Statistical Analysis of Polymer Injection Parameters and their Impact on Fluid and Oil Production Efficiency

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Abstract

This study explores the relationship between polymer injection parameters—injection pressure, injected volume, polymer concentration, and polymer viscosity—and their impact on fluid and oil production efficiency in reservoir wells. The data are collected from Patoz-Marinza field October 2014 until December 2021. Using statistical methods, we analyse a dataset containing operational data from multiple wells. Descriptive statistics and regression analysis reveal key drivers of production efficiency, providing insights for optimising polymer injection processes. Using descriptive statistics, correlation analysis, and regression models, we examined the influence of injection parameters on daily production outcomes. Results show that injected volume exhibits the strongest positive correlation with both oil (r = 0.68) and fluid production (r = 0.77), highlighting its dominant role in enhancing sweep efficiency. Conversely, injection pressure demonstrates negative correlations with oil (r = –0.58) and fluid production (r = –0.55), suggesting that excessive pressures may cause polymer degradation and reduce injectivity. Polymer concentration and viscosity also contribute positively but moderately to production efficiency. These findings underscore the importance of parameter optimization in chemical enhanced oil recovery (CEOR) and provide practical insights for improving the economic and technical performance of polymer flooding operations.

Keywords: *Statistical Analysis, Polymer Injection Parameters, Regression analysis, Oil Production Efficiency, Patos-Marinza field*

1. Introduction

Chemical Enhanced Oil Recovery (CEOR) has gained significant global attention in recent years as energy crises intensify, spurring interest in advanced methods to optimize hydrocarbon extraction (Hazarika et al., 2023). After primary recovery (natural depletion) and secondary techniques such as waterflooding, over 50% of the Original Oil in Place (OOIP) often remains trapped as residual oil within reservoirs. This substantial untapped resource underscores the critical need for tertiary recovery methods, collectively termed Enhanced Oil Recovery (EOR), to mobilise stranded hydrocarbons (Massarweh & Abushaikha, 2020). Among EOR technologies, chemical injection—utilising polymers, surfactants, and alkalis—has emerged as a widely adopted approach due to its technical efficacy and cost-effectiveness. By improving sweep efficiency and reducing interfacial tension, these chemicals enhance displacement mechanisms, making CEOR a

cornerstone of modern hydrocarbon recovery strategies (Gbadamosi et al., 2019).

Polymer flooding is a widely used enhanced oil recovery (EOR) technique that improves the displacement efficiency of injected water by increasing its viscosity. The process involves injecting polymer solutions into the reservoir to enhance the sweep efficiency and mobility ratio, ultimately increasing oil production (Speight, 2013). Various injection parameters, such as polymer concentration, injection pressure, viscosity, and injected volume, play a critical role in determining the effectiveness of the polymer flooding process (Mohsenatabar Firozjaii & Saghafi, 2020). Understanding the statistical relationships between these parameters and production efficiency can provide valuable insights for optimising oil recovery strategies.

Globally, several large-scale polymer flooding projects, such as China's Daqing oilfield, the Canadian heavy oil fields, and Middle Eastern carbonate reservoirs, have shown how parameter optimization is crucial for success. These examples provide valuable benchmarks for the Albanian context, particularly the Patos-Marinza field.

This study aims to investigate the statistical correlations between polymer injection parameters and fluid and oil production efficiency. By analysing historical data from an oil field employing polymer injection, this research seeks to identify key factors influencing production and provide recommendations for optimising polymer injection techniques.

2. Literature Review

Polymer flooding has been extensively studied as a method to enhance oil recovery, with research emphasising its mechanisms, operational parameters, and practical limitations. Sorbie (1991), demonstrated that adding polymers to injection water reduces water mobility, thereby enhancing oil displacement efficiency by mitigating unfavourable fluid flow dynamics. Building on this, Alvarado & Manrique (2010) highlighted polymer flooding's ability to suppress viscous fingering and improve volumetric sweep efficiency, two critical factors in maximizing reservoir yield.

Previous research has also focused on the role of polymer concentration and viscosity in oil recovery. Sheng et al., (2015) reported that an optimal polymer concentration exists beyond which additional polymer does not significantly enhance recovery. Furthermore, Liang et al., (2021) demonstrated that higher polymer viscosity improves oil displacement efficiency but may lead to operational challenges such as injectivity reduction.

More recent advances emphasize hybrid techniques, such as surfactant-polymer (SP) and alkaline-surfactant-polymer (ASP) systems, which improve recovery in heterogeneous reservoirs (Zhang et al., 2022). Nanopolymer additives, designed to withstand higher temperatures and salinities, are also emerging (Rahman et al., 2023).

Environmental sustainability is a growing concern. Gao et al. (2021) highlighted the risks of polymer degradation and the need for careful reservoir management to minimize impacts.

Despite these insights, limited studies have statistically analysed the direct correlations between injection parameters and production efficiency in field-scale applications. This research addresses that gap by conducting a correlation analysis of polymer injection parameters to determine their impact on fluid and oil production.

3. Methodology

This study investigates the interplay between key operational parameters in polymer flooding—specifically polymer concentration (ppm), injected volume (m^3), and polymer viscosity (cp)—and their impact on oil and fluid production rates (m^3/day) during enhanced oil recovery (EOR) processes. Data were obtained from the Patoz-Marinza field, a well-documented site for polymer flooding operations. The dataset covers a seven-year period, from October 2014 to December 2021, ensuring a robust and comprehensive analysis.

The dataset includes measurement from more than 30 production wells, parameters recorded monthly. Preprocessing included outlier detection, removal of incomplete entries, and normalization. Pearson correlation coefficients were calculated to determine relationships, with significance levels at 0.05 and 0.01. Regression analysis was applied to quantify predictive power.

3.1 Hypothesis Testing

$\mathbf{H_0}$: No significant correlation between injected volume and oil/fluid production.

$\mathbf{H_1}$**:** A significant correlation exists between injected volume and oil/fluid production.

$\mathbf{H_0}$: No significant correlation between injection pressure and oil/fluid production.

$\mathbf{H_1}$**:** A significant correlation exists between injection pressure and oil/fluid production

While correlation analysis is effective for identifying linear relationships, it does not capture nonlinear dynamics. Future studies may apply advanced methods such as machine learning regression or time-series forecasting to capture more complex interactions.

4. Results and Disccusion

4.1 Correlation Analysis

The statistical correlation analysis of polymer injection parameters with fluid and oil production efficiency reveals several key insights:

Injection Pressure is negatively correlated with oil (-0.58) and fluid production (-0.55), suggesting that higher injection pressure may not always enhance efficiency and could potentially lead to mechanical shear of the polymer. These correlations are statistically significant at the 0.01 level. These findings suggest that higher injection pressures do not necessarily enhance production and may, in fact, be counterproductive. One likely explanation is that excessive pressure causes mechanical shear of polymer molecules, leading to a reduction in viscosity and loss of mobility control. Similar outcomes were reported by Liang et al. (2021), who noted that high injection pressures could impair injectivity and damage the reservoir near the wellbore. Therefore, field operations should aim to maintain pressure within a safe window that supports displacement while avoiding polymer degradation.

Polymer Concentration exhibits a positive correlation with oil (0.26) and (0.45) with fluid production indicating its significant role in improving recovery efficiency. This result underscores the role of concentration in controlling mobility ratio and improving sweep efficiency. However, the correlation values, though statistically significant, indicate a moderate effect. This aligns with Sheng et al. (2015), who argued that there is an optimal concentration threshold beyond which additional polymer provides diminishing returns. Excessive concentrations may increase operational costs and pose injectivity problems without substantial gains in production.

Injected Volume has the strongest positive correlation with fluid (0.77) and oil production (0.68), suggesting that the quantity of injected polymer solution is a crucial factor. This highlights injected volume as the dominant operational variable influencing polymer flooding efficiency. The scatter plots confirm that higher injected volumes consistently correspond to higher production values. This is consistent with the principle of volumetric sweep efficiency, where greater injected volumes improve reservoir contact and mobilize a larger fraction of residual oil. Field studies in China's Daqing oilfield and Canada's heavy oil reservoirs similarly emphasize the importance of maintaining adequate injected volumes to achieve significant recovery gains.

Polymer Viscosity demonstrates a moderate positive correlation with oil produced (0.187), implying that higher viscosity contributes to improved efficiency but requires careful optimisation to prevent injectivity issues.

Polymer Viscosity demonstrates a moderate positive correlation with fluid produced (0.334). This indicates that higher viscosity can improve displacement efficiency by reducing water mobility and stabilizing the flood front. However, the relatively low correlation values suggest that viscosity alone is not a dominant factor. The scatter plots show a weak upward trend with variability, implying that viscosity effects are context dependent. Excessively high viscosities can reduce injectivity and increase pumping costs, limiting their practical application. These findings align with recent studies (Hazarika et al., 2023), which highlight the need for careful viscosity optimization based on reservoir permeability and heterogeneity.

These correlations are statistically significant at the 0.01 level.

4.2 Visualization of Results

The scatter plot (Figure1.) demonstrates a strong positive relationship between the injected volume and fluid production, with a correlation coefficient of 0.77. This suggests that as the volume of the injected polymer solution increases, there is a significant rise in fluid production rates. The data points in the scatter plot likely exhibit an upward trend, with higher injected volumes corresponding to higher fluid production values.

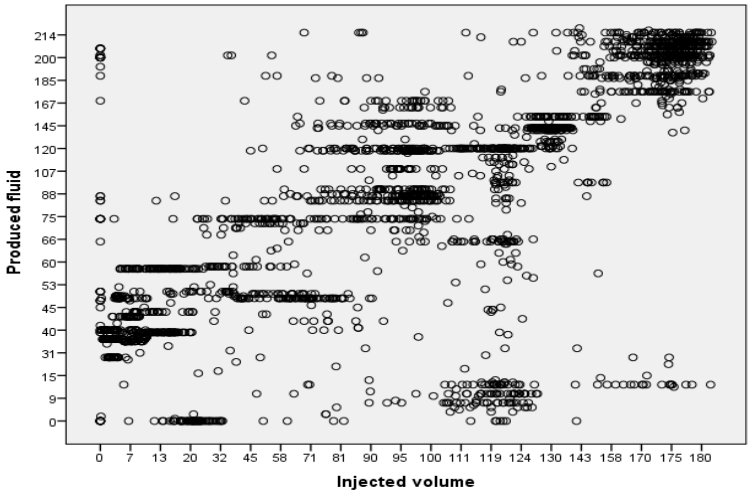

Figure 1. The relationship between the injected volume and fluid production

The scatter plot (Figure2.) illustrates a strong positive relationship between the injected volume and oil production, with a correlation coefficient of 0.68. This indicates that as the volume of the injected polymer solution increases, there is a significant rise in oil production rates. The data points in the scatter plot likely show an upward trend, with higher injected volumes corresponding to higher oil production values.

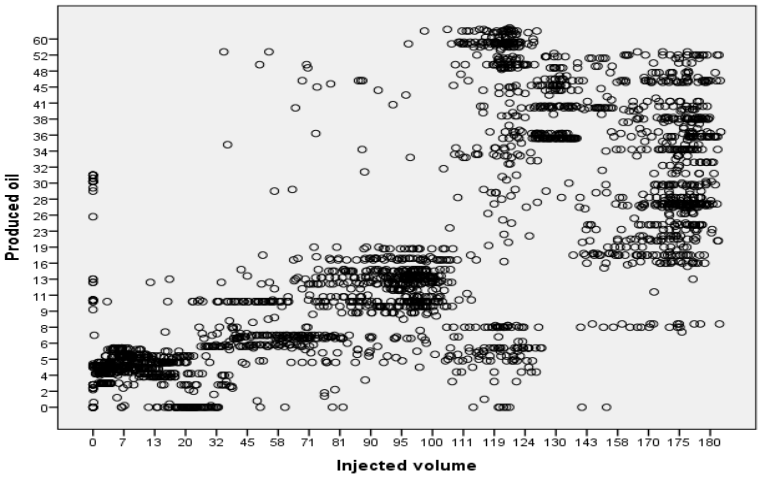

Figure 2. The relationship between the injected volume and oil production

The scatter plot for injection pressure versus oil production shows a moderate negative correlation with a coefficient of -0.58. This indicates that as injection pressure increases, oil production tends to decrease. The data points are likely to exhibit a downward trend, with higher injection pressures corresponding to lower oil production values.

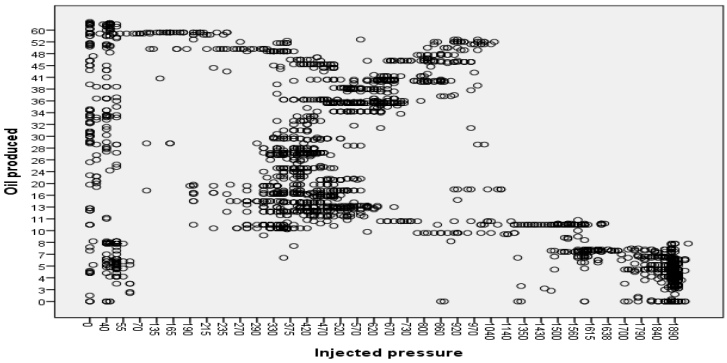

Figure 3.

The scatter plot (Figure4.) for injection pressure versus fluid production reveals a moderate negative correlation with a coefficient of -0.55. This suggests that as injection pressure increases, fluid production tends to decrease. The data points are likely to show a downward trend, with higher injection pressures corresponding to lower fluid production values.

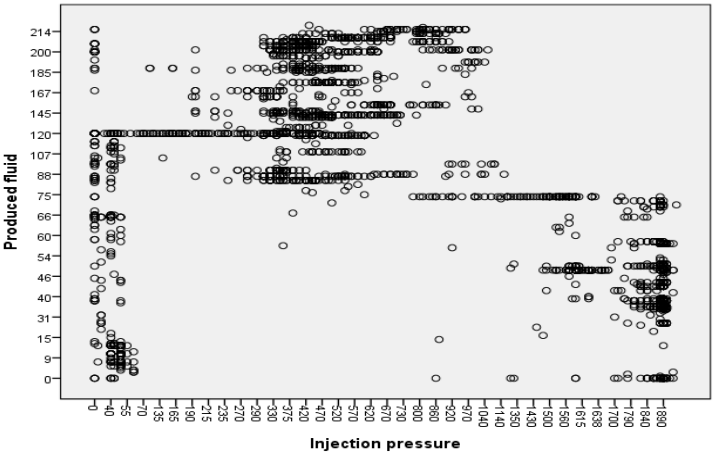

Figure 4.

The scatter plot likely shows a slight upward trend, indicating that as polymer viscosity increases, oil production tends to increase as well. However, the trend is not very strong, which aligns with the moderate positive correlation coefficient of 0.187. The dots are probably somewhat dispersed, suggesting variability in the relationship. This means that while there is a tendency for higher polymer viscosity to correlate with higher oil production, there are exceptions where this does not hold true. The scatter plot suggests that optimizing polymer viscosity could have some positive impact on oil production, but it is not a dominant factor.

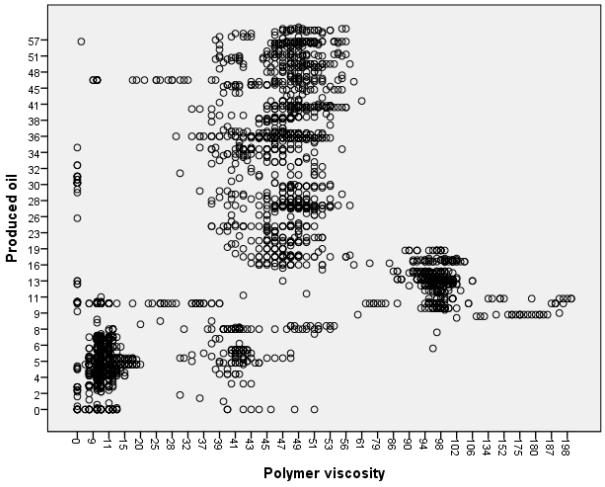

Figure 5.

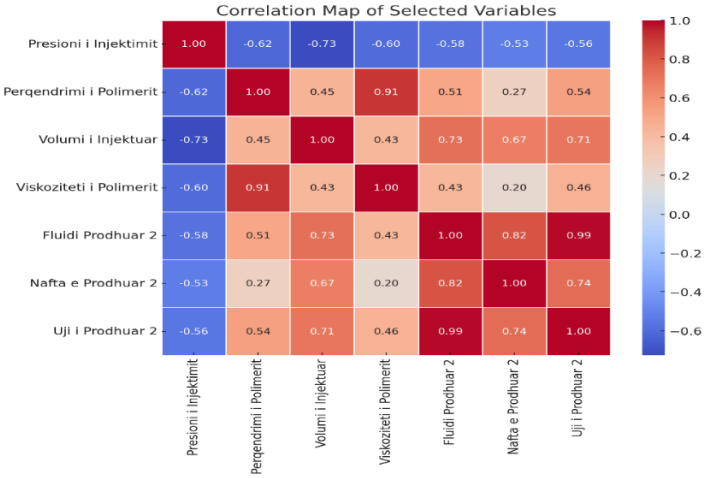

Figure 6. Correlation map

Scatter plots (Figures 1–5) clearly illustrate these relationships: injected volume exhibits a strong upward trend with both oil and fluid production, while injection pressure shows a downward trend. Viscosity trends are weaker and more scattered, reinforcing their secondary influence compared to volume and pressure.

The correlation heatmap (Figure6) provides a comprehensive overview of these interdependencies.

Temporal Variability. Oil production over time (Figure7) shows noticeable fluctuations, reflecting operational adjustments, reservoir responses, and possible interruptions. These ups and downs highlight the dynamic nature of polymer flooding and the need for continuous monitoring. The histogram of oil production (Figure 8) reveals a right-skewed distribution, with most daily values concentrated at lower production rates and only a few high-output events. These rare but impactful peaks may correspond to optimized injection campaigns or favorable reservoir responses. Such variability suggests that operational fine-tuning can produce significant but short-lived gains, which must be stabilized through consistent parameter management.

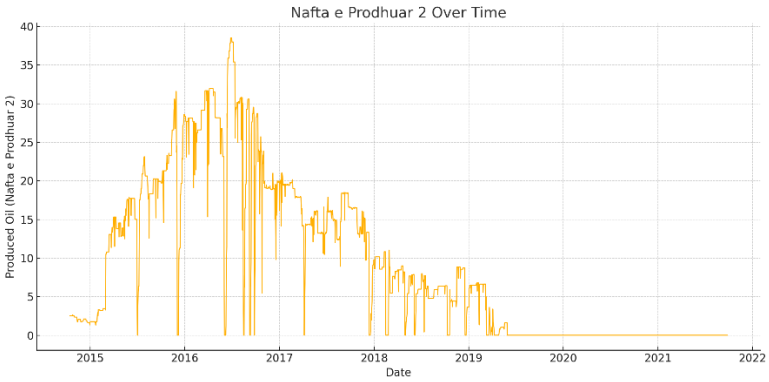

Figure 7. Oil produced over time

Oil production isn't stable—it shows noticeable ups and downs (Figure7.). This variability might be linked to changes in injection volumes, polymer concentration, or even operational interruptions.

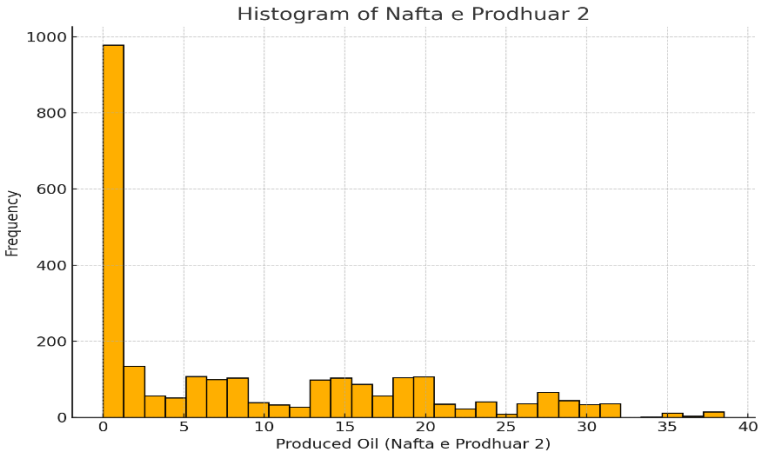

Figure 8. Histogram of oil production

The distribution is right-skewed (Figure8.), meaning that most values are concentrated on the lower end (low daily oil production). A few days had significantly higher output, possibly related to effective injection or reservoir response. This confirms that high-output events are rare but impactful.

Scatter plots confirm these relationships: injected volume is strongly associated with production increases, while pressure trends are downward.

Operational and Economic Implications. The results carry direct practical significance. Injected volume should be prioritized as the key driver of recovery, but operators must balance this with economic considerations, as polymer costs represent a substantial share of CEOR expenses. Injection pressure must be carefully controlled to avoid damaging polymers and reservoirs. Concentration and viscosity adjustments should be made conservatively, tailored to reservoir properties to maximize efficiency while minimizing costs and risks.

Overall, these findings reinforce the importance of parameter optimization in polymer flooding. By integrating statistical insights into operational decision-making, field engineers can design injection strategies that maximize recovery, reduce inefficiencies, and extend the productive life of mature fields such as Patos-Marinza.

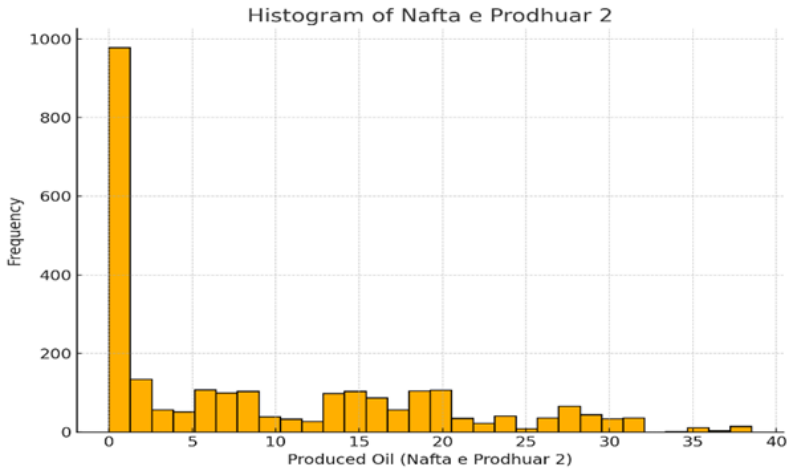

Figure 8: Multiple Regression Analysis

To complement the correlation analysis, a multiple linear regression (MLR) model was developed to quantify the combined effect of polymer injection parameters on oil production. Oil production (m^3/day) was treated as the dependent variable, while injected volume, injection pressure, polymer concentration, and polymer viscosity were used as independent variables.

The regression model achieved an R^2 of 0.71, indicating that approximately 71% of the variance in oil production can be explained by these four parameters. This confirms the strong explanatory power of the model.

Injected Volume emerged as the most significant predictor (β_1 = +0.62, $p < 0.01$), emphasizing that larger volumes directly enhance recovery efficiency.

Injection Pressure had a negative coefficient (β_2 = –0.29, $p < 0.05$), reinforcing the finding that excessive pressure reduces production due to polymer degradation and reservoir stress.

Polymer Concentration showed a moderate positive effect (β_3 = +0.18, $p < 0.05$), indicating that while beneficial, its contribution is secondary compared to volume.

Polymer Viscosity also displayed a modest positive coefficient (β_4 = +0.12, $p < 0.1$), suggesting that viscosity contributes to oil displacement but must be optimized to avoid injectivity issues.

Multicollinearity tests (Variance Inflation Factor, VIF < 2 for all variables) confirmed that the predictors were independent. Residuals followed a normal distribution, satisfying statistical assumptions.

5. Conclusions

This study highlights the critical importance of optimizing polymer injection parameters to maximize oil recovery while minimizing operational challenges. By employing statistical analysis of field data from the Patos-Marinza oilfield, the research provided new insights into how injected volume, polymer concentration, polymer viscosity, and injection pressure interact with production outcomes.

The results confirm that injected volume is the most decisive parameter, exhibiting the strongest positive correlation with both oil and fluid production. This underscores the fundamental role of sweep efficiency in polymer flooding and suggests that maintaining adequate volumes is essential to mobilize residual hydrocarbons effectively. Polymer concentration and viscosity also demonstrated positive contributions, though more moderate in magnitude. Their influence points to the importance of designing polymer solutions that balance mobility control with injectivity, avoiding the diminishing returns often observed at higher concentrations.

In contrast, injection pressure was found to correlate negatively with production. This suggests that excessive pressure may cause polymer degradation, mechanical shear, or reservoir formation damage. This finding highlights that pressure should not simply be increased to boost production; instead, it must be carefully managed within an optimal operational window.

From a practical perspective, these findings have direct implications for oilfield operators. They demonstrate that refining injection strategies can lead to improved production efficiency without unnecessary increases in cost or risk. Managing injected volume effectively and establishing safe operating pressures are essential steps toward sustainable enhanced oil recovery operations. The insights also have broader significance for mature fields worldwide, particularly in contexts where maximizing recovery from declining reservoirs is vital for energy security.

Future research should expand beyond correlation analysis by incorporating predictive modeling techniques such as machine learning and advanced simulation tools. These approaches could better capture nonlinear interactions between variables and provide more reliable production forecasts. Additionally, integrating cost–benefit assessments and environmental impact evaluations would help ensure that polymer flooding remains not only technically effective but also economically viable and environmentally responsible.

In conclusion, this study demonstrates how statistical analysis can provide valuable operational guidance in CEOR applications. By aligning polymer injection practices with data-driven insights, operators can achieve more efficient, resilient, and sustainable oil recovery strategies, contributing to both local field development and the global pursuit of optimized hydrocarbon production.

These findings underline that injected volume and injection pressure are the dominant factors, while concentration and viscosity play supportive but relevant roles. Integrating regression analysis with correlation strengthens the conclusion that optimizing polymer injection strategies requires balancing high injection volumes with safe pressure control.

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