

OPTIMIZING OIL PRODUCTION IN THE NIGER DELTA: A COMPARATIVE ANALYSIS OF GAS LIFT CONTINUOUS AND ELECTRICAL SUBMERSIBLE PUMP (ESP) METHODS FOR THE JK1 WELL USING PROSPER NODAL ANALYSIS

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ABSTRACT:

The ever-declining rate of oil production from an oil well has been a problem for the industry and the broader economy. Despite various mitigation methods, achieving a hundred percent recovery rate remains elusive. Therefore, this article provides a cost-effective and professional approach to address this challenge through a comparative analysis of artificial lift methods. Specifically, we explore the performance of gas lift continuous and Electrical Submersible Pump (ESP) in mitigating the declining productivity of the JK1 well, utilizing PROSPER software for comprehensive nodal analysis. The application of PROSPER nodal analysis shed more light on the need for the implementation of sound engineering practices during selection and operation of suitable artificial lift methods. . The case study, centered on the JK1 well in the Niger Delta, highlights the importance of accurately updating reservoir properties, standard operating conditions, and procedures in the software throughout the production life cycle. The findings of the nodal analysis significantly enhance the output of the JK1 well. Comparative modelling reveals that gas lift continuous and electrical submersible pump methods yield 12,753.4 barrels and 6,771.8 barrels per day, respectively. In contrast, without artificial lift, the well produces zero barrels per day according to Darcy's model. Through a comparative examination of the study's data, it is evident that both artificial lift methods improve well output, with gas lift continuous emerging as the preferred option due to its excellent performance under extreme well conditions. This study not only provides valuable insights into the selection and operation of artificial lift methods but also emphasizes the critical role of advanced nodal analysis tools like PROSPER in optimizing well performance.

Key Words: Production, Optimisation, Nodal analysis, ESP Pump, Artificial lift

1. Introduction

The natural production of an oil well hinges on the reservoir pressure's ability to overcome the bottom-hole flowing pressure—a sum of wellhead, hydrostatic, and tubing frictional pressures¹. Factors such as friction and fluid viscosity contribute to pressure losses, with higher viscosity demanding more pressure for fluid elevation. To forecast production and address decline trends, production decline analysis becomes crucial.²

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¹ Mahmud, H. K. B., & Goenawan, V. (2017). Evaluation of Continuous Gas Lift Systems in an Oil Well. International Journal of Petroleum and Petrochemical Engineering (IJPPE) Volume 3(3), 66-75.

² Animashaun, M. B., & Abrakasa, S. (2014, August). Production Profile Analysis: A Case Study of Well-Y in Niger Delta. In SPE Nigeria Annual International Conference and Exhibition.

Upon completing nodal analysis, the identification and resolution of pressure loss issues become paramount for optimizing flow. Artificial lift emerges as a pivotal solution in the industry to mitigate pressure losses and overcome challenges posed by heavy fluid flow.³ Among the myriad artificial lift methods, gas lift and pumps stand out as the most common.

While pump operations involve lifting fluids by injecting compressed air or vaporous bubbles, gas lifting entails injecting gas into the wellbore fluid to aerate and facilitate its flow to the surface facility (Wikipedia). Several studies have explored artificial lift optimization and production forecasting using various methodologies. For instance, Odjugo et al³ employed Prosper Nodal Analysis for the BARBA-1 well in the Niger Delta, selecting the optimal artificial lift method following a comprehensive exploratory analysis. Other works, such as those by ^{2, 4, 5} have focused on Integrated Production Modeling (IPM) applications, reservoir performance forecasting, and field development planning.

This work's primary objective is to conduct a comparative analysis of Gas Lift Continuous and Electrical Submersible Pump methods for optimization. The study aims to determine the maximum performance achievable by each artificial lift method and establish the maximum gas injection rate for gas lift continuous.

1.1 Production History of JK1 Well

The JK1 well, situated in the Niger Delta, however, due to exclusive rights, the specific name of the oil field is withheld. The data obtained from the company showed a production history of JK1 well from 2011 to 2018 (see Table 1). Initially, the JK1 well was a highly productive asset, boasting an oil rate of 20,394.4 STB per day with a water cut of 0%, utilizing the natural drive mechanism. Commencing with a reservoir pressure of 4000 psi, the well efficiently produced oil.

However, over the years of continue production, the well faced the inevitable decline in reservoir pressure due to continuous production activities. As the reservoir pressure drops to 3000 psi, a corresponding reduction in oil production occurred. Simultaneously, the water cut escalated to 40%, signifying a higher proportion of water relative to oil production. Despite the absence of gas coning and a skin factor of zero, indicating no significant obstructions or gas interference, the declining reservoir pressure and increased water cut rendered the JK1 Well non-productive, necessitating the implementation of a technique to improve the production performance (such as artificial lift).

Therefore, absence of gas coning and a skin factor of zero notwithstanding, the declining reservoir pressure and increased water cut underscore the critical need for artificial lift methods. By selecting

³ Odjugo, T., Baba, Y., Aliyu, A., Okereke, N., Oloyede, L., & Onifade, O. (2020). Optimization of Artificial Lifts Using Prosper Nodal Analysis for BARBRA-1 Well in Niger Delta. *Nigerian Journal of Technological Development*, 17(3), 150-155.

⁴ Ozdogan, U., Keating, J. F., Knobles, M., Chawathe, A., & Seren, D. (2008, June). Recent advances and practical applications of integrated production modeling at Jack Asset in Deepwater Gulf of Mexico. In *SPE Europec featured at EAGE Conference and Exhibition* (pp. SPE-113904).

⁵ Memon, S., & Zameer, A. (2012, March). To develop the optimum Field development plan for condensate wells using Integrated Production Modeling (IPM). In *SPE Saudi Arabia section Young Professionals Technical Symposium* (pp. SPE-160924).

and installing the suitable artificial lift equipment, the JK1 Well can be revived, enabling the extraction of additional oil, and restoring its productivity. Summary of the well is presented in the Table below. Therefore, this work compared two artificial lift method; the Gas Lift Continuous employed by the company with an Electrical Submersible Pump methods for optimum performance.

Table 1: Summary of JK1 Well Production History

Well Depth (ft)	Year	Oil Rate (STB/day)	Water Cut (%)	Reservoir Pressure (psi)
8000	2011	20,394.4	0	4000
8000	2012	18,500.0	10	3800
8000	2013	16,200.0	20	3700
8000	2014	13,500.0	30	3700
8000	2015	10,400.0	35	3600
8000	2016	7,000.0	38	3400
8000	2017	3,100.0	39	3100
8000	2018	0	40	3000

2. Simulation Studies

To conduct this study, the PROSPER software was utilized for well performance and optimization. PROSPER, as described in the Integrated Petroleum Handbook by Petroleum Experts Limited⁶, is a powerful analysis tool that assists both production and reservoir engineers in executing their duties effectively³. The software enables the construction of various well models, allowing access to key variables such as well configuration, fluid PVT characteristics, multiphase Vertical Lift Performance (VLP) correlations, and various Inflow Performance Relationship (IPR) models.

Nodal Analysis, a technique employed in PROSPER, facilitates sensitivity analysis under different operational conditions, ensuring accurate calculations and superior results.⁷ Figure 1 shows a PROSPER main menu interface, which provided a summary of the system, encompassing essential information regarding fluid characteristics, well parameters, artificial lift method, calculation type, well completion, and reservoir properties. The data set used as input parameters as shown in the interface are presented in Table 2 and 3. Hence, the utilization of these data as requirement in PROSPER allows for a detailed examination of well performance, enabling the comparison of Gas Lift Continuous and Electrical Submersible Pump methods under various conditions.

⁶ Experts, P. (2003). Prosper Single Well Systems Analysis User Guide, Manual. Version 8

⁷ Aryan, R., & Shelly, B. Prosper Software for Gas Lift System Design and Simulation. International Journal of Research Publication and Reviews. 4(8), 2874-2884.

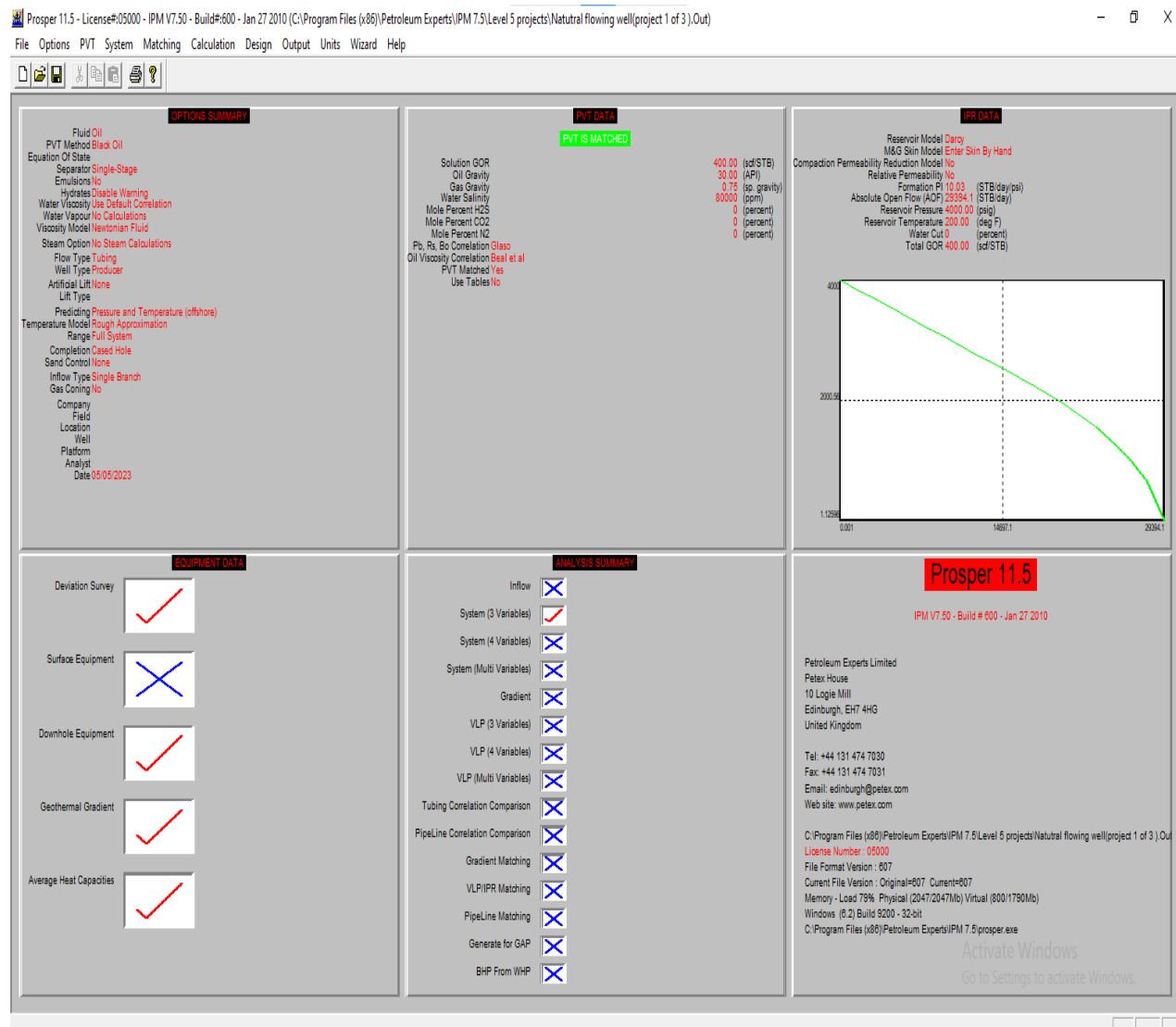


Figure 1: PROSPER main menu interface

Table 2: Input Parameters - Initial Well Properties

Properties	Value
Fluid	Oil and Water
PVT method	Black oil
Separator	Single Stage Separator
Flow Type	Tubing Flow
Well Type	Producer
Sand Control	None
Well completion	Cased Hole
Gas Coning	No
Inflow type	Single Branch
Emulsion	No
Gravel Pack	No
Artificial lift method	None

Table 3: Input Parameters - PVT Data

Properties	Value
Solution GOR	400
Oil Gravity	20
Gas Gravity	0.75
Water Salinity (ppm)	80000
Bubble point (psig)	2407.89
Oil Density	49.0498
Oil Viscosity	1.10796
Gas Z factor	0.90325
Water Density (lb/ft3)	63.9836
Gas Viscosity (centipoise)	0.025188
Gas Density (lb/ft3)	13.642

Simulation of Base Case Scenario

The base case scenario serves as the foundational starting point for the production system simulation, representing the expected or normal conditions. This base case becomes a benchmark for comparison with other scenarios, such as optimization or sensitivity analysis, allowing for a comprehensive evaluation of the system's performance.⁸

⁸ Schiozer, D. J., dos Santos, A. A. D. S., de Graça Santos, S. M., & von Hohendorff Filho, J. C. (2019). Model-based decision analysis applied to petroleum field development and management. *Oil & Gas Science and Technology–Revue d'IFP Energies nouvelles*, 74, 46.

Following the establishment of the base scenario, the next critical step is to provide data for the Inflow Performance Relationship (IPR). The IPR, defining the relationship between production rate and flowing bottom hole pressure,⁹ is essential for accurate system analysis. Information required for IPR includes reservoir pressure, reservoir temperature, water cut, and total Gas-Oil Ratio (GOR). Opting for the straightforward and easily convergent, a Darcy model was selected for both Gas Lift Continuous and Electrical Submersible Pump scenarios. Figure 2 shows the downhole equipment summary developed by PROSPER.

Table 4: Equipment Data

Properties	Value
Measured Depth (ft)	8000
True Vertical Depth (ft)	8000
10'' Conductor Casing depth (ft)	2000
8.3'' Surface Casing depth (ft)	4000
6.6'' Intermediate Casing depth (ft)	6000
4.9'' Production Casing depth (ft)	7700
3.2'' Production Tubing depth (ft)	8000
Temperature at 0 ft	30
Temperature at 8000 ft	200
Overall Heat Transfer Coefficient (BTU/h/ft ² /F)	8.0

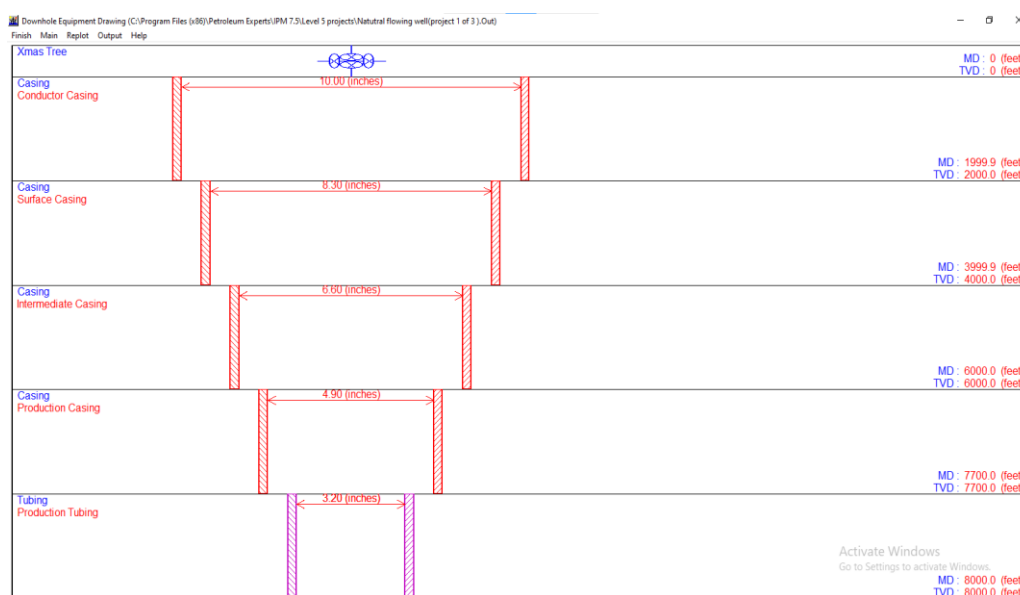


Figure 2: Summary of Downhole Equipment before installation of artificial lift system

⁹ Jahanbani, A., & Shadizadeh, S. R. (2009, June). Determination of inflow performance relationship (ipr) by well testing. In PETSOC Canadian International Petroleum Conference (pp. PETSOC-2009).

The equipment data includes factors such as deviation survey, downhole equipment, geothermal gradient, and average heat capacities. Some of these properties are shown in Table 4. This progression in simulation and data preparation lays the groundwork for a comprehensive analysis of the Gas Lift Continuous and Electrical Submersible Pump scenarios

Inflow Performance Relationship (IPR) and Vertical Lift Performance (VLP)

In the modelling of both gas lift continuous and electrical submersible pump scenarios, several parameters play a crucial role, among them being the Inflow Performance Relationship (IPR) and Vertical Lift Performance (VLP)⁸. These concepts are fundamental in the field of petroleum engineering, each providing unique insights into the behaviour of reservoirs and production systems. The summary of the design parameters for both gas lift continuous and Electrical Submersible Pump (ESP) is shown in Table 5 and 6 respectively.

The IPR is a depiction of the deliverability of the reservoir, showcasing the relationship between the reservoir's capability to deliver fluids and the resulting production rate. On the other hand, the VLP represents the connection between flow rate and the pressure drop along the flow path, extending from the wellbore to the surface facilities.^{10, 11}

Combining the IPR and VLP curves is integral to determining the highest operating point for the well and the overall production system.¹² The intersection of these curves represents the point where flow rate and pressure conditions are most efficient for the system. This ensures that the production system operates optimally, balancing the reservoir's capabilities with the efficiency of fluid transportation. Figure 2 provides a pictographic representation of the intersection of IPR and VLP curves, offering a visual understanding of how these concepts align and contribute to the efficient operation of the well and production system.

¹⁰ Muzaffarov, S. (2022). Comparative analysis of effectiveness in implementation of natural drive and artificial lift methods for hydrocarbon production (Doctoral dissertation).

¹¹ Tayyab, I. (2020). Gas well deliquification: critical rate analysis and artificial lift design & review workflow (Doctoral dissertation).

¹² Cogas, A., Campos, S., Camponogara, E., Gunnerud, V., & Sunjerga, S. (2012). Integrated production optimization of oil fields with pressure and routing constraints: The Urucu field. *Computers & Chemical Engineering*, 46, 178-189.

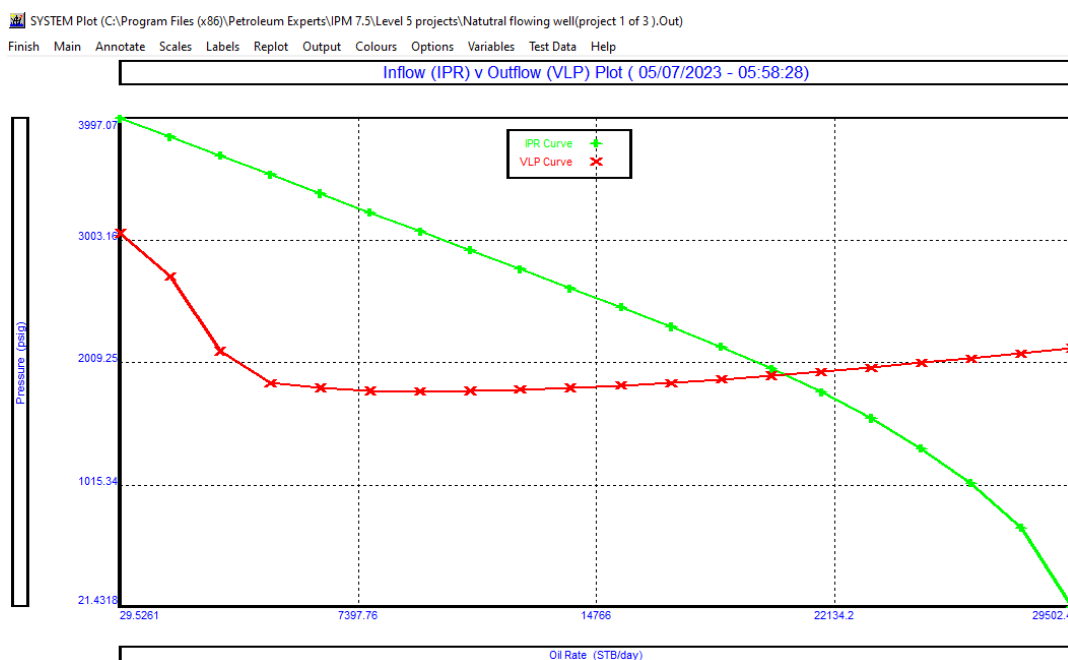


Figure 3: Inflow Performance Relationship (IPR) and Vertical Lift Performance (VLP) Curves

Table 5: Summary of Gas Lift Continuous Design Parameter

Input Parameter	Value
Design Rate Method	Calculated from maximum Production
Maximum Liquid Rate (STB/day)	20,000
Maximum Gas Available (MMscf/day)	10
Max Gas During Unloading (MMscf/day)	10
Flowing Top Node Pressure (psig)	200
Unloading Top Node Pressure (psig)	200
Operating Injection Pressure (psig)	1500
Kick Off injection Pressure (psig)	1500
Maximum Depth of Injection (ft)	7500
Valve Type	Casing Sensitive
GasLift Gas Gravity (sp.gravity)	0.8
Design injected Gas Rate (MMscf/day)	6.83134
Calculated injected Gas Rate MMscf/day)	10.00

Table 6: Summary of Electrical Submersible Pump (ESP) Design Parameter

Properties	Values
Pump depth Measured (ft)	7500
Operating Frequency (Hertz)	50
Length of cable (ft)	7500
Water cut (%)	40
Gas Separator Efficiency (%)	0
Water Cut (%)	40
Top Node Pressure (psig)	200
Motor Power Safety Margin	0
Design Rate (STB/day)	14,000
Total GOR	400
Pump	Centurion G200 5.62 inches (12000-24000 RB/day)
Motor	Reda 540_90.0_std 600HP 3050V 99A
Cable	#1 copper 0.26[volts/1000ft 115[amps] max

A. Sensitivity Analysis

Sensitivity analysis as a powerful method that helps identify key variables influencing well performance and guides optimization efforts. Therefore, in the sensitivity analysis stage, we evaluated the impact of changes to individual input variables in PROSPER Nodal Analysis. Hence, the reservoir pressure, skin, water cut, operating frequency (for ESP), and gas injection rate (for gas lift continuous) were all considered for sensitivity analysis. The results obtained can be used to prioritize optimization efforts, focusing on the most impactful variables.

B. Building Artificial Lift Models

In this study, the process of modeling the production system using either gas lift continuous or ESP involves several crucial steps. The first step is replacing "none" with the selected artificial lift method. There are notable differences in the modeling processes for gas lift continuous and ESP. In the case of ESP modeling, accurate selection of the right pump, motor, and cable is paramount for optimum operation. The proximity of the test point to the Best Efficiency Line (BEL) is key, as it signifies the point of greatest pump efficiency, as illustrated in Figure 4. In contrast, gas lift continuous modeling involves a critical consideration of the gas injection rate. This rate determines the speed at which gas is injected into the wellbore, reducing hydrostatic pressure and creating a pressure gradient that aids in lifting fluids to the surface. The outcome is reflected in the gas lift performance curve shown in Figure 5.

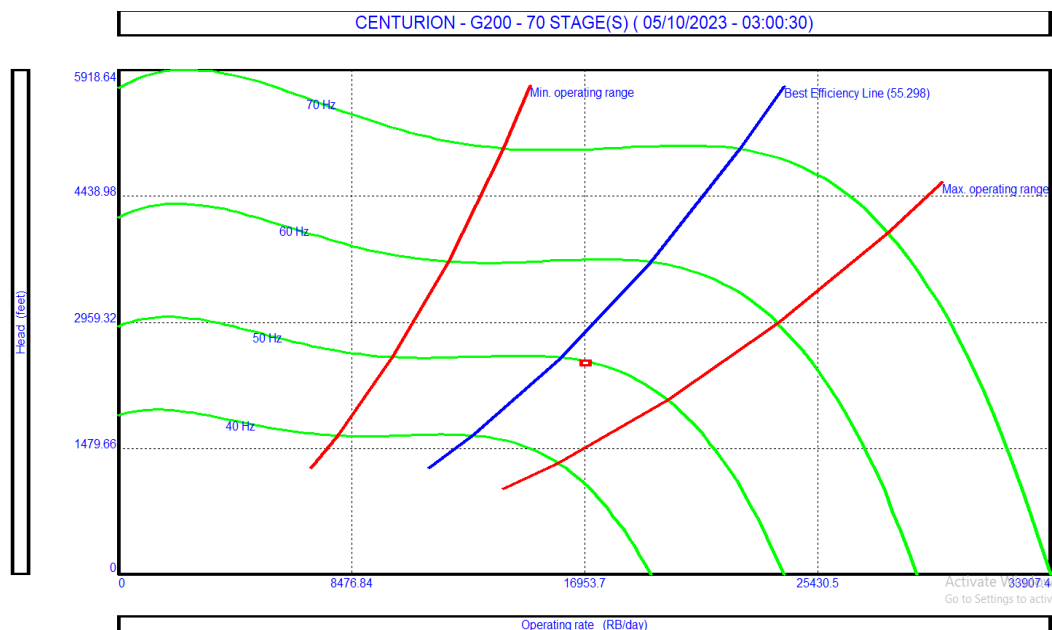


Figure 4: Electrical Submersible Pump Pump Plot

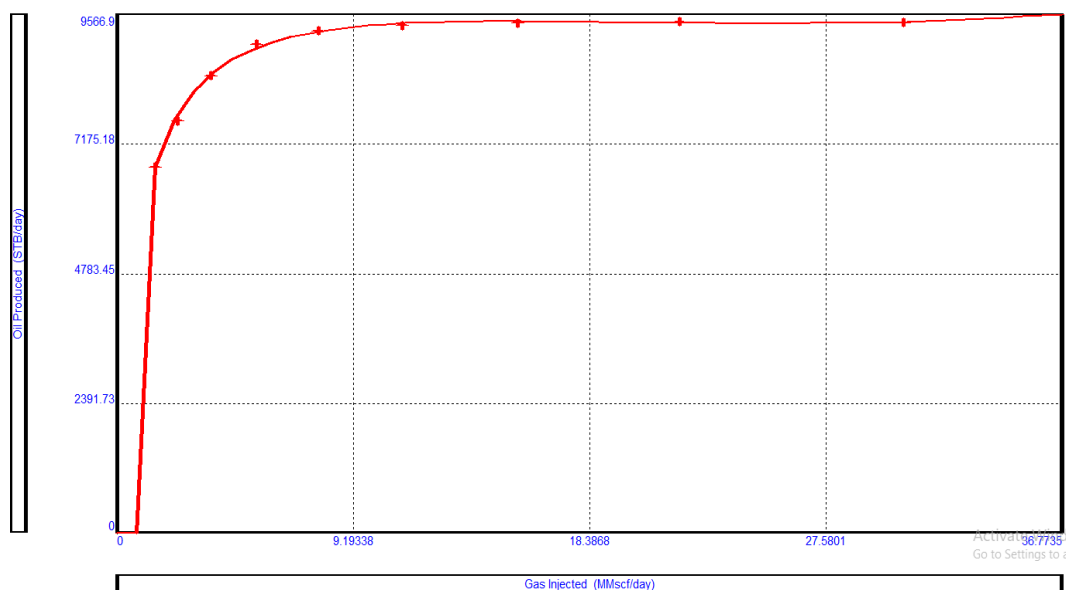


Figure 5: Gas Lift Performance Curve

Result and Discussion

At an initial reservoir pressure of 3000 psia and a water cut of 40%, Figure 6 illustrates that the well did not yield any production. This observation validates the notion that a decrease in reservoir pressure and an increase in water cut adversely affect the overall performance of the well.

Upon designing the gas lift continuous model using parameters in section 2.2 and specifying the required gas injection rate, two scenarios were considered. In the first scenario (Figure 7), the well was modeled for varying water cut (40%-80%), while keeping the reservoir pressure constant at

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3000 psi. In the second scenario (Figure 8), the water cut was kept constant at 40%, with the reservoir pressure varying from 3000 psia to 1000 psia. The results demonstrate that even under worst-case conditions, the well can still produce efficiently with the assistance of gas lift continuous.

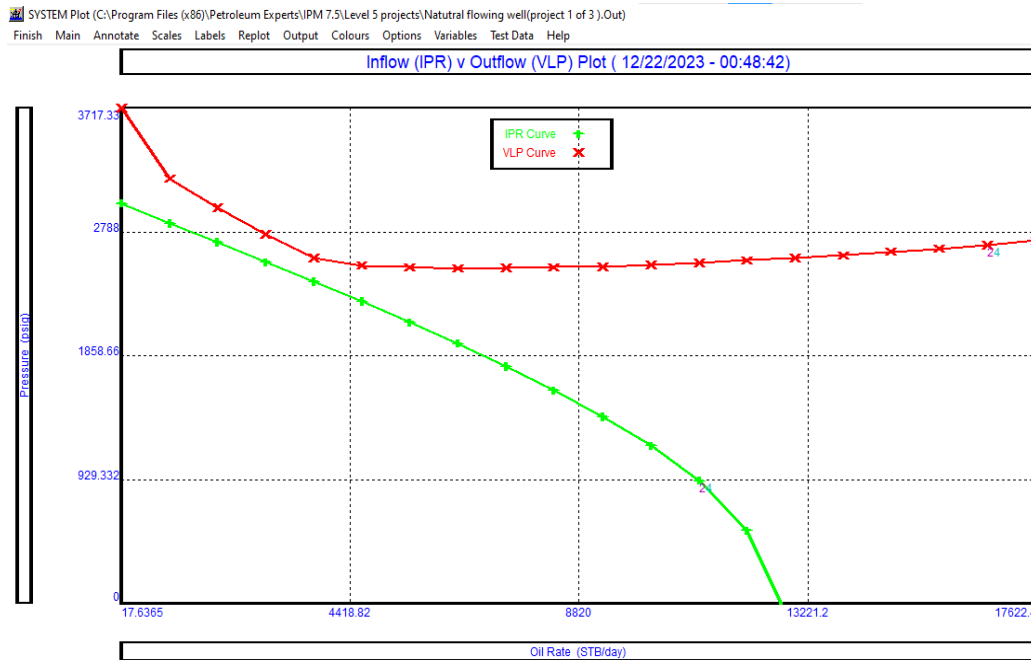


Figure 6: IPR and VLP curves for the initial well condition

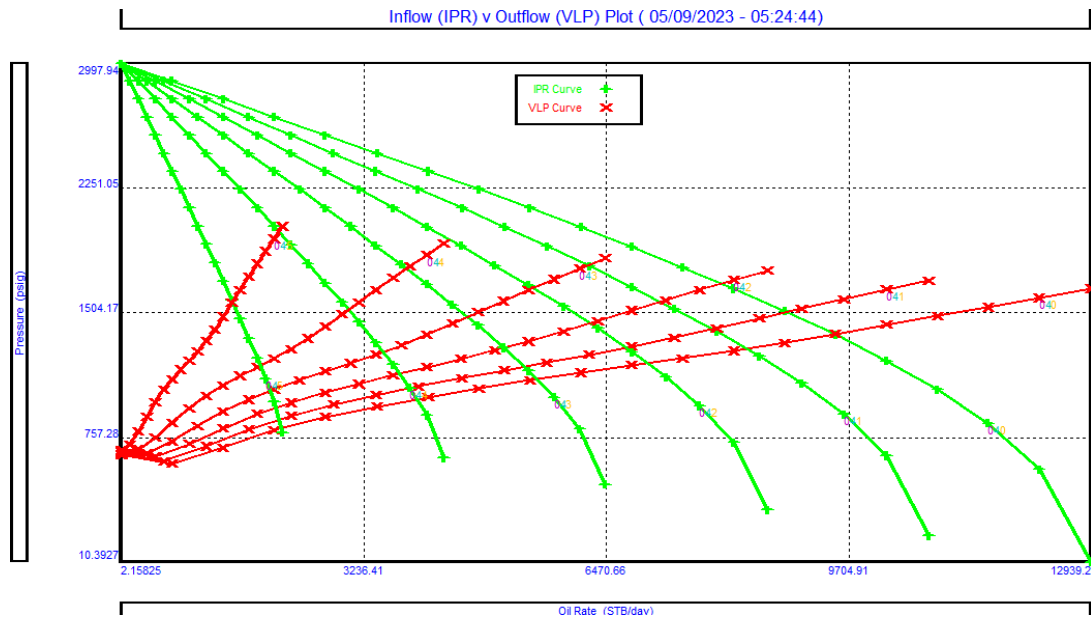


Figure 7: Water Cut Sensitivity Analysis for gas lift continuous model

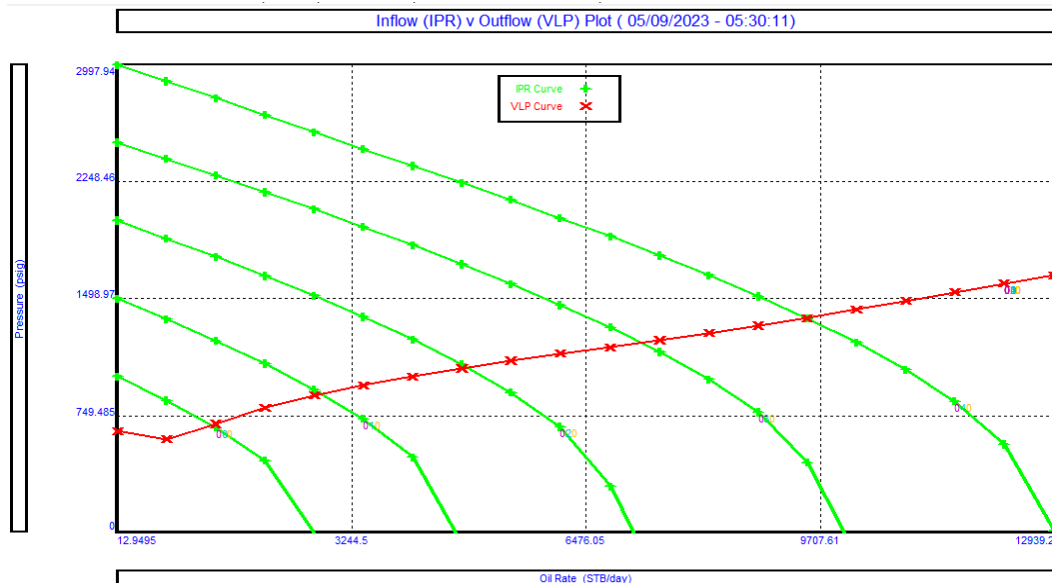


Figure 8: Reservoir Pressure Sensitivity Analysis for gas lift continuous model

After designing the ESP model with the correct pump, cable, motor, and other parameters reported in section 2.2, two scenarios were examined. In the first scenario (Figure 7), the well was modeled for varying water cut (40%-80%), with the reservoir pressure held constant at 3000 psi. The second scenario (Figure 8) involved keeping the water cut constant at 40%, while varying the reservoir pressure from 3000 psia to 1000 psia. Figure 7 highlights challenges for the ESP, especially at extremely high-water cuts (90%), where the pump fails due to gas entrainment and potential interference. Gas interference may lead to performance problems, decreased efficiency, and eventual pump damage. In Figure 8, the ESP also struggled under extremely low reservoir pressure

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conditions (2500-1000 psia). These findings underscore the importance of carefully selecting and optimizing artificial lift methods based on specific well conditions and operational requirements.

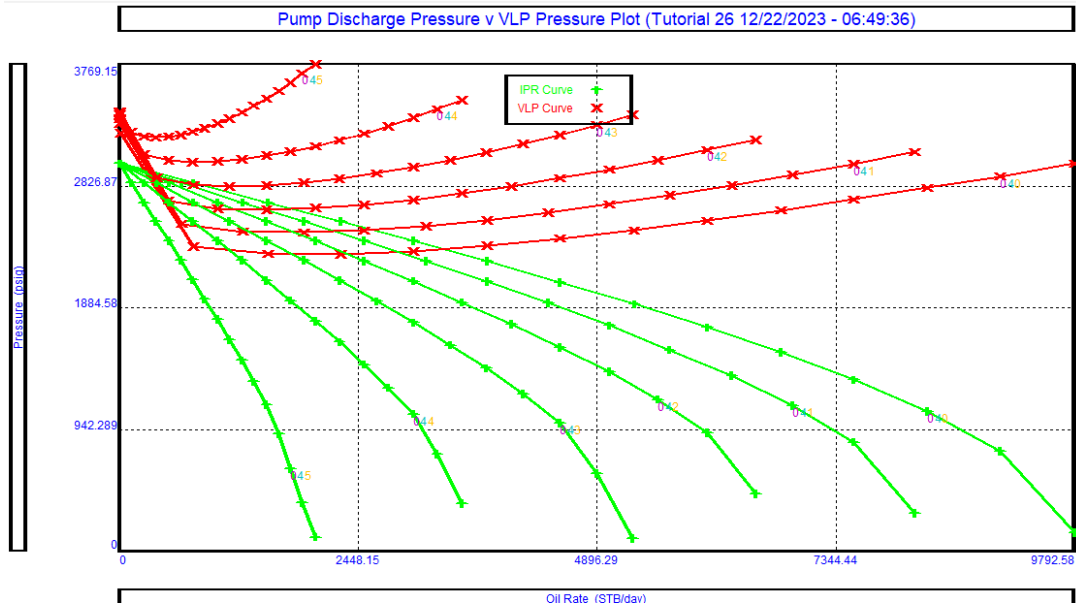


Figure 7: : Water Cut Sensitivity Analysis for Electrical Submersible Pump model

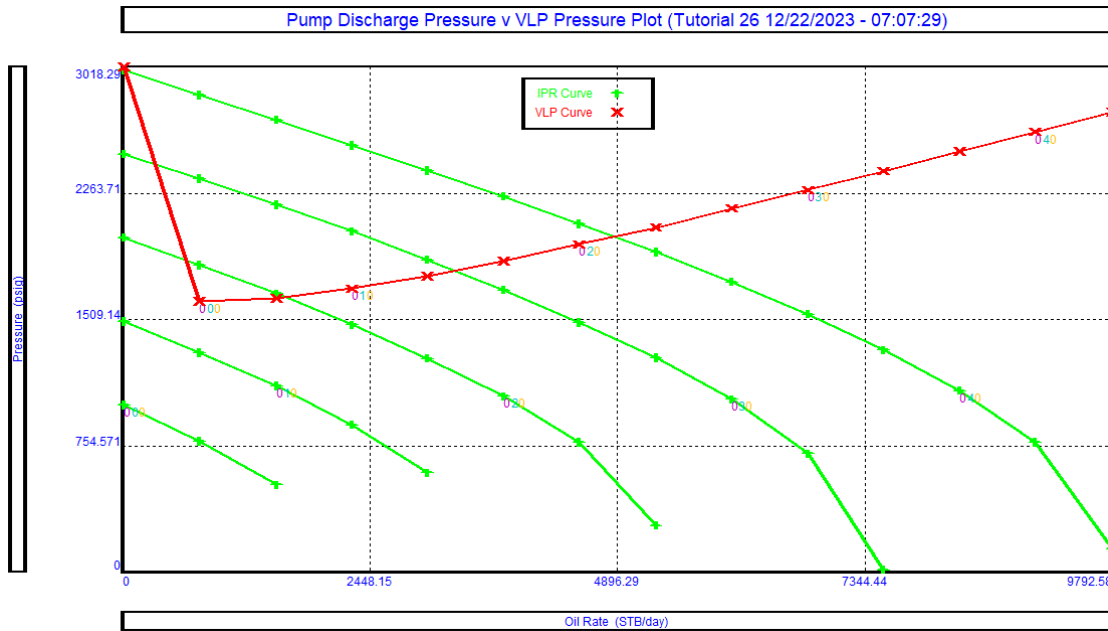


Figure 8: Reservoir Pressure Sensitivity Analysis for Electrical Submersible Pump model

3. Conclusion

In conclusion, this study provided valuable insights into the performance and effectiveness of two artificial lift methods: continuous gas lift and electrical submersible pump (ESP). Three distinct

models were developed—the basic case model, continuous gas lift model, and electrical submersible pump model—each incorporating factors such as the Inflow Performance Relationship (IPR) curve, PVT data, downhole equipment, and temperature profile along the well. The analysis highlighted the advantages of the gas lift continuous method, showcasing efficiency and prolonged adaptability to changing well conditions. Conversely, the ESP demonstrated strength in scenarios characterized by declining well reservoir pressure and increasing water cuts. An intriguing observation during sensitivity analysis revealed that, despite validating oil production for gas lift continuous at different reservoir condition parameters, the IPR and VLP curves did not intersect. Addressing this anomaly is a complex task requiring advanced knowledge of ESP, MBAL, and reservoir management, exceeding the scope of this paper. While the outcomes of this study are positive, it is essential to acknowledge the complexity of production optimization. Not every well can be individually optimized, and optimization software, such as GAMS and GAP from PETEX, becomes crucial when considering multiple wells to maximize operational revenue and achieve full-field optimization.

This study contributes to the understanding of artificial lift methods, but further research is encouraged to explore the observed anomalies and expand the applicability of the findings in diverse reservoir and operational settings.

Author Contributions

Conceptualization, Writing the original draft: Tochukwu Gerald Ozeh.

Review and Editing: Nura Makwasi, and Muhammad Umar Garba.

All authors have read and agreed to the published version of the manuscript.

Acronyms

PROSPER= Production System Performance

PVT=Pressure-Volume-Temperature

ESP= Electrical Submersible Pump

IPR=Inflow Performance Relationship

VLP=Vertical Lift Performance

BEL= Best Efficiency Line

MBAL= Material Balance