovery is crucial for economic evaluations, field development planning, and reserve categorization. Proven, probable, and possible reserves represent different levels of certainty regarding hydrocarbon recovery. By employing DCA techniques and analyzing production data, engineers can gain valuable insights into reservoir behavior and make informed decisions regarding field development and production optimization (Alagoz et al., 2024a; Alagoz et al., 2024b).

Maximizing Estimated Ultimate Recovery (EUR) in unconventional gas reservoirs relies on effective completion techniques like hydraulic fracturing and refracturing. While hydraulic fracturing enhances productivity in low-permeability formations, fractures may close over time, requiring proppants to maintain their effectiveness. When initial completions fall short, refracturing can rejuvenate production. Decline curve analysis, particularly hyperbolic modeling, is essential for evaluating production performance and optimizing recovery strategies.

2. Field History

The Marcellus Shale is a Middle Devonian-age geological formation renowned for its significant natural gas reserves. This black, low-density shale spans the subsurface of New York, Pennsylvania, Ohio, and West Virginia, often at depths exceeding one mile below the surface. The formation primarily consists of organic-rich black shale interbedded with limestone, making it an exceptional target for hydrocarbon exploration and production. Its geologic characteristics, such as high total organic carbon (TOC) content and favorable porosity, have established the Marcellus Shale as one of the most prolific natural gas reservoirs in North America.

Over time, the Marcellus Shale has demonstrated remarkable growth in gas production, playing a transformative role in the U.S. energy landscape. Analyzing monthly dry shale gas production trends reveals that while its development initially lagged behind other major shale formations, it quickly surpassed them to become the leading contributor to national shale gas output. This rapid ascent is attributed to advancements in horizontal drilling and hydraulic fracturing technologies, which have unlocked the vast potential of this unconventional resource. Today, the Marcellus Shale is central to the U.S. natural gas supply, underpinning energy security and driving economic growth in the regions it underlies.

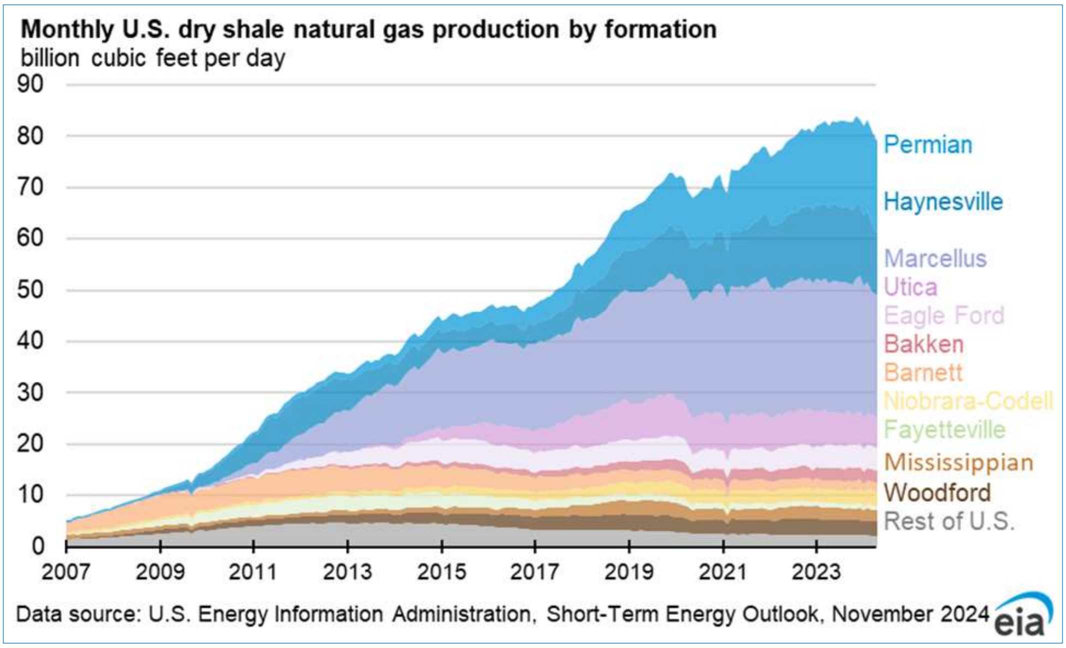

Fig. 1. Monthly US Dry Shale production (US Energy Information Administration, 2024)

3. Methodology

DCA using Arps' equations is widely recognized as an essential tool in petroleum engineering for estimating the EUR of oil and gas wells. The methodology is particularly favored for its simplicity and effectiveness, especially when compared to more complex reservoir simulation models (Alagoz et al., 2023). Arps' equations—exponential, hyperbolic, and harmonic decline models—are applied to production data to characterize how the production rate decreases over time, helping engineers forecast future production and evaluate reservoir performance.

In practice, the DCA process begins by fitting the decline models to historical production data, typically plotted on a Cartesian scale. As the production data is analyzed, different stages of decline behavior often emerge. Initially, production might follow one pattern (exponential or hyperbolic), but as well as the ages decline rate may change, and a different model may become more suitable (Houghton et al., 2020; Li et al., 2021).

These transitions highlight the challenges engineers face in determining the most accurate decline model for each stage of the well's life. This type of analysis is essential for optimizing recovery strategies and understanding reservoir dynamics.

For example, the exponential decline model is most applicable when the reservoir is in boundary-dominated flow, where the decline rate is constant, whereas hyperbolic and harmonic models are used in transient flow conditions when the decline rate slows over time (Arps, 1945). The ability to choose the appropriate model is key to producing reliable EUR estimates, which are critical for both economic analysis and reservoir management decisions.

Thus, despite the advancement in more sophisticated simulation technologies, Arps' decline curve models continue to play a vital role due to their adaptability, simplicity, and efficiency in production forecasting. To investigate this phenomenon, an initial hypothesis was formulated: each well's decline curve transitions between two distinct behaviors over the reservoir's lifespan. To test this hypothesis, it was first assumed that the decline curve adhered to a single behavior throughout the reservoir's life. For simplicity, an exponential decline model was applied, as it is characterized by a b-exponent of 0 and requires fewer parameters to estimate cumulative production. This choice served as a baseline for evaluating whether the observed decline curves exhibit consistent or variable behavior.

The process began by converting production time data into days and calculating the daily gas flow rates. These rates were then plotted against time on a Cartesian scale to analyze the decline behavior. Fig. 2 illustrates a representative decline curve plot, showing gas production rates versus time. Observing the changes in the curve's behavior provided insights into the dynamic nature of production decline, further validating the hypothesis of evolving decline patterns during the reservoir's lifecycle. This analysis underscores the importance of accurately characterizing production decline for robust EUR predictions and reservoir management strategies.

The following methodology was employed to estimate the well life based on production data. The process begins by utilizing two production flow rates, q1 and q2 recorded at two distinct times, t1 and t2 to determine the nominal decline rate (D). This is achieved using the formula:

$$D = \frac{\ln(q_1/q_2)}{t_2 - t_1} \tag{1}$$

This approach facilitates the calculation of the decline rate by examining changes in production rates over a defined time interval. By accurately determining "D", it is possible to model production trends and predict the time at which the well will no longer be economically viable. This method underscores the importance of precise data collection and analysis in optimizing well performance and forecasting long-term production behavior. To estimate the well life, the nominal decline rate (D) is used alongside the initial production flow rate (qi) and the final flow rate (q). The calculation employs the following formula:

$$t = \frac{\ln(q_i/q)}{D} \tag{2}$$

This formula determines the time required for the production rate to decline from qi to q under the assumption of a constant nominal decline rate. By incorporating these parameters, the method provides a reliable estimation of the well's productive lifespan, aiding in the planning and management of reservoir exploitation strategies.

The well life values obtained from the previous step were used to validate the hypothesis regarding the behavior of decline curves. Specifically, these calculations were intended to determine whether the production decline for each well followed a single decline type or transitioned between two distinct types over time.

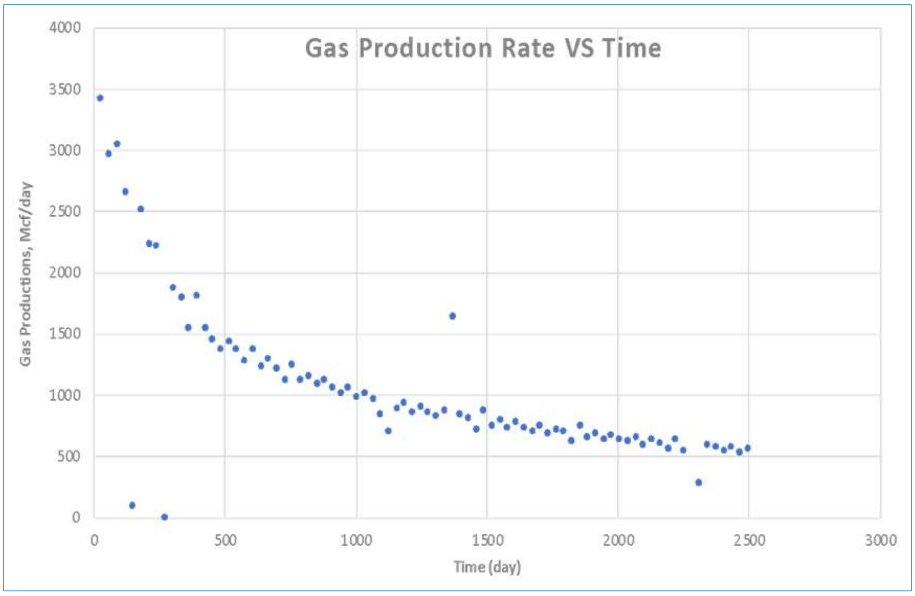

Fig. 2. Decline curve example

The methodology was applied to 14 wells, and the resulting well life estimates yielded implausible values, exceeding several million years. Such results are physically unrealistic for natural gas wells, as it is not feasible for them to sustain production over such an extended timeframe. These findings corroborated the initial assumption, confirming that the decline curves exhibit a change in behavior. The evidence strongly suggests that the decline curves start with one type during the early life of the well and, at a certain point, transition to a different decline type. This observation highlights the dynamic nature of production decline and emphasizes the need for models that can account for these transitions to improve production forecasting accuracy.

Following the confirmation that production decline behavior involves two distinct decline curve types, further analysis was conducted to determine the specific nature of this transition. The research revealed that natural gas production rates initially follow an exponential decline curve during the early life of the well. At a certain point, the decline behavior transitions to a hyperbolic decline curve, which continues until the well reaches full depletion. This understanding was pivotal for advancing the project, as it provided a framework for accurately modeling production behavior over the well's lifespan.

The key challenge was identifying the precise transition point at which the decline curve shifts from hyperbolic to exponential behavior. According to insights from the Oil and Gas Property Evaluation textbook, plotting the production rate versus time on a semi-logarithmic scale offers a solution. In such a plot, the production data forms a straight line once the decline transitions to an exponential curve. This critical information enabled the identification of the transition point, where the decline behavior changes. Fig. 3 illustrates a representative semi-log plot of production rate versus time, clearly indicating the point at which the curve transitions to a straight line, signaling the onset of exponential decline. This methodology provides a robust approach for accurately characterizing production decline and improving the reliability of production forecasts.

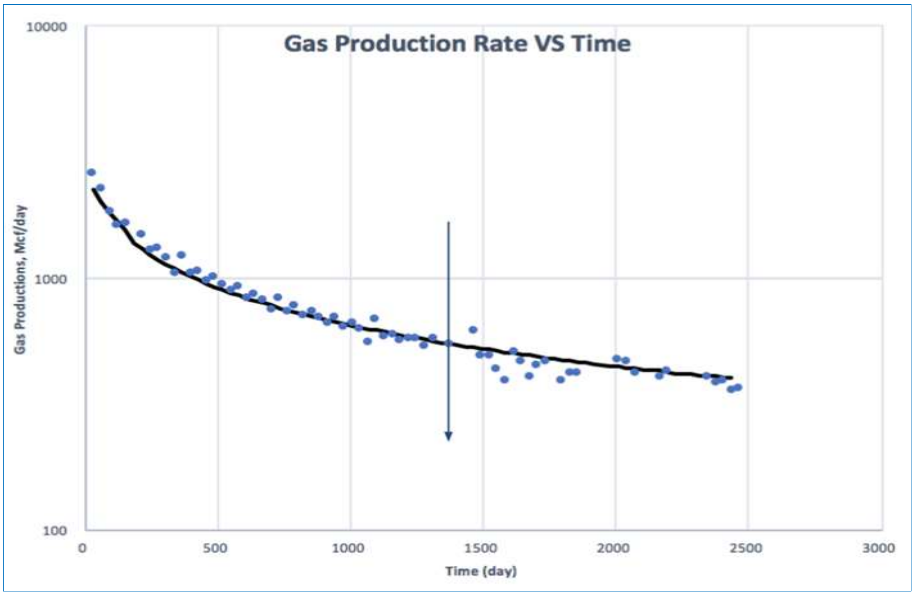

Fig. 3. Semi-log plot of production rate vs time

Once the transition time between hyperbolic and exponential decline curves is identified, calculating the EUR for each well becomes straightforward. Each decline phase within a well's lifecycle is treated separately, and the required parameters are determined using Arps equations. This process involves calculating the cumulative production and the lifespan of the well for both the hyperbolic and exponential decline phases. The total EUR is then computed as the sum of the EUR values for each decline phase, while the total well life is the sum of the durations of the hyperbolic and exponential decline periods.

For this study, the following procedure was employed to estimate the ultimate recovery and lifespan of natural gas wells using cumulative production data (in MCF) and production time (in date format):

1- Convert the date values to time in days, then calculate the daily production rate (q) in MSCF/Day by dividing cumulative production by time in days.
2- Using spreadsheet software such as Excel, plot the gas flow rate (q) versus time in days to generate the decline curve.
3- To determine the hyperbolic decline exponent (b) and the initial decline rate (di), apply curve-fitting techniques. This involves using the hyperbolic decline equation:

$$q(t) = q_i\left(1 + b \cdot d_i \cdot t\right)^{-\frac{1}{b}} \quad (3)$$

To accurately calculate the well life and EUR for the hyperbolic portion of the decline curve, the following steps were taken:

3.1. Identifying the Transition Time

The first step involves determining the time at which the decline curve transitions from hyperbolic to exponential. This is achieved by converting the production data to a semi-logarithmic plot. The point at which the curve starts to approximate a straight line on the x-axis represents the transition time. This point, denoted as $tswitch$, is recorded as the time when the transition occurs.

3.2. Flow Rate at Transition Time

Once the transition time is identified, the flow rate q at $t$switch is calculated using the hyperbolic decline equation:

$$q(t) = q_i\left(1 + b \cdot d_i \cdot t\right)^{-\frac{1}{b}} \quad (4)$$

Here, b and di are the parameters obtained through curve fitting, and $t$switch is the time at which the curve transitions to an exponential decline. This calculation provides the flow rate at the specific time when the production shifts from hyperbolic decline to exponential decline.

Calculating Cumulative Production and Well Life for Hyperbolic Decline: With the flow rate at the transition time and all other required parameters now known, the cumulative production and life of the well for the hyperbolic decline phase can be calculated. These values are derived by plugging the relevant parameters into the appropriate formulas for hyperbolic decline. By doing so, the total cumulative production and the remaining life of the well during the hyperbolic phase are estimated, providing a comprehensive understanding of the well's performance during this period.

This methodology allows for precise estimation of well life and EUR by accounting for the transition between different decline curve types, ultimately improving production forecasts and reservoir management.

$$Q = \frac{q_i^b}{(1-b)D_i}\left(q_i^{1-b} - q^{1-b}\right) \tag{5}$$

$$t = \frac{\left(q_i / q_{el}\right)^b - 1}{bD_i} \tag{6}$$

Calculate the nominal decline rate D for the exponential part using the following equation, where q1 and q2 can be any points on the exponential curve.

To calculate the nominal decline rate (D) for the exponential portion of the production decline, the following equation is used:

$$D = \frac{\ln\left(\frac{q_1}{q_2}\right)}{t_2 - t_1} \tag{7}$$

Here, $q1$and $q2$ represent the production rates at any two points on the exponential decline curve, and $t1$ and $t2$ are the corresponding times in days. This equation allows for a precise determination of D by measuring the natural logarithmic difference in production rates over a specified time interval. Using this method ensures that the nominal decline rate for the exponential phase is accurately captured, enabling the calculation of cumulative production and well life for this portion of the decline curve. This step is integral to modeling the overall production behavior and optimizing resource recovery predictions.

After determining the nominal decline rate (D) for the exponential portion of the production curve, the well life and EUR for this segment can be calculated using the following formulas:

$$Q = \frac{q_i - q}{D} \tag{8}$$

$$t = \frac{\ln(q_i / q)}{D} \tag{9}$$

Here, qi is the initial production rate at the start of the exponential decline, q is the flow rate at the economic limit (estimated as 3 MSCF/day), and D is the nominal decline rate.

To estimate the overall performance of the well, the following calculations were performed:

3.3. Total EUR

The total EUR for the well is obtained by summing the cumulative production from the hyperbolic and exponential portions of the decline curve:

$$EUR_{total} = EUR_{hyperbolic} + EUR_{exponential} \tag{10}$$

This represents the complete recovery potential of the well over its productive lifespan.

3.4. Total Well Life

The total productive life of the well is calculated by summing the well life determined for the hyperbolic and exponential phases:

$$Life_{total} = Life_{hyperbolic} + Life_{exponential} \tag{11}$$

This value indicates the combined duration of production for both decline phases, accounting for the transition in decline behavior. Additionally, a summary table is provided, presenting the equations used to calculate EUR and well life for the three primary decline curve types: Hyperbolic, Harmonic, and Exponential. This tabulated summary highlights the methodologies employed, ensuring clarity and consistency in the calculations across different decline behaviors. This comprehensive approach ensures a precise estimation of the well's recovery potential and production lifespan, enabling better reservoir management and decision-making.

The total EUR for a well is determined by summing the cumulative production from both the hyperbolic and exponential segments of the decline curve. This comprehensive calculation provides an accurate representation of the total recovery potential of the well over its productive lifespan. By accounting for both decline phases, the analysis ensures that the transition between the hyperbolic and exponential behaviors is adequately captured, leading to a realistic estimation of the well's ultimate recovery.

Similarly, the total productive life of the well is calculated by combining the durations of production for the hyperbolic and exponential phases. This approach reflects the complete lifecycle of the well, taking into consideration the shift in decline behavior as the reservoir depletes. The resulting value represents the total time the well is capable of economically producing hydrocarbons. To facilitate the calculation process, a summary table is provided. This table outlines the equations used to estimate both the ultimate recovery and the productive life of the well for the three primary types of decline curves: hyperbolic, harmonic, and exponential. By standardizing these methodologies, the table ensures consistency and clarity in applying the DCA to various production scenarios.

4. Discussion

Using Arp's equations outlined in Table 1 and estimating the hyperbolic exponent, the well life was calculated for fourteen distinct wells. With the well life and the effective decline rate determined, the Estimated Ultimate Recovery (EUR) for each well was computed using the appropriate formulas. The hyperbolic exponent (b), as previously discussed, serves as a key indicator of the type of decline curve observed, thereby guiding the selection of equations applicable to each well's production profile.

Table 1 –DCA for various production scenarios

Exponential	Hyperbolic	Harmonic
$Q = \frac{q_i - q}{D}$	$Q = \frac{q_i^b}{(1-b)D_i}\left(q_i^{1-b} - q^{1-b}\right)$	$Q = \frac{q_i}{D_i}\ln\left(\frac{q_i}{q}\right)$
$t = \frac{\ln(q_i / q)}{D}$	$t = \frac{\left(\frac{q_i}{q_{el}}\right)^b - 1}{bD_i}$	$t = \frac{\left(\frac{q_i}{q_{el}}\right) - 1}{D_i}$

To demonstrate the application of Arp's equations and clarify the methodology, four wells were selected to illustrate four distinct cases. These examples highlight the variations in decline curve behaviors and the corresponding adjustments in calculations, ensuring the robustness of the approach across diverse production scenarios. This analysis provides a comprehensive framework for estimating EUR and well life, tailored to the unique characteristics of each well.

4.1. Case 1

In the first case, flow rates were plotted against time for the given well, and the value of the hyperbolic exponent was estimated. Using this estimated value, the flow rates for the corresponding decline curve were calculated based on the appropriate formula. These calculated flow rates were then used to plot the resulting decline curve, providing a visual representation of the well's production behavior over time (Fig. 4).

Since the hyperbolic exponent value was determined to be less than one, the hyperbolic decline curve equations were utilized to estimate the ultimate recovery for the well. To identify the transition point from the hyperbolic to the exponential decline phase, two approaches were employed. The first involved calculating the well life using the hyperbolic well life equation, while the second relied on converting the production plot to a logarithmic scale of rate versus time. Both methods were implemented to cross-verify the results and ensure the accuracy and reliability of the calculations.

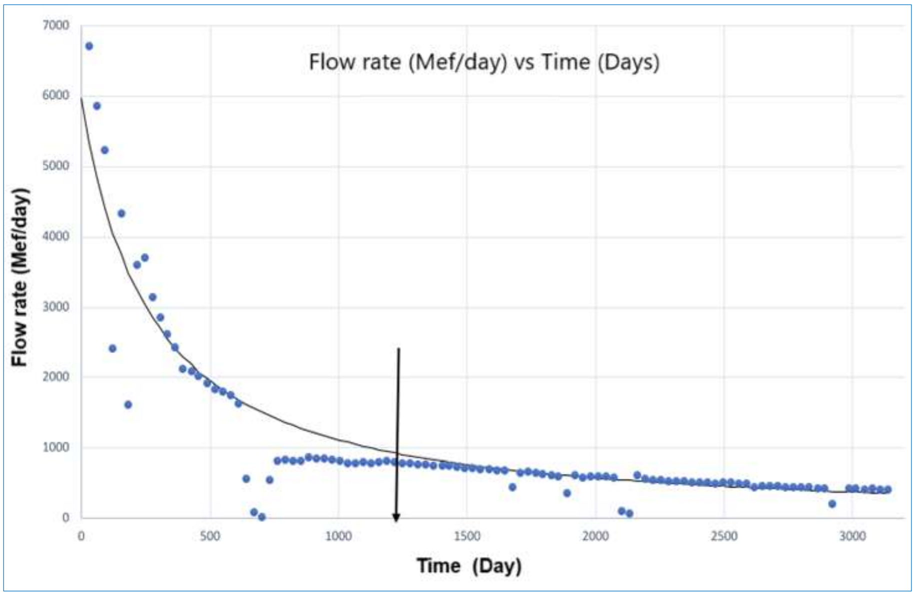

Fig. 4. Flow rate vs time for Case 1

By applying the equations corresponding to both types of decline curves, the following results were obtained: the hyperbolic exponent was determined to be 0.85, indicating a hyperbolic decline curve behavior. The well life was calculated to be approximately 23.9 years, and the EUR for the well was found to be 3999.58 MMCF. These values highlight the production characteristics and provide critical insights into the reservoir's long-term performance.

4.2. Case 2

For this well, following the same methodology outlined in Case 1, it was determined that the decline curve exhibited harmonic behavior prior to the transition point. However, after the identified transition point, the decline curve shifted to an exponential behavior (Fig. 5). The results for this well are as follows: the hyperbolic exponent was calculated to be 1, indicating a hyperbolic decline curve. The well life was determined to be approximately 20.5 years, and the EUR was calculated to be 663.863 MMCF. These findings provide valuable insights into the production profile and performance of the reservoir.

4.3. Case 3

The same equations applied to the previous two wells that were utilized for this case. The calculated value of the hyperbolic exponent indicates a hyperbolic decline curve during the early production phase (Fig. 6). However, the exponent value exceeding 1 suggests the presence of transient flow within the reservoir.

The results are as follows: the hyperbolic exponent was 1.69, the well life was estimated at 39.5 years, and the EUR was determined to be 2700.43 MMCF. These findings highlight the unique flow characteristics and production potential of the reservoir.

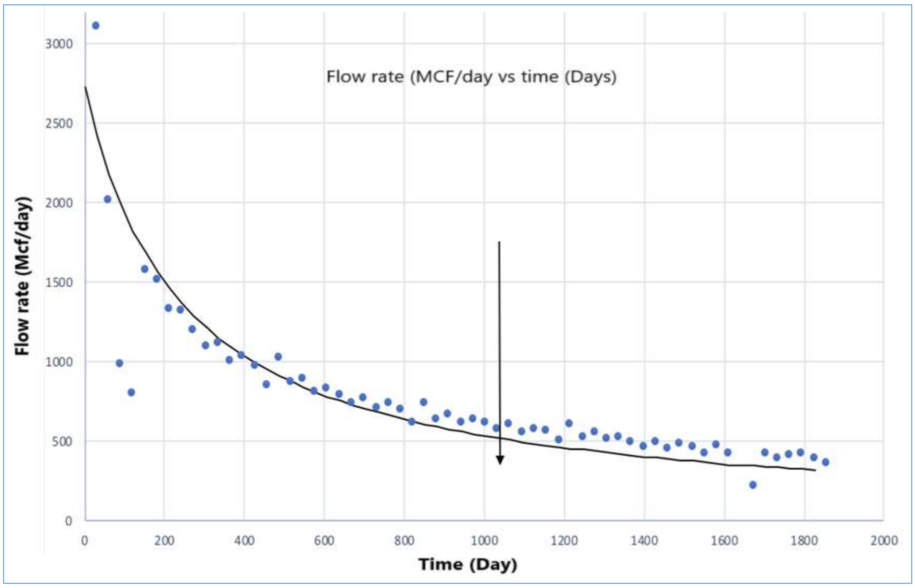

Fig. 5. Flow rate vs time for Case 2

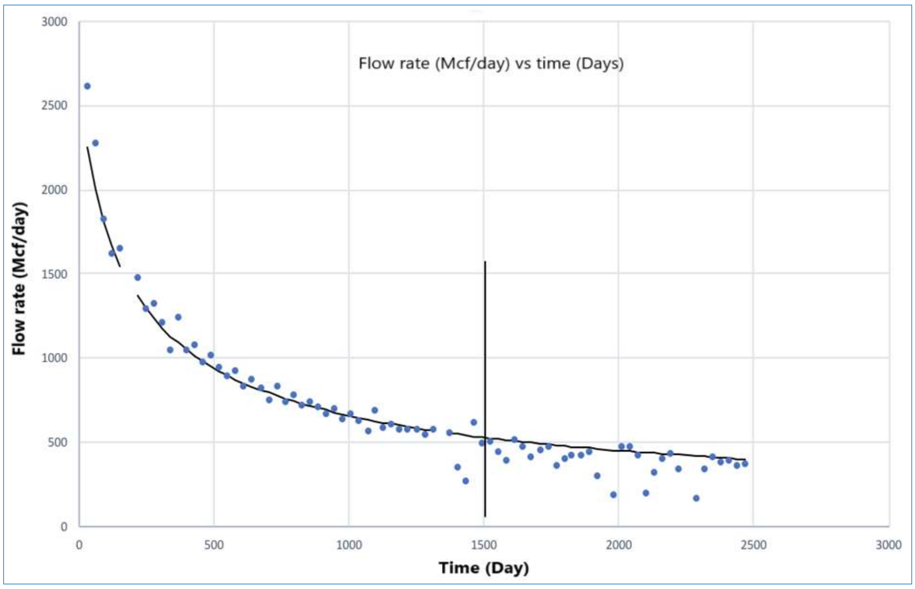

Fig. 6. Flow rate vs time for Case 3

4.4. Case 4 (Special Case)

This case differs from the previous examples as it represents a refractured well. To fully understand this scenario, it is important to first grasp the concept of hydraulic fracturing, commonly referred to as "fracing" in the industry. Hydraulic fracturing is a critical component of well completion in unconventional reservoirs, particularly those with low permeability, such as shale formations (Fig. 7).

The process involves the installation of packers in the horizontally drilled section of the reservoir. Once the packers are in place, slick water is pumped at high pressure down the wellbore. The packers restrict the flow of fluid, creating pressure at the perforation. This pressure causes the formation to fracture along the path of least resistance, creating a fracture that extends deeper into the source rock. This fracture, known as the half-length of the fracture, plays a key role in enhancing well productivity by providing a pathway for hydrocarbons to flow more easily to the wellbore.

Over time, the fractures created during the fracturing process will begin to close due to the stress acting on them. To maintain the effectiveness of these fractures, it is necessary to keep the fractures open. This is achieved by pumping proppants into the well. Proppants are typically made of sand grains, but they can also be coated with ceramic materials or other chemicals to enhance their shape and increase their strength. The purpose of these modifications is to improve the proppant's ability to withstand the pressures in the reservoir and to enlarge the diameter of the grains, thereby maximizing their effectiveness in preventing fracture closure and ensuring continued fluid flow (Fig. 8).

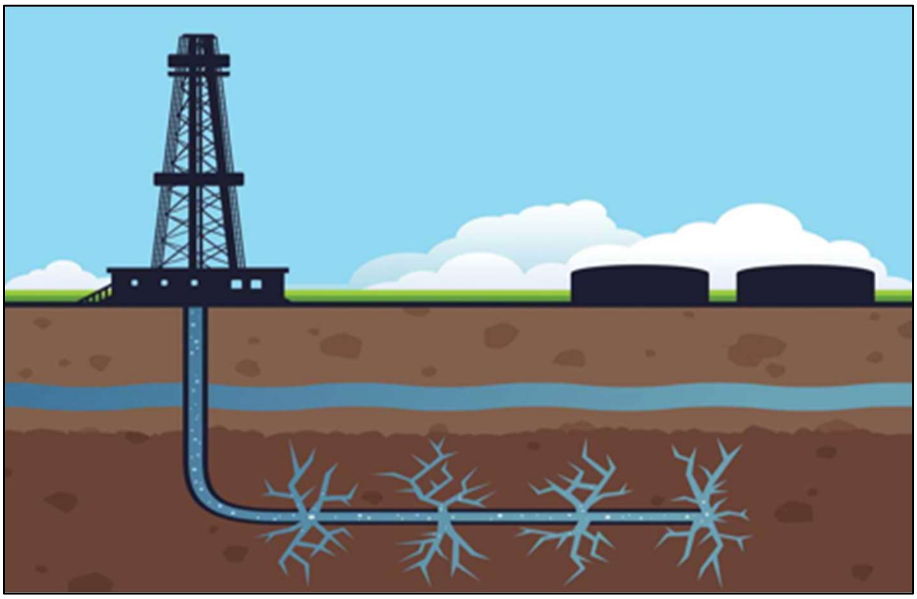

Fig. 7. Fracing skecth

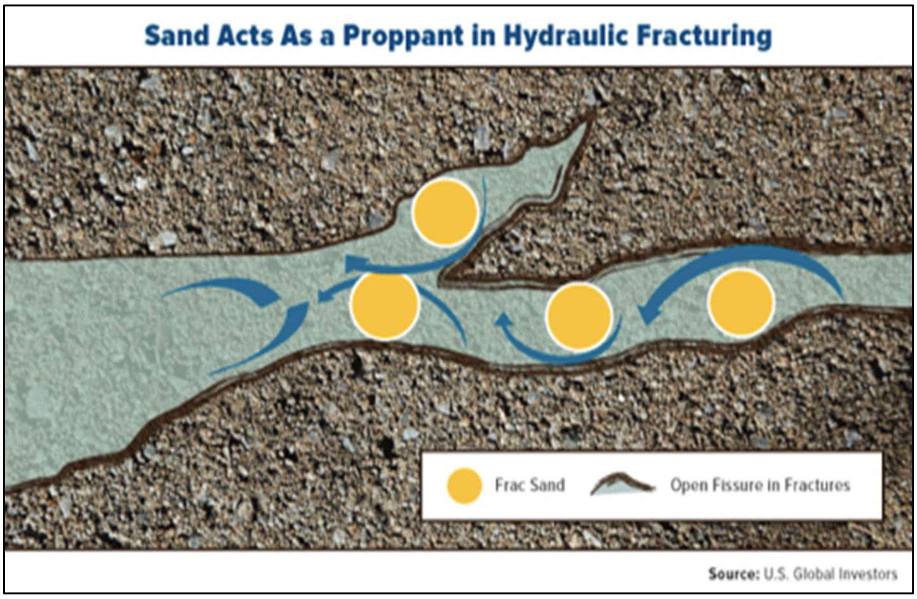

Fig. 8. Closure look at the hydraulic fractures

As previously mentioned, proppants are used to maintain the fractures by preventing their closure. However, selecting the appropriate type of proppant for a given formation and the effective stresses acting on it requires further study and careful consideration. This leads us back to the specific case at hand: the refractured well. We can infer that the well underwent refracturing due to the inefficiency of the initial proppant treatment or the company's objective to enhance production rates. In either case, the refracturing process aims to improve the well's overall performance and productivity (Fig. 9).

The graph above illustrates the decline curve analysis for this particular case. It is evident that the production rate has been declining sharply from the outset. After a few years, however, there is a noticeable increase in the production rate, approximately 70%. This increase can only be interpreted as a result of the well-being refractured, likely due to the "ineffective initial completion" (Jacobs, 2014).

In this specific case, the decline curve analysis using Arps' equations had to be conducted twice—once for the initial completion and again for the refractured section. Our primary focus is on the refractured section. Based on visual observations, it appears that the well did not experience any significant behavioral changes throughout its life.

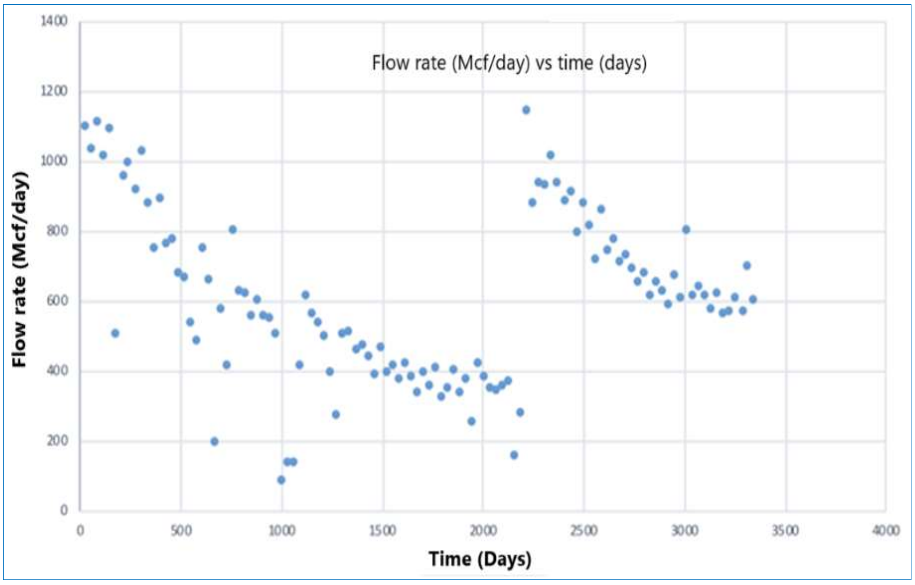

Fig. 9. Gaz rate vs time

More specifically, the well exhibited hyperbolic behavior from the beginning and continued with the same behavior throughout its operation, without transitioning to an exponential decline. Therefore, we applied only the hyperbolic equations in our calculations.

The results of these calculations were consistent with our assumptions. The following values were obtained:

Hyperbolic Exponent (b) = 1.3 (Refractured)
Well Life (t) = 31.4 years
Estimated Ultimate Recovery (EUR) = 4007.2 MMCF

This well yields the highest recoverable hydrocarbons among all the wells considered in this study. Fig. 10 provides a comparison of the estimated ultimate recovery for all 14 wells analyzed.

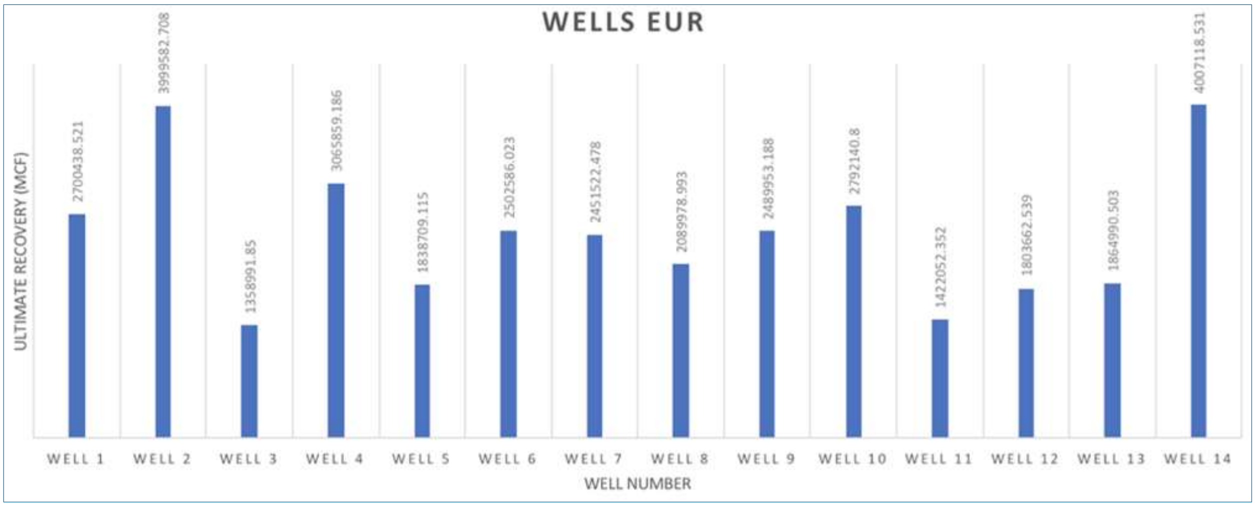

Fig. 10. Analyzed wells EUR

Advancements in hydraulic fracturing technologies have significantly increased the production of unconventional oil and gas resources (Al Krmagi, 2024). The cumulative production from such operations highlights the vital role of hydraulic fracturing in stimulating reservoirs and enhancing hydrocarbon recovery (Dehdouh et al., 2024). Furthermore, accurate production forecasting remains critical to supporting sustainable development in unconventional reservoirs (Laalam et al., 2024). These tools and techniques allow operators to make informed decisions regarding well completions and refracturing strategies, ultimately aiding in maximizing EUR and ensuring long-term reservoir performance.

5. Future Recommendations

Unconventional reservoirs, such as those in the Marcellus Shale in Pennsylvania, are characterized by extremely tight formations, which significantly hinder the natural flow of hydrocarbons to the surface. The porosity and permeability of these formations are typically much lower compared to conventional reservoirs, making it challenging to recover the desired volumes of oil or gas. Due to these limitations, traditional methods of production are often ineffective, and more advanced recovery techniques must be applied to unlock the full potential of these reservoirs.

In the case of the Marcellus Shale, we highly recommend refracturing them well, a method that has been thoroughly explained and supported by a proven example above. Refracturing, or re-fracking, involves reopening existing fractures in the reservoir to enhance permeability and stimulate further hydrocarbon production.

This technique is particularly beneficial for unconventional reservoirs where initial production rates may decline rapidly due to the limited flow of hydrocarbons through the tight formation. Refracturing can significantly increase productivity, extending its productive life and improving the overall recovery factor. Fig. 11 shows comparison of the well life for the 14 wells analyzed in this study.

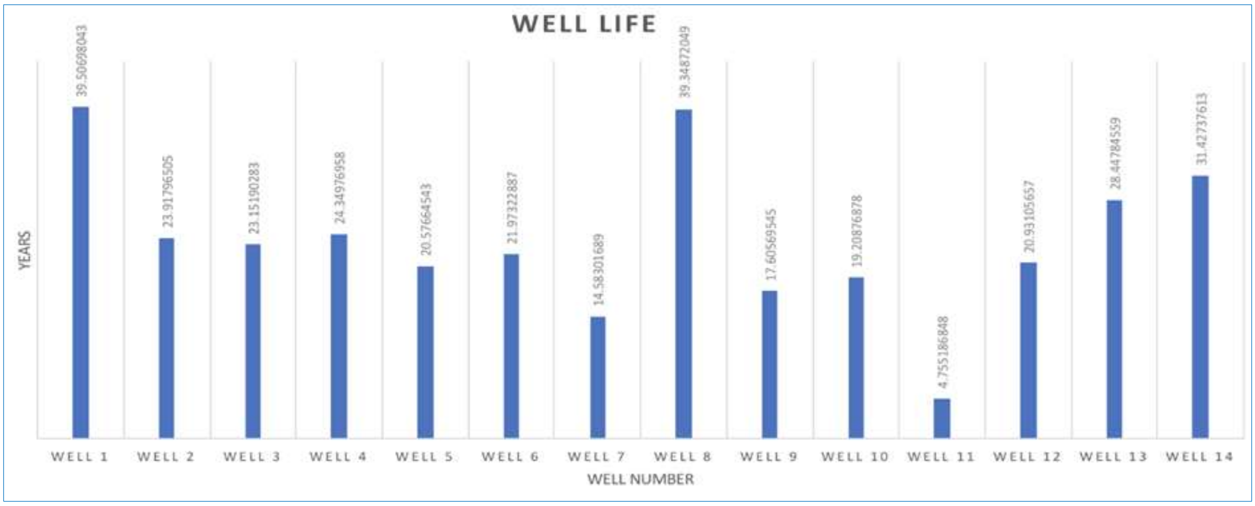

Fig. 11. Well life

Alternatively, many companies explore other recovery methods, such as drilling infill wells, which can also be an effective means of enhancing production. Infill wells are drilled in areas between existing wells, tapping into previously untapped sections of the reservoir to access additional drainage areas. This method is typically considered a more cost-effective option compared to refracturing because it avoids the need for complex hydraulic treatments and can take advantage of the infrastructure already in place. Drilling an infill well can help maximize production from a reservoir by reaching areas that were not fully accessed by earlier wells. This method has been successfully implemented in numerous regions, proving its effectiveness in increasing recovery rates without the high costs associated with refracturing.

Ultimately, the goal of any recovery method is to produce the maximum number of hydrocarbons in the most economically feasible manner. While refracturing may be the best solution in some cases, drilling infill wells can provide an attractive alternative, especially when cost considerations are paramount. The decision between these methods depends on a variety of factors, including the reservoir's characteristics, the cost-effectiveness of each method, and the overall production strategy for the field. Both approaches, however, aim to maximize hydrocarbon recovery and optimize the economic returns from unconventional reservoirs.

6. Conclusion

Ultimately, determining the EUR and the life expectancy of the reservoir is crucial for effective reservoir management and economic planning. These two factors provide essential insights into the potential production from the well and help in making informed decisions about investment and operational strategies. By accurately estimating the EUR, companies can project the total volume of hydrocarbons that can be recovered over the life of the well, which is a key input for cost analysis and profitability assessments. Additionally, knowing the expected reservoir life allows operators to optimize production scheduling, maintenance planning, and long-term resource allocation.

Decline curve analysis using Arps' equations is a proven and highly effective method for forecasting well performance over time. This technique provides a reliable means of estimating future production rates based on historical data, making it an indispensable tool in reservoir engineering. Many industry-standard software packages integrate Arps' decline curve analysis, streamlining the process and enhancing the efficiency and accuracy of production forecasting. These software tools are programmed to apply the equations automatically, which reduces the likelihood of errors and allows for faster, more consistent results.

The ultimate objective of this project is to determine the EUR and the time required to produce from the targeted well using decline curve analysis. By applying Arps' equations, we can generate accurate predictions of both the well's cumulative production and its life span, which are critical for developing optimal strategies for well operations and investment planning. In doing so, this project not only provides valuable insights into the expected performance of the well but also supports sound decision-making that can significantly impact the financial and operational success of the field.

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