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Original Article

Oil Well Performance Forecasting Using Decline Curve Analysis: Tharjiath Oil Field, South Sudan

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Decline Curve Analysis (DCA), Oil Well Performance, Tharjiath Oil Field, Production Forecasting, Reservoir Management.

ABSTRACT

This study applied Decline Curve Analysis (DCA) to forecast the performance and reserves of oil wells in the Tharjiath Oil Field, located in South Sudan's Muglad Basin. Historical production data from five wells were analyzed to compare exponential, hyperbolic, and harmonic decline models. The exponential model was found to be the most accurate, as it closely matched observed production trends by assuming a constant percentage decrease, aligning well with the initial production behaviour in the Tharjiath Oil Field. To further validate the findings, Oil Field Manager (OFM) software was used to simulate future production trends based on the exponential model. This robust platform enabled comprehensive analysis and visualization of reservoir performance, confirming the effectiveness of DCA in predicting well performance and reserves and reinforcing the exponential model as the best representation of the reservoir's natural depletion. The findings underscored the necessity of refining forecasts through sensitivity analysis, which involved varying key input parameters such as initial production rates, decline rates, and reservoir pressure. This systematic alteration of variables allowed the study to identify a range of potential outcomes and assess the associated uncertainties in production predictions. Additionally, the study emphasized the benefits of integrating DCA with real-time production monitoring and reservoir simulation models to enhance forecast accuracy. The study also recommended further exploration of Enhanced Oil Recovery (EOR) techniques, including water flooding and gas injection, to optimize recovery and extend the economic life of the field. Some recommendations were made to expand DCA applications to all wells in the field, incorporate real-time data into the forecasting process, and address the economic and policy implications for sustainable reservoir management.

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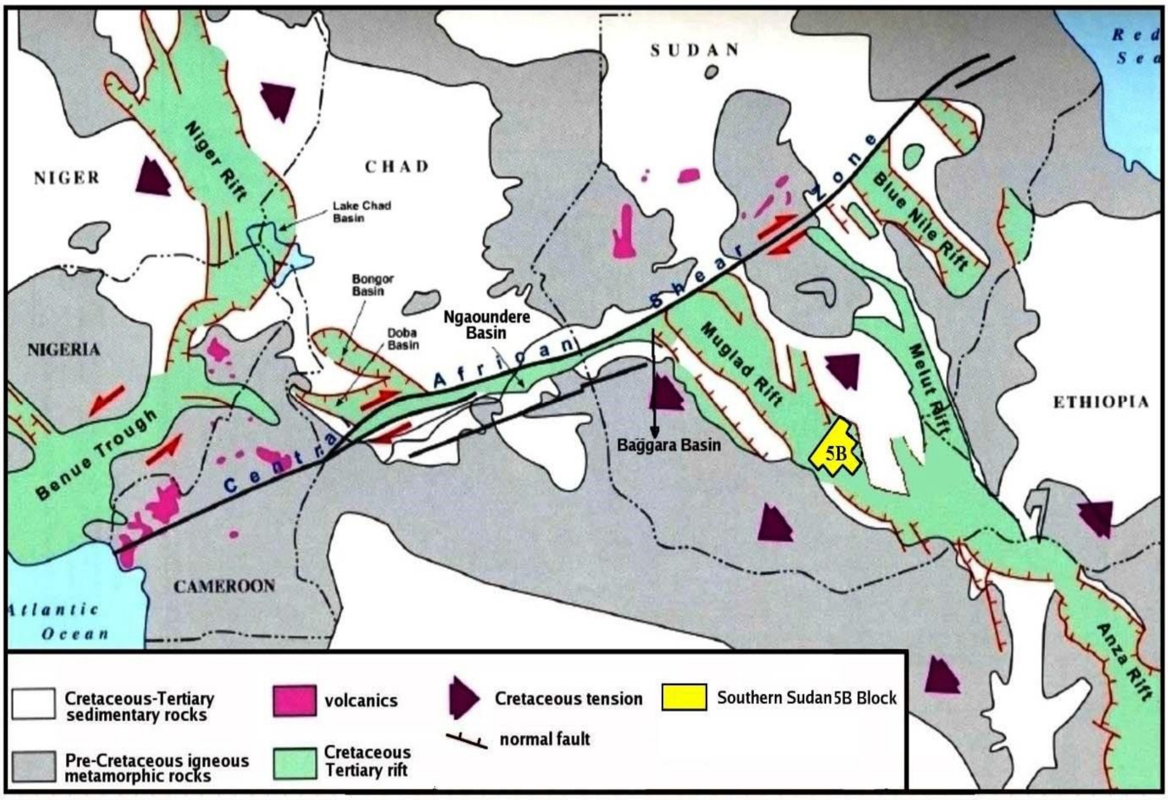
INTRODUCTION

The Tharjiath Oil Field is located within the Muglad Basin in Unity State, Bentiu, South Sudan (Figure 1.1). The Muglad Basin is a significant part of the Western and Central African Rift System (WCARS), which is renowned for its substantial petroleum reserves. This rift basin (Ali and Haggag, 2013) has been a focal point for oil exploration and production, contributing greatly to the oil industry in South Sudan (Gach et al., 2023; Juach et al., 2024). Given the basin's historical importance and ongoing role in the country's energy sector, the Tharjiath oil field has been used as a key area of this present study. This research paper focuses on the Tharjiath Oil Field, analyzing the reservoir's performance and forecasting future production using Decline Curve Analysis (DCA). The subsequent sections below will explore the methodologies employed in this study, particularly the application of DCA. The presentation of the findings and recommendations to optimise exploration and production in the field will be conclusively highlighted.

Figure 1.1: Regional Geological Map of South Sudan (Schull, 1988)



Geological Setting of the Muglad Basin

The Muglad Basin, located in South Sudan, is a significant petroleum basin, with geological Formations spanning from the Precambrian to the Quaternary period. The basin's geology is

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composed of two main categories (Juach et al., 2024and El-Amin and Hammad, 2007):

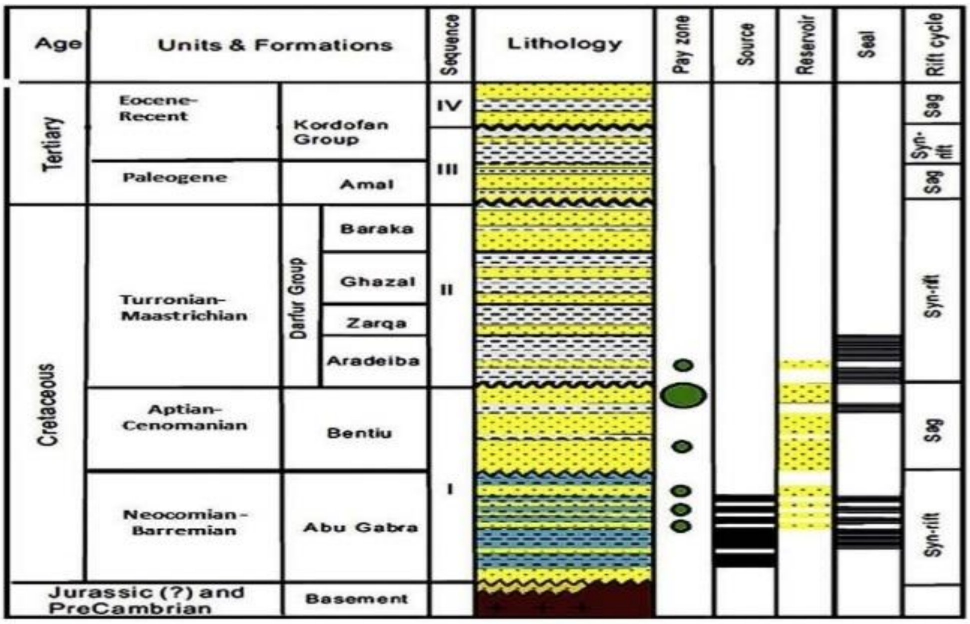
- Basement Rocks which include ancient Precambrian rocks, such as metasediments, quartzites, marbles, and gneisses. These rocks form the basin's foundation and are found predominantly at its periphery. The Sudan Basement Complex plays a critical role in the basin's structural configuration and petroleum potential.
- Sedimentary Cover which overlies the basement rocks, comprises a series of sedimentary layers deposited from the Late Jurassic to the Quaternary period.

These categories also include three major rifting episodes (Ali and Haggag, 2013):

- Late Jurassic/Early Cretaceous, which includes the Abu Gabra Formation, consists of non-marine sandstones and shales and serves as a primary source rock;
- Late Cretaceous Bentiu Formation, composed of fluvial sandstones, form the major petroleum reservoir; and
- Tertiary Aradeiba and Darfur Groups, along with other Formations like Baraka and Ghazal, provide additional source rocks and reservoirs for the basin's petroleum system.

These geological Formations (Makeen et al., 2015 Hargue *et al*., 1992; Gach et al., 2023; Juach et al., 2024).), particularly the shales and sandstones, are critical to understanding the basin's petroleum system and its potential for oil production in the Muglad basin (Figure 1.2).

Figure 1.2: Muglad Basin Chrono-stratigraphic Chart Based on Palynological Data (Hargue *et al*., 1992)



Justification and Purpose of the Study

Petroleum engineers face challenges in predicting the future performance of wells in mature reservoirs. Accurate production forecasting is essential for estimating remaining reserves and optimizing economic planning, ensuring efficient resource recovery and minimizing operational costs. One widely used method for this is Decline Curve Analysis (DCA), which uses historical production data to estimate future production trends.

However, selecting the appropriate decline curve model is challenging due to the unique decline behaviours exhibited by different reservoirs based on geological variations. In this study, the production data from the Tharjiath oil field in South Sudan's Muglad Basin was analyzed using DCA methods to understand decline trends and

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further evaluate how various decline models impact production forecasting and remaining reserves estimation in the five selected wells in the Tharjiath Oil Field.

MATERIALS AND METHODS

How DCA Was Applied

This study employed Decline Curve Analysis (DCA) to forecast the future production rates of five selected wells in the Tharjiath oil field. DCA was utilized to project the wells' future performance, offering insights into their anticipated decline over time based on historical production data. The method facilitated the estimation of key parameters, such as production rates and ultimate recovery, which are critical for effective reservoir management.

Thus, to obtain a comprehensive range of potential outcomes, the study compared three primary types of decline curves: exponential, hyperbolic, and harmonic. These models were evaluated to determine their respective forecasts of production decline, encompassing both optimistic and pessimistic scenarios. By assessing these models, the study aimed to capture the inherent variability and uncertainties associated with predicting the future of the well performance. The results from these models enabled the identification of potential scenarios that could impact the long-term productivity of the oil field.

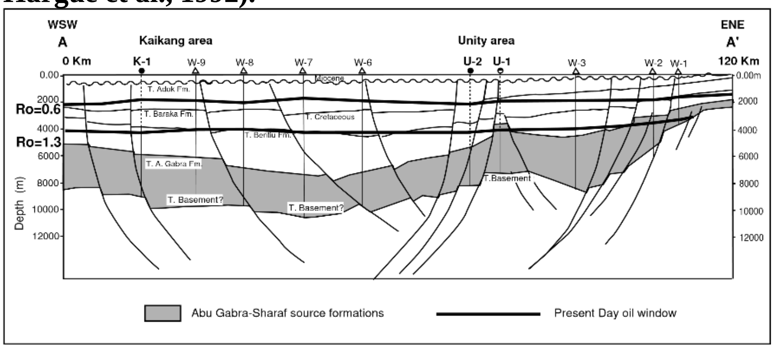
Additionally, further analysis was conducted through the generation of detailed graphical plots, which were employed to visualize production trends and decline rates. These plots provided a clear, graphical representation of the data, facilitating a more thorough evaluation of forecast accuracy and offering valuable insights into the wells' production performance over time. This production performance analysis was crucial in validating the selected decline models, ensuring that the predictions were consistent with historical trends.

Basin Configuration

The Tharjiath oil field is situated in Block 5A of South Sudan, within the expansive Muglad Basin, one of the most significant rift basins in South Sudan. Spanning over 800 kilometres in length and covering an area of approximately 120,000 square kilometres (Schull, 1988; Rop, 1990; 2003), the Muglad Basin is characterized by deep, fault-bounded blocks formed through extensional tectonics, with a northwest-southeast alignment that is consistent with both the Kenyan Anza and South Sudan rift systems.

Geologically, the basin consists of a sedimentary succession predominantly made up of Late Jurassic and Tertiary non-marine sequences, which were deposited during periods of tectonic extension (Figure 2.1). The basin's formation is closely tied to tectonic movements associated with the opening of the southern portions of the Atlantic and Indian Oceans (Rop et al., 2023; Gach et al., 2023), which contributed to the broader regional rifting process. These tectonic events have played a key role in shaping the basin's structural framework and its petroleum potential (Bloom, 2002; Rop, 2003).

Figure 2.1: The Sub-basins of Abu Gabra Source Rock Typically have a Half-graben Geometry, which was Modified by Subsequent Re-activation During Younger Rift Cycles (Schull 1988 and Hargue et al., 1992).



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The Muglad Basin has proven to be highly prospective for petroleum accumulation, hosting some of South Sudan's most significant oil fields, including the Tharjiath, Heglig, and Unity fields. A comprehensive understanding of the basin's geological structure is essential for accurate reservoir modelling and production forecasting (Schull, 1988).

Basin Tectonics

The tectonic history of the Muglad Basin plays a critical role in its geological evolution and petroleum potential (Schull, 1988; Hargue et al., 1992). Situated within the East African Rift System, the basin has experienced a series of rifting events that have profoundly influenced its structural configuration and the distribution of sedimentary deposits (Rop et al., 2023). These tectonic processes generated fault-bounded blocks, which provided accommodation space for sediment deposition and facilitated the migration and trapping of hydrocarbons (Bett et al., 2021). The development of the basin's tectonic framework has thus been fundamental in shaping the petroleum systems that underlie the region

The structure of the Muglad Basin has been shaped by three major rifting events (Gach et al., 2023; Juach et al., 2024; Gandol et al., 2016). The first event, which occurred during the Late Jurassic to Early Cretaceous period, established the basin's fault-bounded configuration and created the necessary accommodation space for significant sediment deposition (Key et al., 1987; Rop, 2012; 2013; Sirma et al., 2015 Rop et al., 2021). Key Formations, such as the Abu Gabra and Bentiu, were deposited during this rifting episode and are integral to the basin's petroleum system. The second phase of rifting, occurring in the Late Cretaceous, deepened and restructured the basin, leading to the deposition of the Aradeiba and Darfur Group sediments. These deposits played a critical role in sealing and trapping hydrocarbons within the underlying reservoirs. The final phase of rifting, during the Tertiary period, further reshaped the basin, resulting in the deposition of the Amal, Nayil, and Tendi Formations, which enhanced the basin's petroleum potential.

Petroleum System

The petroleum system of the Muglad Basin is notably productive, owing to a combination of rich source rocks, favourable reservoir rocks, and effective seal formations. The primary components of the basin's petroleum system include source rocks, reservoir rocks, and seal rocks (Mustafa et al., 2018). Among the primary source rocks, the Abu Gabra and Baraka Formations are particularly rich in organic material and serve as the main hydrocarbon source for the basin. Overlying these source rocks are the reservoir rocks, which include the Bentiu, Aradeiba, and Amal Formations. Composed predominantly of fluvial and sandstone deposits, these formations exhibit high porosity and permeability, essential for the accumulation of significant quantities of hydrocarbons. Finally, the Aradeiba and Darfur Group Formations act as effective seals, preventing the upward migration of hydrocarbons and ensuring their entrapment within the reservoir rocks.

The interaction between these geological and tectonic features has fostered a robust petroleum system, positioning the Muglad Basin as one of the most significant oil-producing regions in South Sudan (Gach et al., 2023; Juach et al., 2024). A comprehensive understanding of these geological processes is critical for effective reservoir management (Bett et al., 2021) and for guiding future development initiatives, which are essential for sustaining and expanding the country's oil production capabilities.

Petroleum Systems of the Muglad Basin

The Muglad Basin contains two primary petroleum systems: the Abu Gabra AG2 and AG4 systems. Together, these systems account for the basin's hydrocarbon production, with the AG2 system contributing 58.1% and the AG4 system contributing 41.9% (Gach et al., 2023). A notable characteristic of these systems is the migration patterns of hydrocarbon accumulations. Specifically, 43% of the hydrocarbons generated

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from the AG2 source rocks accumulate within the AG2 assemblage, while 57% of hydrocarbons from the AG4 source rocks migrate and accumulate beneath the AG2 assemblage. This highlights the complex migration dynamics within the basin, which necessitates further research to refine production forecasts and evaluate remaining reserves, particularly in fields such as Tharjiath (Salem, 2021; Hubbert & Robertson, 2004).

Source Rocks

The primary source rocks in the Muglad Basin are found in the Abu Gabra Formation, particularly in the AG2 and AG4 units. The AG2 system plays a critical role in hydrocarbon expulsion, with significant oil generation potential observed in wells such as Suf-1 (CNPCIS, 2003). However, evaluations of source rock potential in the southern part of the basin are complex due to limited well data. Sandier lithologies in the southern Abu Gabra Formation suggest a lower hydrocarbon generation potential compared to other areas in the basin.

Stratigraphic Units in the Muglad Basin

The Muglad Basin consists of nine seismic stratigraphic units, including AG-4, AG-3, AG-2, AG-1, Bentiu, and Darfur Formations. Of these, the AG-2 and AG-4 units are particularly critical due to their similarity to the Bentiu Formation. These units comprise interbedded sandstones and claystones, which are vital for understanding the basin’s petroleum reservoirs (Abu-Sitta & Yousif, 2010; Ali & Haggag, 2013). These interbedded sequences play a crucial role in the accumulation and trapping of hydrocarbons within the basin.

Oil Generation Potential

The upper part of the Abu Gabra Formation, particularly in well Abu Sufyan-1, demonstrates significant oil generation potential due to its high organic content. The AG-2 unit, in particular, stands out for its organic richness, reinforcing its importance as a primary hydrocarbon source (RRI & GRAS, 1991). These characteristics make the AG-2 unit a critical source for hydrocarbon generation within the basin.

Source Rocks in Other Formations

While the Tendi and Bentiu Formations do not show substantial source rock potential, the Abu Gabra and Darfur Group Formations are recognized for their high-quality source rocks (Abu-Sitta & Yousif, 2010; Ali & Haggag, 2013). Seismic data from the Suf C-1 well further support the presence of viable source rocks within these formations, enhancing the overall hydrocarbon potential of the Muglad Basin.

In conclusion, the Abu Gabra Formation, particularly the AG-2 and AG-4 units, is a fundamental component of the Muglad Basin’s hydrocarbon generation system. A comprehensive understanding of these units is crucial for optimizing recovery in fields such as Tharjiath, where significant oil production potential remains.

Trapping Mechanisms and Reservoirs in the Muglad Basin

The migration and accumulation of hydrocarbons within the Muglad Basin are influenced by a range of geological factors, including source rock potential, migration pathways, and structural features of the basin (Figure 2.2). These factors collectively contribute to the efficiency of hydrocarbon trapping and reservoir formation, as described by Schull and Ali (1994) and Ali and Haggag (2013). The Abu Gabra Formation, particularly its lower and upper units, is rich in Type I kerogen and contains over 2.0 wt.% Total Organic Carbon (TOC), making it an ideal candidate for hydrocarbon expulsion.

Thermal maturity across the basin varies, with the highest levels observed in the lower units, particularly in the western part of the Keyi area. These units have reached optimal conditions for hydrocarbon generation, as indicated by their thermal maturity levels (Bett et al., 2021). Modelled migration pathways suggest that certain fields align with predicted migration routes, though some fields exhibit alternative migration mechanisms. These alternative pathways suggest more complex migration histories than initially

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expected, affecting the distribution of hydrocarbons within the basin.

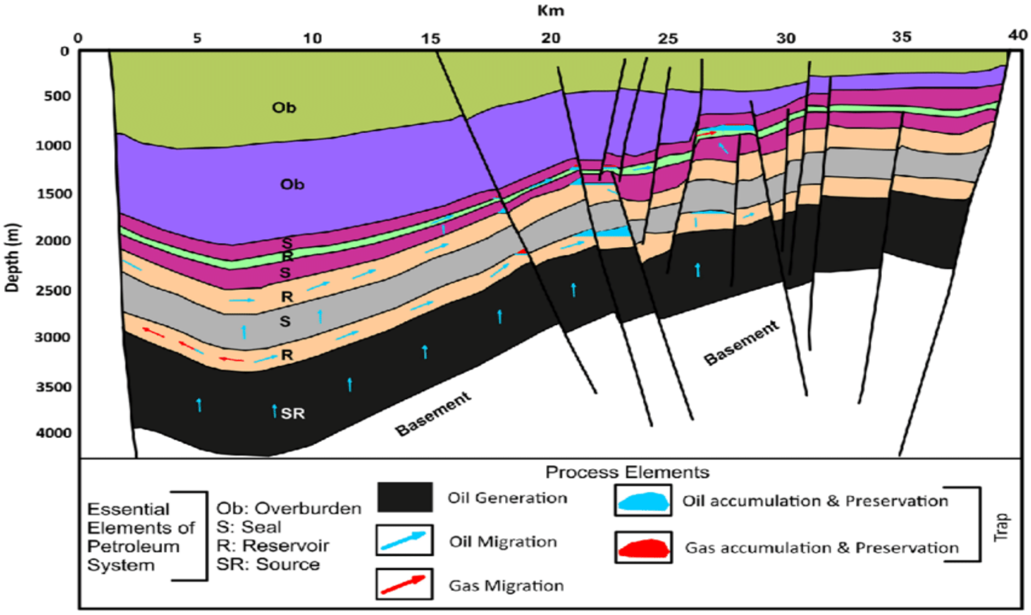
The Muglad Basin contains several key reservoir rocks, primarily from the Cretaceous and Paleocene periods. Notable Formations such as the Abu Gabra and Bentiu offer favourable conditions for hydrocarbon accumulation due to their high porosity and permeability (Bett et al., 2021). The basin is further characterized by a range of structural traps, including faulted anticlines and stratigraphic traps, which are essential for the trapping and accumulation of hydrocarbons. These traps create localized areas of high pressure, facilitating the accumulation of oil and gas, which is crucial for effective hydrocarbon extraction.

Fault reactivation (Rop et al., 2023) has also played a significant role in the redistribution and migration of oils, particularly by facilitating the movement of heavier oils into younger reservoirs. This process has significantly influenced the current distribution of hydrocarbons throughout the basin and continues to affect reservoir performance over time.

For accurate Decline Curve Analysis (DCA) predictions, it is essential that reservoir conditions remain stable. Factors such as pressure depletion, water flooding, and secondary recovery operations must be consistent to ensure the reliability of decline curve models. Any operational disruptions, including equipment failure or significant changes in operational conditions, can lead to inaccurate predictions, affecting the forecasting of production rates. Moreover, uncertainty in aquifer behaviour and water influx patterns poses challenges for the precise application of DCA models, particularly in gas reservoirs where water influx plays a key role in influencing reservoir pressure.

In summary, the trapping mechanisms and reservoir dynamics in the Muglad Basin are shaped by complex geological structures, hydrocarbon generation, migration, and accumulation processes. These elements are vital for understanding the basin's petroleum potential and for developing effective reservoir management strategies (Ali & Haggag, 2013).

Figure 2.2 Fluid Migration Pathways in Northern and Central Muglad Basin (Idris *et al*., 2005)



Major Studies on Decline Curve Analysis (DCA) in the Muglad Basin

Several pivotal studies have significantly contributed to the advancement and refinement of Decline Curve Analysis (DCA) in petroleum reservoir management, particularly in regions such as the Muglad Basin. Arps (1945) is widely regarded as the pioneer in the development of DCA, having introduced the fundamental models

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of exponential, hyperbolic, and harmonic decline. These models have since become the cornerstone of production forecasting and reserves estimation in oil and gas fields worldwide. Arps' work laid the foundation for a simple yet effective approach to predict the future performance of wells based on historical production data, providing essential tools for resource management and decision-making.

Han et al., 2019) explored production forecasting for shale gas wells in transient flow using machine learning and decline curve analysis (DCA). The study highlighted the effectiveness of integrating these methods to enhance prediction accuracy and address challenges in forecasting production behaviour in shale gas reservoirs. Agrawal et al. (2008) expanded on this approach by exploring dimensionless parameters in DCA. Their study focused on the influence of factors such as water influx and gas cycling on production forecasts, particularly in gas reservoirs where water influx presents significant challenges. This research highlighted the need for incorporating external factors—such as water influx, gas injection, and aquifer behaviour—into DCA models to increase their reliability in predicting future production. By addressing these complexities, Agrawal et al. contributed to improving the applicability of DCA across diverse reservoir types, including those found in the Muglad Basin.

Hubbert and Robertson (2004) made significant strides in refining DCA by focusing on reducing bias in rate-time extrapolation. Their work emphasized the importance of accurately capturing the non-linear behaviour of production data, especially during the transition from transient flow to boundary-dominated flow. By reducing bias in the extrapolation of rate-time curves, Hubbert and Robertson provided a more reliable framework for assessing long-term production trends and estimating ultimate recovery (EUR), which is essential for the accurate forecasting of the performance of the well in fields like Tharjiath and other regions in the Muglad Basin.

Furthermore, Kegang (2006) and Khulud et al. (2013) expanded the global application of DCA by showcasing its utility in optimizing reservoir management and enhancing resource estimation. These studies underscored the importance of DCA not only for individual well forecasting but also for field-wide evaluations, resource optimization, and development planning. By refining DCA techniques, these authors contributed to improving the efficiency of resource extraction, particularly in mature or declining oil fields, where accurate predictions of remaining reserves are critical for making informed operational and financial decisions.

In the context of the Muglad Basin, recent studies have also contributed to understanding the petroleum potential and source rock characterization in the region. For instance, Juach et al. (2024) evaluated the petroleum potential of the Muglad Basin in South Sudan, focusing on the source rock characteristics of the Kaikang West-1 well. Their analysis of the source rocks' ability to generate hydrocarbons further enhances the understanding of the basin's petroleum prospects.

In a recent study, Gach et al. (2023) conducted a comprehensive investigation of the source rocks encountered in the LT-1 well in northern Kenya. Their research provides detailed insights into the identification and petrophysical characteristics of these source rocks, which are integral for evaluating the hydrocarbon potential in the region. Complementing this, Rop et al. (2023) examined the evolutionary dynamics of the East African Rift System (EARS), highlighting how the rift's geological development influences the spatial distribution and occurrence of petroleum resources. Their findings underscore the critical role of understanding tectonic processes for optimizing hydrocarbon exploration strategies.

In addition, Rop, Mayik, and Gach (2023) offered an extensive geological analysis of the petroleum source rocks from the LT-1 well, significantly advancing the characterization of source rock properties. This research provides vital data for assessing the region's hydrocarbon potential and offers key insights that can guide future

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exploration efforts in northern Kenya. Rop (2013, 2024) further contributed to this body of work, with studies on the oil and gas prospectivity in northwestern Kenya, reinforcing the importance of applied geological principles in mineral and petroleum exploration across Kenya's diverse rift basins.

Rop's earlier works, such as his stratigraphic study in the Loiyangalani area (1990) and his review of oil and gas prospectively (2015), have also contributed significantly to the understanding of hydrocarbon resources in Kenya, providing foundational geological frameworks that support current exploration and development efforts. Bett et al. (2021) also contributed to this discourse by conducting a geochemical evaluation of the hydrocarbon potential of source rocks in the Anza Basin, offering valuable insights into the basin's petroleum prospects.

Decline Curve Analysis as a Tool for Prediction

Decline Curve Analysis (DCA) serves as an indispensable tool in predicting key reservoir parameters, including future production rates, ultimate oil recovery (EUR), and well lifespan. This is particularly relevant once wells transition into a boundary-dominated flow, a stage where the rate of decline becomes more consistent and predictable. DCA relies on historical production data to forecast future performance, making it a vital tool for decision-makers in the oil and gas industry.

One of the primary functions of DCA is to provide an estimate of future production rates based on past performance. This is essential for anticipating the decline in well output over time, allowing for strategic planning regarding production scheduling, field management, and resource allocation. By analyzing historical production data and fitting it to a decline model (exponential, hyperbolic, or harmonic), operators can predict when production will begin to significantly decline, which is particularly important when production rates fall below certain economic thresholds (often 10 barrels per day, as noted by Hubbert & Robertson, 2004).

DCA is also crucial for estimating the ultimate recovery (EUR) from a reservoir. EUR is the total amount of hydrocarbons that can be recovered from a well or field over its productive life, and accurately forecasting it is critical for long-term investment planning and economic viability assessments. Through DCA, operators can estimate the total recoverable hydrocarbons by fitting decline curves to production data and adjusting for factors such as reservoir pressure, fluid characteristics, and recovery techniques.

In addition to forecasting production rates and estimating EUR, DCA plays a central role in assessing the economic viability of oil fields and individual wells. By accurately predicting production trends, operators can evaluate the potential profitability of continued production, identify optimal times for intervention (e.g., secondary recovery methods such as water flooding or gas injection), and make informed decisions about future investments in reservoir management and development.

However, it is important to recognize that DCA is most effective under stable reservoir conditions. In reservoirs where operational disruptions such as pressure depletion, water flooding, or secondary recovery operations are significant, the accuracy of DCA predictions can be compromised. Furthermore, external factors, such as aquifer behaviour and water influx, can introduce uncertainties in the models, particularly in gas reservoirs where water influx plays a crucial role in maintaining reservoir pressure. Therefore, continuous monitoring of reservoir conditions and the incorporation of real-time data into DCA models are essential for ensuring the reliability of the predictions.

The application of DCA in the Muglad Basin, particularly in fields like Tharjiath, is invaluable for assessing the long-term viability of production and for optimizing reservoir management strategies. By understanding the nuances of hydrocarbon migration, pressure dynamics, and reservoir characteristics, operators can refine DCA models to provide more accurate forecasts

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and ultimately maximize the economic potential of the basin's oil reserves.

Primary Decline Models in DCA

Decline Curve Analysis (DCA) utilizes three primary models to predict future reservoir performance: exponential, hyperbolic, and harmonic decline. The exponential decline assumes a constant rate of decline, making it ideal for simple, single-phase fluid reservoirs. In contrast, the hyperbolic decline model accounts for varying decline rates, making it suitable for more complex, multi-phase fluid reservoirs. The harmonic decline model represents a slower, more gradual decline, which is particularly useful for tight formations or high-viscosity oils.

Despite its effectiveness, DCA has several challenges and limitations. It is most reliable once wells have transitioned into boundary-dominated flow, a phase that may take years to reach in low-permeability reservoirs, thus delaying the accurate application of the analysis. In the early stages of production, data may be sparse or inconsistent, making it difficult to predict future performance. Additionally, in heterogeneous reservoirs with varying fluid behaviours, simple decline models may not capture the full complexity, leading to inaccurate forecasts.

Moreover, external factors such as water flooding or secondary recovery operations can alter the natural decline trends, complicating the use of traditional models. Water influx, in particular, poses challenges, especially in gas reservoirs where it can significantly affect reservoir pressure. In summary, while DCA is a powerful tool for production forecasting, its accuracy depends on factors such as the availability of consistent data, the transition to boundary-dominated flow, and the ability to account for reservoir heterogeneity and operational influences.

METHODOLOGY

This study employed Oil Field Manager (OFM) software to analyze oil production in the Tharjiath oil field, focusing on forecasting production rates and estimating remaining reserves using Decline Curve Analysis (DCA). Historical production data from five wells were analyzed through exponential, harmonic, and hyperbolic decline models based on Arps' methodologies, with the application of relevant constraints to enhance the accuracy of the forecasts.

DCA Model Description (Forecast)

The OFM software was used to apply historical data for modelling future production trends through Decline Curve Analysis (DCA). Forecasts were initiated based on the wells' initial production rates, with observed decline trends serving as the foundation for future projections. To enhance the accuracy of the forecasts, relevant production constraints were incorporated into the modelling process.

Decline Curves for Reserve Estimates

The DCA was used alongside reserve estimates derived from simulation models to provide a comprehensive assessment. Operational and financial factors, such as production constraints and operating costs, were integrated into the analysis to improve the reliability of the reserve estimates.

OFM Workflow Capabilities

The OFM software facilitated the generation of production trends, diagnostic plotting, and seamless integration with operational platforms. Its advanced forecasting capabilities enabled precise decision-making in well and field management, supporting more informed and effective strategies.

Quantitative and Qualitative Approach

The study integrated quantitative methods with qualitative evaluation to tackle uncertainties such as inconsistent data, reservoir heterogeneity, and fluctuations in reservoir pressure. This approach enhanced the reliability of production forecasts and reserve estimates, ensuring a more comprehensive understanding of field performance.

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Conclusion

The application of Decline Curve Analysis (DCA) within the OFM software proved to be an effective tool for generating accurate production forecasts and reserve estimates for the Tharjiath oil field. By integrating high-quality data with robust modelling techniques, the study enabled the development of optimized oil field management strategies, ultimately supporting more informed decision-making and improved reservoir management.

DATA INTERPRETATION, ANALYSIS, RESULTS AND DISCUSSIONS

Analysis of Decline Curve Analysis (DCA) Application

Kegang and Jun (2012) presented a study on the theoretical foundations of Arps empirical decline curves and further discussed the mathematical principles underlying Arps's equations, which are widely used for forecasting production in oil and gas reservoirs. They emphasized the importance of understanding these theoretical bases to improve the accuracy of decline curve analysis, particularly in complex reservoir conditions where traditional assumptions may not hold. Their work aimed to enhance the application of decline curve analysis in real-world scenarios, providing insights for better production forecasting and reservoir management. This section evaluates the application of Decline Curve Analysis (DCA) to production data from the five wells in the Tharjiath oil field, utilizing the Arps (1956) method. The analysis covers two periods: an initial production phase beginning in 2006, followed by a forecasting period extending through 2037. Key parameters such as initial production rate, decline rate, and exponential decline parameter were estimated using historical regression techniques.

For well TJ-3A, production data from 2006 to June 2024 were used, with forecasts extended to July 2037. The exponential decline model provided the best fit, resulting in an estimated ultimate recovery (EUR) of 3,689.25 Mbbl, remaining reserves of 1,971.54 Mbbl, and a final production rate of 189.435 bbl/d by 2037.

Three decline models—exponential, harmonic, and hyperbolic—were tested during the analysis. The exponential model most accurately reflected the natural depletion pattern observed in the field. Forecasts suggest that production will continue to decline until it reaches an economically non-viable level around 2037.

Key findings include:

- The exponential decline model is the most appropriate for the Tharjiath oil field.
- EUR and remaining reserves are critical for long-term planning and effective reservoir management.
- The results provide valuable insights for investment decisions and underscore the need for enhanced oil recovery (EOR) strategies.

In conclusion, DCA serves as an effective tool for estimating reserves, forecasting production, and optimizing field management strategies. The exponential decline model was identified as the optimal method for predicting well performance, providing crucial insights for resource management and sustaining field development. The next section delves into further analysis through well data from figures and tables.

Results Analysis, Discussion and Conclusion of TJ-3A

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Figure 1: Oil Production Decline Curve Historical Regression and Future Forecast with, Final Rate, EUR, Cumulative Production and Reserve for TJ-3A. (Production History Plot of Forecast Rates vs Time)

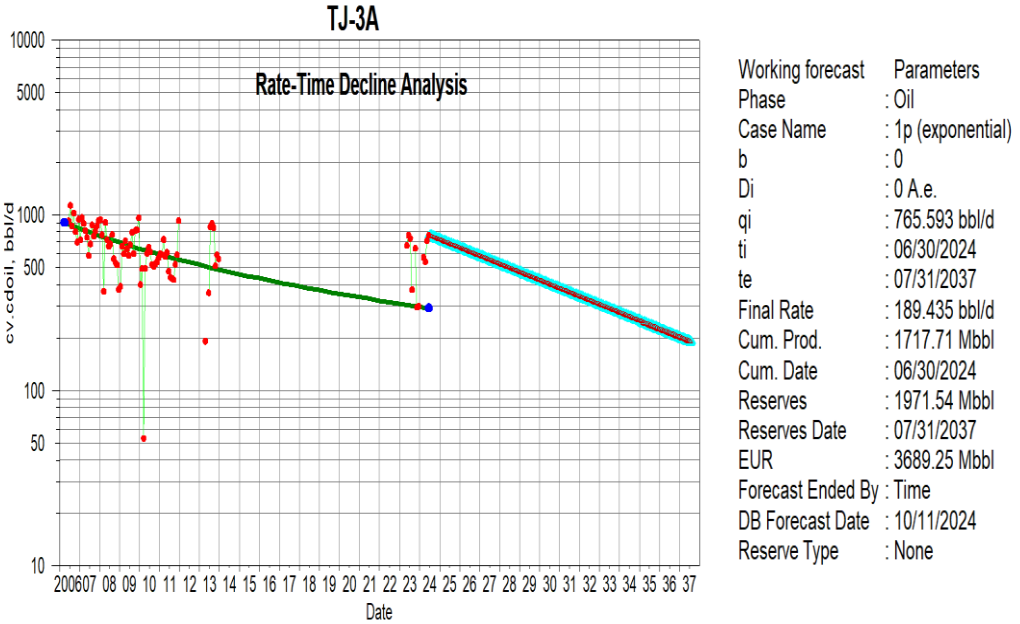

Table 1: Production Oil Forecast Report of TJ-3A Using Decline Curve Analysis (DCA) of Tharjiath Oil Field of Muglad Basin

N0	Date	Rate bbl/d	Date	Rate bbl/d	Date	Rate bbl/d	Date	Rate bbl/d
1	7/31/2024	758.69	1/31/2028	522.08	7/31/2031	359.47	1/31/2035	247.29
2	8/31/2024	751.85	2/29/2028	517.67	8/31/2031	356.23	2/28/2035	245.28
3	9/30/2024	745.28	3/31/2028	513	9/30/2031	353.12	3/31/2035	243.06
4	10/31/2024	738.56	4/30/2028	508.53	10/31/2031	349.93	4/30/2035	240.94
5	11/30/2024	732.12	5/31/2028	503.94	11/30/2031	346.88	5/31/2035	238.77
6	12/31/2024	725.51	6/30/2028	499.54	12/31/2031	343.75	6/30/2035	236.69
7	1/31/2025	718.97	7/31/2028	495.04	1/31/2032	340.65	7/31/2035	234.55
8	2/28/2025	713.11	8/31/2028	490.57	2/29/2032	337.78	8/31/2035	232.44
9	3/31/2025	706.68	9/30/2028	486.29	3/31/2032	334.73	9/30/2035	230.41
10	4/30/2025	700.51	10/31/2028	481.9	4/30/2032	331.81	10/31/2035	228.33
11	5/31/2025	694.19	11/30/2028	477.7	5/31/2032	328.82	11/30/2035	226.34
12	6/30/2025	688.13	12/31/2028	473.39	6/30/2032	325.95	12/31/2035	224.29
13	7/31/2025	681.93	1/31/2029	469.12	7/31/2032	323.01	1/31/2036	222.27
14	8/31/2025	675.78	2/28/2029	465.3	8/31/2032	320.09	2/29/2036	220.4
15	9/30/2025	669.88	3/31/2029	461.1	9/30/2032	317.3	3/31/2036	218.41
16	10/31/2025	663.84	4/30/2029	457.08	10/31/2032	314.44	4/30/2036	216.5
17	11/30/2025	658.04	5/31/2029	452.95	11/30/2032	311.69	5/31/2036	214.55
18	12/31/2025	652.11	6/30/2029	449	12/31/2032	308.88	6/30/2036	212.68
19	1/31/2026	646.23	7/31/2029	444.95	1/31/2033	306.1	7/31/2036	210.76
20	2/28/2026	640.96	8/31/2029	440.94	2/28/2033	303.6	8/31/2036	208.86
21	3/31/2026	635.18	9/30/2029	437.09	3/31/2033	300.86	9/30/2036	207.04
22	4/30/2026	629.64	10/31/2029	433.15	4/30/2033	298.24	10/31/2036	205.17
23	5/31/2026	623.96	11/30/2029	429.37	5/31/2033	295.55	11/30/2036	203.38
24	6/30/2026	618.51	12/31/2029	425.5	6/30/2033	292.97	12/31/2036	201.54
25	7/31/2026	612.93	1/31/2030	421.66	7/31/2033	290.33	1/31/2037	199.73
26	8/31/2026	607.41	2/28/2030	418.22	8/31/2033	287.71	2/28/2037	198.1
27	9/30/2026	602.1	3/31/2030	414.45	9/30/2033	285.2	3/31/2037	196.31
28	10/31/2026	596.67	4/30/2030	410.83	10/31/2033	282.63	4/30/2037	194.6
29	11/30/2026	591.47	5/31/2030	407.13	11/30/2033	280.16	5/31/2037	192.84

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N0	Date	Rate bbl/d	Date	Rate bbl/d	Date	Rate bbl/d	Date	Rate bbl/d
30	12/31/2026	586.13	6/30/2030	403.57	12/31/2033	277.63	6/30/2037	191.16
31	1/31/2027	580.85	7/31/2030	399.93	1/31/2034	275.13	7/31/2037	189.44
32	2/28/2027	576.11	8/31/2030	396.33	2/28/2034	272.89		
33	3/31/2027	570.92	9/30/2030	392.87	3/31/2034	270.42		
34	4/30/2027	565.93	10/31/2030	389.32	4/30/2034	268.06		
35	5/31/2027	560.83	11/30/2030	385.93	5/31/2034	265.65		
36	6/30/2027	555.93	12/31/2030	382.45	6/30/2034	263.33		
37	7/31/2027	550.92	1/31/2031	379	7/31/2034	260.95		
38	8/31/2027	545.95	2/28/2031	375.91	8/31/2034	258.6		
39	9/30/2027	541.19	3/31/2031	372.52	9/30/2034	256.34		
40	10/31/2027	536.31	4/30/2031	369.27	10/31/2034	254.03		
41	11/30/2027	531.63	5/31/2031	365.94	11/30/2034	251.81		
42	12/31/2027	526.83	6/30/2031	362.74	12/31/2034	249.54		

Interpretation of Figure 1 and Table 1

Figure 1 presents the historical production data of Well TJ-3A alongside forecasted production rates based on the Decline Curve Analysis (DCA) method. The graph illustrates the well's natural depletion, following an exponential decline model, with production gradually decreasing over time. The analysis reveals that the production rate consistently decreases at a fixed percentage, characteristic of natural reservoir depletion. The forecast indicates that this decline will continue through 2024 to 2037, as the well enters the later stages of its depletion. As the production decreases, cumulative production increases, with the Estimated Ultimate Recovery (EUR) acting as a vital metric for evaluating the well’s total production potential. By 2037, the production rate is expected to significantly decrease, with future reserves predicted based on the modelled decline curve.

Table 1 provides a detailed forecast of the production rate for TJ-3A from July 2024 to December 2037. Starting with an initial rate of 758.69 bbl/d in July 2024, the production is expected to drop steadily, reaching 199.73 bbl/d by July 2037, following the typical pattern of natural depletion.

Results Analysis of Table 1

The analysis of the forecasted data in Table 1 indicates a steady decline in production over the 13-year period. The initial production rate began at 758.69 bbl/d in July 2024, with the forecast predicting a drop to 199.73 bbl/d by 2037 due to the depletion of reservoir pressure. The decline follows an exponential trend, consistent with the natural depletion behaviour of the reservoir. As the production rate decreases, cumulative production increases, contributing to the EUR, which helps estimate the total recovery from the well. This long-term forecast period provides valuable insight for resource planning and evaluating the well's sustainability.

Conclusion

The analysis of Well TJ-3A indicates a typical natural depletion pattern, with production decreasing exponentially over time. Decline Curve Analysis (DCA) proves to be an effective tool for forecasting future production and estimating EUR, providing reliable projections for the well’s performance. Despite the decline in production, the well will continue to contribute at reduced rates, with EUR assisting in evaluating the economic viability of the well. The consideration of Enhanced Oil Recovery (EOR) methods is essential to prolong production and reduce the rate of decline, ensuring the well’s extended viability.

Recommendations

In order to extend the productive life and improve recovery, it is recommended to explore EOR techniques such as water flooding or gas injection. Regular production monitoring will also be critical to refine forecasts and enhance reservoir management strategies. A comprehensive field-wide assessment involving similar analyses of other wells in the Tharjiath field will provide a

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broader understanding of field performance and help improve decision-making. Additionally, further studies should focus on evaluating other decline models, such as hyperbolic and harmonic, to refine forecasting accuracy.

Hyperbolic Decline Model Analysis

An alternative approach using the hyperbolic decline model was applied to Well TJ-3A, yielding a EUR of 3,872.08 Mbbl, remaining reserves of 2,154.37 Mbbl, and a forecasted final production rate of 265.44 bbl/d by 2037. This model suggests a more gradual decline, indicating a longer productive life before reaching the economic shut-in point.

Comparison of Decline Models

The exponential, hyperbolic, and harmonic models were compared, with the exponential model best matching the natural depletion trends observed in the well's production history. The hyperbolic model provides a more gradual decline, thus suggesting a potentially longer productive life, especially if EOR techniques are implemented. The harmonic model, however, is less suited for Well TJ-3A as it typically applies to more complex depletion behaviours.

Conclusion

The exponential decline model best aligns with Well TJ-3A's production history, accurately reflecting the natural depletion pattern. While the hyperbolic model offers a more optimistic outlook, it is more applicable in scenarios where EOR methods may be employed. Hence, for long-term planning, the exponential model remains the most suitable, but the hyperbolic model can be considered for scenarios where EOR techniques might extend the productive life of the well.

Redundancy in the presentation of similar graphical data, such as those in Figure 1 and Table 1, as well as Figures 2 to 5, which illustrate the oil production decline curve, historical regression, and future forecasts for the TJ-3A well (including key parameters like final production rate, Estimated Ultimate Recovery (EUR), cumulative production, and reserves), and Tables 2 to 5, which provide the production oil forecast for TJ-3A based on Decline Curve Analysis (DCA) of the Tharjiath oil field in the Muglad Basin, is minimized by adopting a more focused approach. Consequently, the subsequent sections offer a succinct interpretation, comprehensive results analysis, and key conclusions, without redundantly re-presenting the graphical and tabular data. This approach ensures an academically rigorous and coherent discussion that highlights the essential insights drawn from the data, which are further synthesized in the concluding sections along with recommendations. By consolidating the information concisely yet thoroughly, the analysis promotes a clearer understanding of production trends and their implications for future operational strategies.

Interpretation, Results Analysis, and Conclusion for Figure 2 & Table 2

Figure 2 illustrates the oil production decline curve for Well TJ-3A, showcasing a steady decrease in production due to natural reservoir depletion. The graph forecasts key metrics such as the final production rate, Estimated Ultimate Recovery (EUR), and remaining reserves. These projections highlight the well's expected decline in production over time.

Table 2 provides a detailed month-by-month forecast, showing a consistent reduction in production from 758.7 bbl/d in July 2024 to 266.86 bbl/d by 2037. This aligns with the typical decline trend for a well undergoing natural depletion.

Key Findings: The production rate decreases steadily over the 13-year period, with more significant drops early on and slower declines in later years. As production decreases, cumulative production continues to rise, although at a diminishing rate. The forecast indicates that by 2030, the production rate will slow, reflecting the effectiveness of well management practices.

Conclusion: The well is expected to continue producing for many years but at diminishing rates. Enhanced Oil Recovery (EOR) methods may be

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required to prolong the well's productive life and maximize recovery.

Hyperbolic Decline Model

A hyperbolic decline model was applied to Well TJ-3A, resulting in a more gradual decline compared to the exponential model. The forecast under this model shows:

- EUR: 3,872.08 Mbbl
- Remaining Reserves: 2,154.37 Mbbl
- Final Production Rate (2037): 265.44 bbl/d

Model Comparison: The exponential model best represents the natural depletion trends observed in the Tharjiath field and is recommended for long-term planning. However, the hyperbolic model suggests a more optimistic outlook, which may be relevant if Enhanced Oil Recovery techniques are applied.

Final Conclusion: The exponential decline model is most suitable for forecasting the well's future production, as it aligns with the field's natural depletion trends. However, the hyperbolic model offers a more favourable projection, especially when considering potential EOR techniques that could extend the well's life.

Summary of Figure 3, Table 3, and Results Analysis for Well TJ-3A

Figure 3 presents the oil production decline curve for Well TJ-3A, displaying both historical production data and projected future production rates. The graph emphasizes key metrics such as the final production rate, Estimated Ultimate Recovery (EUR), cumulative production, and remaining reserves, illustrating a gradual decline in production over time due to natural reservoir depletion.

Table 3 provides a month-by-month forecast of the well's production from July 2024 to December 2037. Starting at 758.72 bbl/d in July 2024, the production rate is expected to decrease to 320.56 bbl/d by June 2037, marking a 58% reduction over the 13-year period. The forecast predicts a slowdown in the rate of decline after 2030.

Results Analysis: The production from Well TJ-3A is projected to decline steadily, with more significant reductions in the first few years (about 10-15 bbl/d per month), followed by slower declines after 2030. As production continues to decrease, the EUR is gradually achieved, and secondary recovery methods, such as water injection, may be required by 2037 to maintain production levels. Despite the decline in output, the well will continue contributing to the overall field production for many years.

Conclusion

Well TJ-3A is expected to experience a gradual decline in production over the next 13 years, with significant reductions by 2037. To maintain production beyond this period, enhanced oil recovery (EOR) methods may be necessary. Effective reservoir management and secondary recovery strategies will be crucial for optimizing long-term production from the well.

Results Analysis and Conclusion of Figure 4 and Table 4

Interpretation

Figure 4 presents the decline curve for oil production in Well TJ-4 within the Tharjiath oil field. The graph illustrates both the historical production data and forecasted future production rates. Key indicators such as the final production rate, Estimated Ultimate Recovery (EUR), cumulative production, and remaining reserves are shown, highlighting the expected decline in production as the reservoir depletes over time. Table 4 provides a detailed month-by-month forecast of TJ-4's production from July 2024 to December 2037. Based on Decline Curve Analysis (DCA), the forecast reveals the typical behaviour of a mature well, with production rates steadily decreasing as the reservoir is depleted.

Results Analysis

The production rate for Well TJ-4 starts at 712.17 bbl/d in July 2024 and declines consistently over time. In the initial years, the rate of decline is more significant, with reductions of approximately 15-20 bbl/d per month, which gradually slows down

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after 2030 to about 10 bbl/d per month. As production decreases, cumulative production increases, but at a diminishing rate. The EUR suggests that the well will reach its economic limit by 2037. The forecasted decline shows that production will continue for several years, though at lower rates. To sustain production levels and extend the productive life of the well, secondary recovery methods such as water injection may become necessary.

Different decline models were tested for the forecast, including exponential, hyperbolic, and harmonic models. The hyperbolic model predicts a more gradual decline compared to the exponential model, offering a more optimistic outlook for the well's future. According to the hyperbolic model, production will stabilize at 393.471 bbl/d by 2037, indicating a slower decline and a higher final production rate than the exponential model.

Conclusion

Well TJ-4 will continue producing oil, but with a significant reduction in output over the next 13 years. The forecast suggests that secondary recovery methods will be needed to maintain production and maximize the extraction of remaining reserves. The hyperbolic decline model provides a more optimistic future outlook, as it forecasts a more gradual decline, which could be beneficial if enhanced recovery techniques are implemented. However, effective reservoir management will be essential to optimize the well's production and ensure that it continues contributing to the field's overall output for as long as possible.

Interpretation, Results Analysis, and Conclusion of Figure 5 and Table 5

Interpretation

Figure 5 illustrates the oil production decline curve for Well TJ-4 in the Tharjiath oil field, located in the Muglad Basin. The figure includes both historical production data and forecasted future production rates, which help predict the well's future performance. It highlights key metrics such as the final production rate, Estimated Ultimate Recovery (EUR), cumulative production, and remaining reserves, all of which are affected by the well's natural depletion. The decline curve shows a gradual reduction in production as the reservoir matures and depletes over time.

Table 5 provides a detailed month-by-month forecast for TJ-4's production from July 2024 to December 2037. The forecast, derived from Decline Curve Analysis (DCA), indicates that production will continue to decrease gradually as the well ages. In the initial years, the decline is significant, with a more substantial drop in production, followed by a slower decline in the later years.

Brief Summary of Figure 5 and Table 5

Production begins at 715.08 bbl/d in July 2024, and by July 2037, it is expected to decrease to 393.47 bbl/d, representing a 45% reduction over the 13-year period. The decline is more pronounced in the early years, with monthly reductions of 100-120 bbl/d, but this rate slows after 2030, with smaller reductions of around 10-15 bbl/d per month. While the exact EUR is not specified, cumulative production increases, though at a diminishing rate over time. The EUR is expected to remain significant, but it will decline as the well matures.

The harmonic decline model, which assumes a slower, more gradual reduction in production, predicts a final rate of 438.4 bbl/d by 2037, offering a more optimistic outlook compared to the exponential and hyperbolic models, both of which suggest a steeper decline.

Conclusion

Well TJ-4 is expected to continue producing oil for many years, but at decreasing rates. By 2037, the production rate is forecasted to drop to 393.47 bbl/d, indicating a gradual reduction in output over the 13-year period. As production declines, enhanced recovery methods may be necessary to maintain output and maximize recovery from the remaining reserves. The harmonic decline model, with its more gradual forecast, offers a more optimistic outlook, while the exponential model is

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typically used for natural depletion in the field. Effective reservoir management will be crucial to optimize the well's performance and extend its productive life.

CONCLUSION AND RECOMMENDATIONS

Decline Curve Analysis (DCA) is a vital method for predicting the future production behaviour of oil wells based on historical data. This analysis involves plotting production data over time and applying three primary decline models—Exponential, Hyperbolic, and Harmonic—to determine the best fit for forecasting future production rates. The X-axis typically represents time (months or years), while the Y-axis indicates production rate (bbl/day).

The Exponential Decline Curve assumes a constant percentage rate of decline, suitable for wells with rapid initial production decreases. In contrast, the Hyperbolic Decline Curve allows for a more gradual and flexible decline rate, accommodating variations in reservoir depletion. The Harmonic Decline Curve represents an even slower decline, ideal for wells experiencing prolonged depletion, particularly in high-viscosity oil reservoirs.

Successful DCA hinges on comparing these models against historical production data to identify the model that best reflects observed trends. This process enhances the reliability of production forecasts, informing decisions related to field development, enhanced oil recovery (EOR) strategies, and resource management.

In conclusion, DCA offers critical insights for accurate reserve estimation and production forecasting, enabling effective planning and sustainable oil field development. Future improvements in DCA techniques should incorporate additional factors such as pressure changes, reservoir heterogeneity, and operational constraints to further enhance forecasting accuracy.

Plot Example:

Production Rate (bbl/d)

```
|
|                         Exponential Decline
|                       /
|                      /
|                     /    Harmonic Decline
|                    /
|                   /
|                  /  Hyperbolic Decline
|                 /
|                /
|
|----------------------------------------> Time
```

A Cumulative Production vs. Time chart is a crucial tool for visualizing the total oil produced by a well over time, illustrating the accumulation of production despite declining rates. This chart

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can be represented as either an area graph or a line chart, with the X-axis typically denoting time (in months or years) and the Y-axis indicating cumulative oil production (in barrels, bbl).

By plotting each well's cumulative production, the chart effectively demonstrates how total output builds up over the forecast period. This visualization is essential for estimating the well's Estimated Ultimate Recovery (EUR), as it provides insights into long-term production behaviour and remaining reserves. Overall, the Cumulative Production chart serves as a valuable resource for tracking well performance and informing resource management decisions.

Plot Example:

```
Cumulative Production (bbl)
|
|                    /
|                  /  Well 1 (Exponential)
|                /
|              /
|          ____/______
|            /
|          ____/____
|     Well 2 /       Well 3
|
|------------------------------------------> Time
```

The **Forecasted Remaining Reserves and Decline Forecasts** chart is a vital tool for visualizing projected remaining oil reserves in an oil field over time, based on decline curve analysis. This chart can be presented as either a bar graph or a line chart, with the X-axis representing time (typically in years) and the Y-axis indicating forecasted remaining reserves (in barrels, bbl).

The chart illustrates the gradual decrease in remaining reserves as production progresses and the well matures. Forecasted reserves are calculated using decline rates derived from various models—exponential, hyperbolic, and harmonic—providing insights into the volume of oil still available for extraction. This visualization aids in predicting the future production potential of the field and supports decision-making regarding secondary recovery methods and the economic viability of ongoing operations. Overall, the chart serves as an essential resource for effective resource management and strategic planning in oil field development.

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Plot Example:

Remaining Reserves (bbl)

|

| |

| Well 1 | |

| | Well 2|

| Well 3 | | |

| ... | | ... |

|

|---> Time

The **Comparison of Decline Models** chart serves as a critical tool for visually comparing the exponential, hyperbolic, and harmonic decline curves for a specific well, illustrating how each model predicts future production rates. This chart is essential for determining which model best fits historical production data and provides the most accurate forecasts for future output.

In the chart, the X-axis represents time (typically in months or years), while the Y-axis indicates production rate (in barrels per day, bbl/day). Multiple lines are plotted on the same graph, each corresponding to one of the decline models—exponential, hyperbolic, and harmonic—facilitating a direct comparison of their behaviours over time. This analysis aids in identifying the most suitable model for projecting the well's production trajectory, thereby informing future reservoir management decisions and enhancing the overall effectiveness of production forecasting.

Plot Example:

Production Rate (bbl/d)

|

| Exponential

| _________

| /

| /

| Hyperbolic   /

| ______   /

| /   _______/

| /

| /

|----------------------------- Time

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The **Forecast Accuracy** chart is an essential tool for comparing actual historical production data with predicted production values derived from various decline curve models. This chart visually represents the accuracy of each model in forecasting future production rates.

In the chart, the X-axis denotes time (in months or years), while the Y-axis indicates production rate (in barrels per day, bbl/day). A solid line represents the actual historical production data, while dashed lines illustrate the predicted production using exponential, harmonic, and hyperbolic models. This visual comparison enables an assessment of the forecast accuracy of each model by demonstrating how closely the predicted values align with observed production trends. Ultimately, the chart provides valuable insights into which model offers the most reliable forecast for future production, aiding in informed decision-making for reservoir management and production strategies.

Plot Example:

```
Production Rate (bbl/d)

|

|   *   *  Actual Production

| *    *

| *       *

|----------------- Predicted Production (Exponential)

|                 Predicted (Hyperbolic)

|----------------------------- Time
```

The **Sensitivity Analysis** chart is a critical tool for examining how variations in key parameters, such as decline rates or initial production rates, impact production forecasts. In this chart, the X-axis represents the varying parameters, while the Y-axis displays the forecasted production, either in barrels per day (bbl/day) or cumulative production.

Using bars or lines to represent different scenarios or sensitivity parameters, the chart illustrates how adjustments in input variables influence production projections. This analysis is essential for understanding the robustness of the forecasts and the potential range of outcomes based on different assumptions or parameter variations. By identifying how sensitive production forecasts are to changes in key parameters, operators can make more informed decisions regarding reservoir management and production strategies, ultimately enhancing the reliability of their forecasts.

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Plot Example:

```
Production Rate (bbl/d)
|
|    /
|   / Sensitivity Analysis (Decline Rate)
|  /
| /
|/________
|             /
|
|---------------------------- Time
```

Brief Summary of Recommendations and Conclusions

The recommendations from the Decline Curve Analysis (DCA) of the Tharjiath Oil Field highlight the importance of utilizing various analytical approaches to improve production forecasting and management. Employing Exponential, Hyperbolic, and Harmonic decline curves is essential for identifying the most accurate model for predicting future production behaviour. Additionally, a Cumulative Production chart will offer insights into field performance over time, while a forecasted reserves chart will aid in estimating remaining recoverable reserves for strategic planning.

By comparing decline models, the most suitable one for projecting future production rates can be selected, enhancing prediction reliability. The forecast accuracy plot will assess how well the chosen models align with actual production data, validating forecast accuracy. Furthermore, sensitivity analysis will evaluate the impact of key parameter variations on production forecasts, facilitating effective risk management.

In conclusion, integrating these analyses and visual tools will provide a comprehensive understanding of the Tharjiath Oil Field's production decline and performance, supporting informed decision-making in production management, reserve estimation, and long-term development planning.

Summary from the Combined Graph and Chart

This section summarizes the evaluation of oil well performance in the Tharjiath Oil Field through Decline Curve Analysis (DCA) and production forecasting, utilizing a combined graph and chart. The recommended visual representation is the Decline Curve Model Comparison (Production Rate vs. Time) graph, which is crucial for assessing well performance.

This graph compares the three primary decline models—Exponential, Hyperbolic, and Harmonic—against actual historical production data. The solid line represents observed production, providing a direct reference for validation, while the dashed lines depict the forecasted trends from each model.

By analyzing these models, the graph identifies the one that best fits historical data, with the Exponential model often demonstrating the closest alignment with observed depletion patterns. It also highlights the differing rates of production decline among the models, offering insights into future production rates. This comparison is vital for making informed decisions regarding reservoir optimization, secondary recovery methods, and long-term development

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strategies. Overall, the graph validates forecasted decline patterns against actual data, ensuring reliable predictions and supporting effective future production planning based on the most appropriate model.

Graph Example:

```
Production Rate (bbl/d)
|
|                  ------------------- Exponential Model
|                 /
|             ----/
|            /     Harmonic Model
|       -----
|      /        Hyperbolic Model
|     /
|    /
|   /
|  *  Actual Data  (solid line)
| *
|*
|-----------------------------------------> Time (Months/Years)
```

The **Cumulative Oil Production vs. Time** graph, which can be presented as either an area chart or a line graph, visually represents the total oil production over time for the Tharjiath Oil Field. This graph effectively highlights production trends despite the natural decline observed during the analysis period.

In this chart, the X-axis represents time (in months or years), while the Y-axis displays cumulative production in barrels (bbl). By aggregating total production across all wells, the graph provides an overview of the field's performance while also distinguishing the production trends of individual wells.

This visualization offers a comprehensive understanding of the reservoir's depletion dynamics, illustrating how the output of the field has evolved over time and identifying the contributions of each well to the cumulative production trend. Ultimately, this graph serves as a valuable tool for assessing overall field performance and informing strategic decisions related to reservoir management and production optimization.

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Chart Example:

```
Cumulative Production (bbl)
|
|                         /
|                        /
|                    ____/___ Well 1 (Exponential Decline)
|                    /
|              ____/___  Well 2
|              /
|     ________/___  Well 3
|   /
|  /
| /
|/
|-----------------------------------------> Time (Months/Years)
```

Key Insights from the Combined Graph and Chart

The first graph, ***Decline Rate Comparison***, reveals that the Exponential decline model aligns most closely with historical production data, indicating a consistent decrease in production over time due to natural reservoir depletion. The second chart, ***Cumulative Production vs. Time***, illustrates the total cumulative production across all wells, showing a gradual increase in total oil produced despite the steady decline in individual production rates, as predicted by the DCA models.

Together, these visualizations provide a comprehensive overview of the Tharjiath Oil Field's current performance and future outlook, emphasizing expected production trends and cumulative recovery based on DCA forecasts. The analysis confirms that the field is experiencing natural depletion, with production rates steadily declining. The ***Exponential decline*** model is identified as the most accurate representation of this behaviour.

While individual well production rates are decreasing, cumulative production continues to rise, reflecting the field's ongoing contribution to overall output. The integration of Decline Curve Analysis (DCA) and production forecasting offers a clear, holistic view of the field's performance and future projections, indicating that production will continue to decline over time.

Final Recommendations and Concluding Remarks

This study underscores the importance of Decline Curve Analysis (DCA) in optimizing the management of the Tharjiath Oil Field. It is recommended that DCA be systematically applied across all wells to enhance production forecasting and overall performance assessment. The exploration of alternative decline models, such as the Modified Hyperbolic and Arps models, is advised to capture variations in depletion patterns, particularly in wells with atypical behaviour, thereby improving forecast accuracy.

Future analyses should incorporate scenario-based forecasting to evaluate the impact of

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varying decline rates, reservoir pressures, and recovery factors, facilitating more robust production predictions. Additionally, the implementation of enhanced oil recovery (EOR) techniques, including water flooding and gas injection, is recommended to counteract natural production declines and prolong the field's productive life.

The integration of real-time data from reservoir monitoring tools is essential for continuous updates to DCA-based forecasts, enabling adaptive management strategies. Regular adjustments to production strategies based on ongoing monitoring will be crucial for sustaining field performance.

Concluding Remarks

DCA is pivotal for effective reservoir management in mature fields facing natural depletion. While it provides reliable forecasts, its limitations in complex reservoirs influenced by external factors necessitate continuous monitoring and real-time data integration to enhance prediction accuracy.

The dynamic nature of the oil and gas industry calls for adaptive forecasting models that account for market fluctuations and operational challenges. Incorporating sensitivity analyses and risk assessments will improve the understanding of external influences on production trends.

Addressing declining production rates requires a comprehensive strategy that integrates enhanced recovery methods, continuous monitoring, and adaptive forecasting. These approaches will extend the productive life of oil fields and optimize resource extraction.

In conclusion, this study emphasizes the need for refined forecasting methodologies, real-time data integration, and the adoption of EOR techniques to sustain oil field performance. By continuously updating forecasts and considering dynamic factors, operators can develop effective production strategies that ensure long-term reservoir sustainability and enhance operational efficiency.

Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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