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Production Optimization Through Horizontal Well Geometry : Toe-Up Vs Toe-Down

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Abstract

Horizontal wells are wells that are widely used in the oil and gas industry considering their effectiveness in increasing the productivity of a well. In field V, horizontal wells are not completely horizontal (90 degrees). Due to deviations in the geological formation, the drilled wells follow the formation dip. This study aims to determine the most optimal well model from several scenarios (toe-up, horizontal, or toe-down) and identify the dominant flow regime in the well. In this study, the author models well productivity and flow regimes with several scenarios. Such as the original scenario, true horizontal (90 degrees), toe-up (95 and 100 degrees) and toe-down (80 and 85 degrees). In each scenario, several different flow patterns or flow regimes can occur such as dispersed bubble flow, plug flow, annular flow, and slug flow. After comparing the productivity of each scenario, the results show that the toe-up scenario (100 degrees) has the highest oil production rate of 9401.8 STB/day, the original scenario 8599.7 STB/day, and the toe-down scenario (80 degrees) with 8237.6 STB/day has the lowest oil production rate. Therefore, toe-up (100 degrees) is the optimal well model used for horizontal wells in the V field compared to other scenarios. The gradient matching results for all well scenarios show a bubble flow pattern along the horizontal section of the well.

Keywords Horizontal Well, Toe-Up, Toe-Down, Well Productivity, Flow Regime, Oil Production

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INTRODUCTION

The oil and gas industry continues to develop innovative technologies to maximize hydrocarbon production efficiently and sustainably [1]. One such innovation is the use of horizontal wells, which have become increasingly common due to their ability to increase reservoir contact area and improve production rates, especially in thin or low-permeability reservoirs [2]. Unlike vertical wells, horizontal wells are drilled at high inclinations, allowing for more effective reservoir

[1] Ikhwannur Adha, "RESERVOIR DI LAPANGAN CIPLUK KENDAL" 3, no. September (2021): 39–50.
[2] (Sima, 2022)

drainage [3]. However, due to formation dip and geological heterogeneity, these wells are often not perfectly horizontal (i.e., 90°), resulting in wellbore geometries that curve upward (toe-up) or downward (toe-down) [4]. These geometries are typically adapted to follow the natural formation layers and to mitigate flow assurance challenges such as liquid loading [5].

Undulating well trajectories in horizontal wells can significantly impact multiphase flow behavior. In toe-down geometries, the lowest sections of the well can trap liquids, causing liquid blockage, while in toe-up geometries, gas accumulation may lead to gas blockage [6]. Both conditions can reduce well productivity and complicate production performance prediction [7]. To understand these effects, production simulators such as PERFORM and WELLFLO are often used [8]. These tools incorporate multiphase flow correlations to model inflow and outflow performance, allowing engineers to simulate various scenarios and optimize well designs [9]. However, limitations in data input (e.g., number of deviation survey points) and flow modeling accuracy remain challenges.

This study focuses on modeling horizontal well productivity under different wellbore geometry scenarios—namely, toe-up (95° and 100°), true horizontal (90°), and toe-down (80° and 85°) using a production simulator. The aim is to determine the most productive well trajectory and to analyze the dominant flow regime in each case using gradient matching techniques. The findings from this study are expected to offer insights into how wellbore inclination influences oil, water, and gas production, and provide recommendations for optimal horizontal well design in structurally complex reservoirs.

METHOD

This research aims to evaluate the impact of horizontal wellbore geometry on well productivity and fluid flow behavior by using a commercial production simulator. The methodology consists of several key stages: data preparation, well trajectory modeling, production simulation, and flow regime analysis through gradient matching. The data used in this study

[3] (Salfigo, 2021)
[4] (Malrin, 2022)
[5] Deny Fatryanto Edyzoh Eko Widodo, "Analisa Performa Reservoir Tight Gas Menggunakan Analisa Decline Curve Metode Duong Pada Sumur Vertikal Dan Horizontal Multifrakturing Menggunakan Simulasi Reservoir," *PETROGAS: Journal of Energy and Technology* 2, no. 1 (2020): 1–15, https://doi.org/10.58267/petrogas.v2i1.28.
[6] Firdaus Firdaus and Rohima Sera Afifah, "Analisa Injeksi Surfaktan+KCL Untuk Meningkatkan Perolehan Produksi Minyak Pada Formasi AB-2b Di Formasi Air Benakat," *PETROGAS: Journal of Energy and Technology* 4, no. 2 (2022): 27–41, https://doi.org/10.58267/petrogas.v4i2.126.
[7] (Monde, 2019)
[8] (Salfigo, 2021)
[9] (Manik, 2021)

includes deviation survey data (measured depth and true vertical depth), subsurface equipment data, reservoir fluid properties (PVT), surface production data (oil, gas, and water rates), and geothermal gradient data. Due to the limitation of the simulator used, which allows a maximum of 20 deviation survey points, the original deviation data was filtered to select 20 representative points that best describe the well's actual trajectory.

Four wellbore geometry scenarios were modeled to compare their performance: (1) the original scenario using actual deviation data from the field, (2) a true horizontal scenario assuming a constant inclination of 90 degrees, (3) a toe-up scenario with inclinations of 95 and 100 degrees, and (4) a toe-down scenario with inclinations of 80 and 85 degrees. Each scenario was modeled using the same production simulator for consistency and comparability. The reservoir model used in the simulator was the "Horizontal Well–No Flow Boundaries" type, as it most accurately represents the actual field conditions. Pressure loss due to friction and vertical fractures were excluded from the model, as these are not applicable to the studied reservoir characteristics. Model validation was conducted using gradient matching, which adjusts flow correlations to match simulated results with actual surface production data. This process ensures that the model reflects field behavior and improves the accuracy of subsequent scenario analysis.

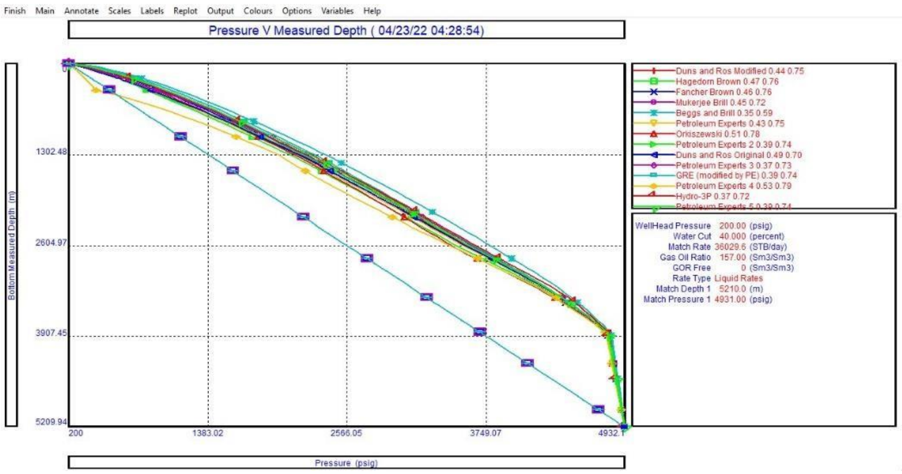
Flow regime analysis was carried out by interpreting gradient matching results, which provided insights into dominant flow types such as bubble flow, slug flow, plug flow, and annular flow. The simulator also offered data on slip velocity, phase holdup, and superficial velocities for both gas and liquid phases. These indicators were used to assess the likelihood of flow assurance issues, including liquid loading, particularly in toe-down geometries where fluid can accumulate in the lower sections of the well. Key performance metrics evaluated across all scenarios included oil production rate (STB/day), gas production rate (MMscf/day), water production rate (STB/day), bottomhole flowing pressure (BHFP), and the intersection point of IPR (Inflow Performance Relationship) and OPR (Outflow Performance Relationship) curves. These results were analyzed to determine which wellbore geometry offers the best performance in maximizing oil production while minimizing flow restrictions due to multiphase behavior.

RESULT AND DISCUSSION

This section presents the outcomes of the simulation for various horizontal wellbore geometries and discusses the implications on production performance and fluid flow behavior. Four scenarios were analyzed: original geometry, true horizontal, toe-up (95° and 100°), and toe-down (80° and 85°). The results were evaluated based on oil, gas, and water production rates, flow regime patterns, and intersection points of the IPR and OPR curves.

Oil, Gas, and Water Production Performance

The simulation results show significant differences in oil production rates across the scenarios. The toe-up geometry with a 100° inclination yielded the highest oil production rate at 9,401.8 STB/day, followed by the original trajectory at 8,599.7 STB/day, and the toe-down geometry at 80° producing the lowest at 8,237.6 STB/day. This trend indicates that toe-up configurations tend to be more effective in facilitating fluid flow toward the surface due to gravitational assistance.



3.1 Gradient Matching Plot with All Correlations

In terms of gas production, the toe-up 100° scenario also showed the highest rate at 8.33 MMscf/day, while the toe-down 80° scenario resulted in a lower gas output. Water production followed a similar trend, with toe-up configurations producing more water (6,267.9 STB/day) compared to toe-down scenarios. These results suggest that increasing the inclination angle (toe-up) enhances overall production, possibly due to reduced fluid holdup and more favorable flow dynamics.

Flow Regime Analysis

Flow regime identification using gradient matching revealed that the dominant flow pattern in all scenarios was bubble flow, particularly in the horizontal sections of the wellbore. In some cases, especially near the middle of the well, the flow transitioned to slug flow, which is a critical indicator of potential liquid loading. The presence of slug flow implies periodic liquid accumulation and release, which can lead to unstable production behavior.

Interestingly, in the toe-down 80° scenario, a deviation in flow behavior was observed. While most correlations identified bubble and slug flow transitions, the Petroleum Experts 3 correlation indicated the presence of dispersed bubble flow, which differs from the other scenarios. To improve model accuracy, the researcher selected the Petroleum Experts 4 correlation based on a lower standard deviation against field data. This approach ensured more reliable interpretation of flow regimes.

Impact of Inclination on Flow Dynamics

The variation in production performance across different geometries can be attributed to the effect of inclination angle on gravitational forces acting on the fluids. In toe-up configurations, the steeper angle facilitates natural movement of fluids toward the surface, reducing backpressure and enhancing reservoir energy utilization. According to Brito et al. (2014), increased well inclination promotes reservoir expansion, which helps drive fluids upward more effectively. On the other hand, toe-down geometries can trap liquids in the lower sections of the wellbore, leading to higher liquid holdup and potential flow restrictions. This condition hinders the efficient

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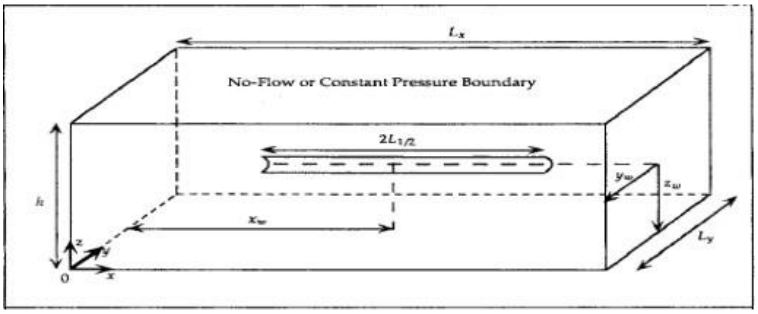
		Correlation	Parameter 1	Parameter 2	Standard Deviation
1	Reset	Duns and Ros Modified	0.43864	0.75195	0.67432
2	Reset	Hagedorn Brown	0.46821	0.76463	0.63818
3	Reset	Fancher Brown	0.4558	0.75989	0.83545
4	Reset	Mukerjee Brill	0.44592	0.7219	1.09619
5	Reset	Beggs and Brill	0.3479	0.59412	0.67969
6	Reset	Petroleum Experts	0.42642	0.75	0.68652
7	Reset	Orkiszewski	0.50933	0.77988	0.71045
8	Reset	Petroleum Experts 2	0.39078	0.7381	0.96289
9	Reset	Duns and Ros Original	0.49028	0.70019	0.98291
10	Reset	Petroleum Experts 3	0.37235	0.73238	0.95361
11	Reset	GRE (modified by PE)	0.38671	0.73653	0.69629
12	Reset	Petroleum Experts 4	0.52706	0.78554	0.76025
13	Reset	Hydro-3P	0.37167	0.71545	0.33691
14	Reset	Petroleum Experts 5	0.3868	0.73692	0.49609
15	Reset	OLGAS 2P	0.88413	0.88414	0.81445
16	Reset	OLGAS 3P	0.88413	0.88414	0.81445
17	Reset	OLGAS3P EXT	0.88413	0.88414	0.81445

transport of fluids and may require artificial lift methods or intervention to restore productivity.

IPR and OPR Intersection Analysis

The intersection points of the Inflow and Outflow Performance Relationship (IPR and OPR) curves for all scenarios occurred at an average bottomhole flowing pressure of 3,700 psig, indicating consistent reservoir pressure conditions across simulations. The average oil production rate across all scenarios was approximately 8,900 STB/day, with average gas and water production rates of 7.8 MMscf/day and 5,900 STB/day, respectively. These findings confirm that toe-up wells, particularly at 100°, consistently outperform other geometries in terms of production rates. The results support previous studies (e.g., Joshi, 1991) stating that horizontal wells located near the



bottom of a reservoir tend to produce more efficiently due to gravitational drainage and favorable fluid migration paths.

CONCLUSION

Based on the simulation results and analysis, it can be concluded that the most suitable reservoir model used in this study is the Horizontal Well–No Flow Boundaries, as it aligns with actual field conditions. The gradient matching feature in the production simulator proved useful in identifying the type of fluid flow within the wellbore, although it has limitations in providing a detailed representation of transient multiphase flow behavior. Among the various horizontal well geometries evaluated, the toe-up geometry with a 100-degree inclination demonstrated the highest oil production rate at 9,401.8 STB/day, indicating superior productivity compared to other configurations. In contrast, the toe-down geometry with an 80-degree inclination showed the lowest oil production rate at 8,237.6 STB/day, while the original trajectory produced 8,599.7 STB/day. These findings suggest that increasing the inclination angle in a toe-up configuration enhances reservoir performance due to better gravitational support and fluid movement. Furthermore, flow regime analysis through gradient matching indicated that the dominant flow type along the horizontal section of the well was bubble flow, which transitions into slug flow in the middle section of the wellbore. This transition is a critical indicator of potential liquid loading issues and should be considered when designing and optimizing horizontal well trajectories.

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