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Nodal Analysis of Electro-Submersible Pump Systems Enhanced with CanSystem

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Artificial lift systems play a crucial role in economically viable hydrocarbon reservoirs, and most oil wells rely on these technologies. However, challenges such as casing size, maintenance, and gas separation can significantly impact project costs and feasibility. Among available systems, Electro-Submersible Pumps (ESPs) have emerged as the most widely used method, particularly in adverse environmental conditions. This study aims to enhance ESP-based lift systems by incorporating CanSystem, a novel technology offering a range of benefits. CanSystem introduces several improvements to ESP systems, including enhanced productivity, reduced space requirements, and ease of corrosion treatment. By carefully analyzing the components of the system, particularly the lower encapsulation, and packing of the pumps, CanSystem optimizes fluid redirection, resulting in increased overall system efficiency. To evaluate the productivity and performance of ESP systems, the study combined the use of AutographPC® software for ESP model selection, Nodal Analysis, and Prosper simulation software. Nodal Analysis provides a comprehensive understanding of the system, allowing for the identification of design errors and the optimization of components. By considering flow dynamics from a reservoir to a nodal point and from a surface to a nodal point, nodal analysis enables a thorough analysis of the system's behavior. Prosper simulation results demonstrate a 6.3 % improvement in productivity index when CanSystem is integrated with Centurion Flex ESP. However, it is important to note that achieving optimal flow rates may be challenging at pressures below 1,400 psi (9.65 MPa). This emphasizes the necessity of tailoring the lift system to specific characteristics of each well to maximize efficiency.

1. Introduction

Artificial lift technology plays a crucial role in economically viable crude oil extraction from hydrocarbon reservoirs, with approximately 90 % of oil wells utilizing this technology (Alrabeh et al., 2021). However, challenges such as casing size, maintenance requirements, and gas separation issues can increase costs and pose financial feasibility concerns for these projects (Al Munif et al., 2021). Careful selection among various artificial lift systems is essential to ensure long-term efficiency under specific extraction conditions. Among the available options, the Electro-Submersible Pump (ESP) has emerged as the most widely used method due to its superior performance in adverse environmental conditions over the past 35 y. ESPs are widely used in crude oil production systems due to their high efficiency, compact size, and ease of corrosion treatment. These systems undergo continuous computational analysis to optimize flow rates, increase production, and reduce energy consumption.
In Ecuador, for instance, artificial lift systems employing ESPs were employed in 1,953 producing wells in 2021, contributing to daily oil production of approximately 472,880 barrels (~75,182 m^3) (Arroyo and Miguel, 2020). ESP-based artificial lift systems provide a viable alternative for extracting fluid from the bottom of the well to the surface when natural pressure differentials are insufficient (Karim and Naser, 2018). However, they have limitations in handling high temperatures and gas-liquid mixtures (Ramonet et al., 2022). Techniques such as sand control screens and pressure valves are employed to mitigate solids production and extend the pump's lifespan, although they can add to costs and affect pressure control. CanSystem technology, designed to combat corrosion near the reservoir, offers additional benefits by optimizing the Total Dynamic Head (TDH) and reducing motor power requirements. The configuration of ESPs is a critical factor in achieving effective fluid redirection

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and optimal performance. Among the various components, the encapsulation and lower pump packing systems play a significant role in this regard. These components work in tandem to facilitate the redirection of fluid to the ESP capsule, ensuring efficient and reliable operation of the system. The encapsulation system of the ESP serves as a protective barrier, enclosing the pump and electrical components within a secure and sealed environment. This encapsulation shields the internal components from the harsh external conditions prevalent in oil wells, including extreme temperatures and high pressures. By providing a robust barrier, the encapsulation system helps maintain the integrity of the ESP and ensures the safe operation of the electrical elements (Khalaf et al., 2019).

Advanced expert systems with intelligent algorithms are used in the current scenario to optimize production rates. These systems incorporate components such as symbolic representation, reasoning, decision pathways, and predefined artificial lift knowledge. Symbolic representation enables the system to capture complex concepts and rules while reasoning processes information logically. Decision pathways guide the system in selecting suitable strategies, and predefined artificial lift knowledge provides insights into lift techniques and optimization. By leveraging intelligent algorithms, these systems analyze data, make informed decisions, and enhance production rates. They offer industries improved operational efficiency and performance (Tavakkoli et al., 2021). Nodal Analysis, developed in 1954, is a predictive technique used as an analytical tool in the oil field. It enables the evaluation of complex systems by analyzing and predicting their behavior. With its ability to assess system performance, Nodal Analysis plays a vital role in optimizing oil field operations (Khalid et al., 2020). This study aims to compare a conventional ESP with a CanSystem-equipped ESP well to assess enhancements in Total Dynamic Head (TDH) and bubble point. AutographPC® software is used for ESP selection, while Prosper software and nodal analysis optimize well performance and identify mechanical issues (Odjugo et al., 2020). Prosper is a simulation software for analyzing oil and gas production systems. Combining AutographPC® and Prosper enables a detailed evaluation of ESP system productivity and performance. CanSystem technology, which offers improved productivity and ease of corrosion treatment, is integrated into the ESP system to optimize fluid redirection and increase overall efficiency. The Prosper simulation evaluates the performance improvements achieved with CanSystem. The specific parameters assessed include Productivity Index, Flow Rate, and the Total Dynamic Head. Tailoring the artificial lift system to each well's characteristics is essential for optimal flow rates, especially below 1,400 psi (Lan et al., 2020). This study proposes CanSystem as a novel approach to enhance ESP-based lift system performance in the oil production sector. The effectiveness of this strategy in optimizing efficiency and productivity is demonstrated through the integration of advanced software tools such as AutographPC® and Prosper. This method contributes to the advancement of the industry by overcoming operational challenges and improving overall system performance.

2. Methodology

2.1 Design of the electrical submersible pump system

The design of the ESP system plays a crucial role in ensuring optimal performance and efficiency. In this study, the AutographPC® software was utilized to assist in the selection of the best ESP model by simulating the behavior of the well in a virtual environment (Baptista et al., 2021). AutographPC® incorporates a comprehensive set of equations related to mass, energy, and momentum transport, as well as thermodynamic characteristics, hydraulic properties, multiphase flow behavior, well completions, and reservoir engineering aspects. These equations, along with input variables, are used to analyze and evaluate the performance of different ESP models (Foronda et al., 2023).

Figure 1 illustrates the variables that are inputted into the AutographPC® software. These variables include reservoir properties such as formation pressure, temperature, and fluid properties, as well as wellbore parameters like casing and tubing sizes, completion details, and fluid flow rates. Additionally, information about the ESP equipment, such as pump specifications, motor power, and electrical characteristics, is also considered in the design process. By inputting these variables into the AutographPC® software, the system behavior can be simulated, and various ESP models can be evaluated based on their predicted performance. The software calculates important parameters such as pump efficiency, head developed, power requirements, and expected production rates. This enables engineers to make informed decisions and select the ESP model that best suits the specific well conditions and production requirements. The use of AutographPC® software streamlines the design process by providing a virtual platform for analyzing different scenarios and optimizing the ESP system design. It eliminates the need for costly and time-consuming trial-and-error approaches by allowing engineers to simulate and compare the performance of multiple ESP models under various operating conditions. This not only enhances the efficiency of the design process but also ensures the selection of an ESP system that can maximize productivity while meeting the technical and economic constraints of the well.

2.2 Nodal analysis

A perfect design assumes that the calculated available head for the pump accurately exceeds the required head demand of the system. However, achieving this perfect design is not always possible. Design errors often arise due to insufficient knowledge or lack of information regarding the well's inflow performance. Inaccurate data can result in the stabilized liquid rate of the ESP system deviating from the design target, ultimately leading to system failure (Khalid et al., 2020).

These issues can be addressed by utilizing Nodal Analysis (NA), which integrates the following components: a) production system, b) pipeline, c) ESP, and d) surface equipment. NA divides the well into two subsystems: a) the subsystem that considers the inflow from the reservoir through potential pressure drop components to the nodal point, and b) the subsystem that considers the outflow system from the surface pressure to the nodal point.

Each subsystem calculates the pressure at the nodal point using specific curves: a) the inflow curve and b) the outflow curve from the separator to the nodal point.

The procedure for conducting NA starts with a) determining the system components that can be changed, b) selecting the system component to optimize, c) placing the nodal point, d) developing the expression for the volumetric inflow and outflow rates, e) defining the necessary data to calculate pressure drop versus flow rate for all components, f) determining the effect of changing the characteristic of the selected component by plotting the inflow against the outflow, g) identifying the intersection point, and h) repeating the steps for each component until optimization is achieved (Vitali et al., 2021).

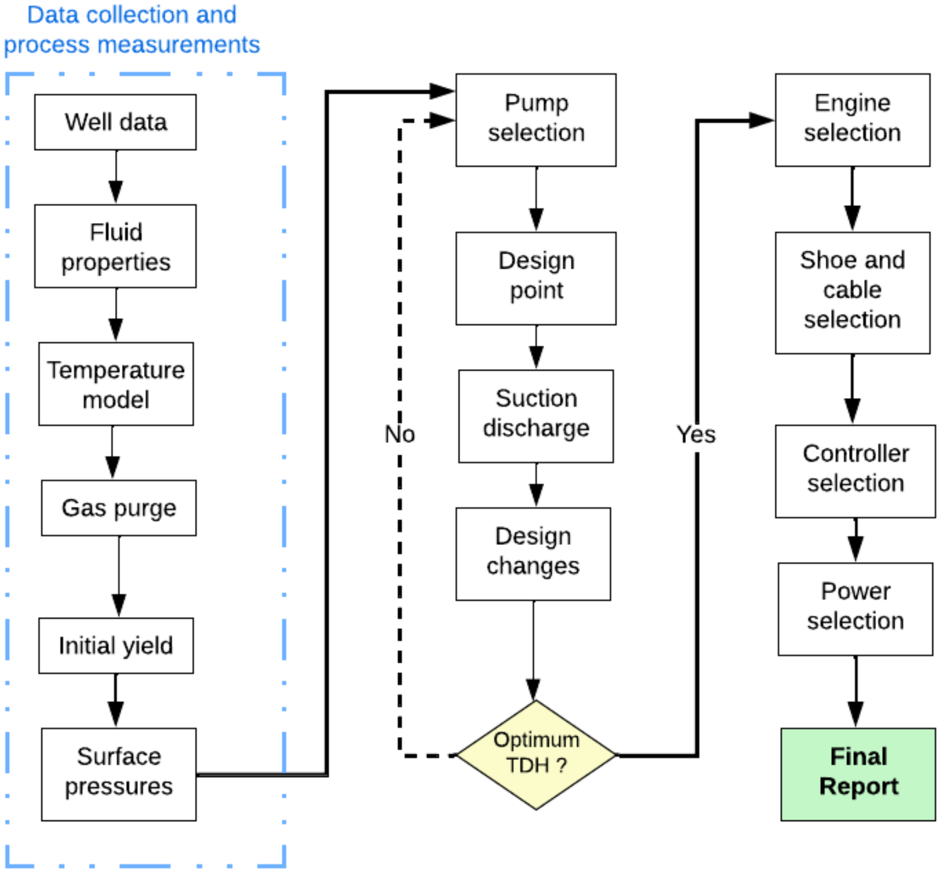

Figure 1: Design of an Electric Submersible Pumping System using AutographPC®

2.3 Prosper productivity analysis

A productivity analysis using Prosper was carried out by the following steps (Odjugo et al., 2020):

- Determine Fluid Properties: n order to construct a successful production flow simulation model, accurately estimate the fluid properties of the reservoir and their variations with temperature and pressure, known as Pressure-Volume-Temperature (PVT) properties. These properties play a crucial role in constructing a successful production flow simulation model.

- Build the Model: Construct a simulation model that accurately represents the production flow. This involves incorporating the reservoir, wellbore, and surface facilities into the model.
- Define Well Constraints: Specify the constraints and parameters for the well, such as tubing size, wellhead pressure, and completion configuration. These factors influence the flow behavior and performance of the well.
- Input Reservoir Data: Provide the necessary reservoir data, including permeability, porosity, reservoir pressure, and productivity index. This information helps to characterize the reservoir and its ability to deliver fluids to the wellbore.
- Configure Tubing and Completion: Set up the tubing and completion design, including selecting the appropriate tubing size, length, and completion components. This step ensures that the well is properly configured to optimize production.
- Define Production Constraints: Specify the production constraints, such as maximum production rate and flowing pressure, to ensure that the analysis aligns with operational requirements.
- Run the Analysis: Execute the Prosper software to perform the productivity analysis. The software utilizes the input data, reservoir properties, and well constraints to simulate the flow performance and predict the production rates and flowing pressures.
- Analyze Results: Examine the output from the Prosper analysis, including production rates, flowing pressures, and other relevant parameters. Evaluate the performance of the well and identify any potential issues or areas for optimization.
- Optimize Well Performance: Based on the analysis results, make adjustments to the well design, completion configuration, or production parameters to optimize the well's performance. This iterative process may involve repeating the analysis with different scenarios or parameters until an optimal solution is achieved.

3. Results

3.1 Prosper productivity analysis result

The Prosper productivity analysis conducted in this study yielded significant results that contribute to the understanding of reservoir behavior and performance. To ensure an accurate representation of reservoir fluid properties, the PVT data obtained was adjusted using appropriate correlations, including the Glasso and Beggs correlations (Yuan et al., 2020) for bubble point pressure, oil solubility, and volumetric factor ratio. The subsaturated oil viscosity correlation by Kim et al. (2016) was also utilized for viscosity adjustments.

Table 1 presents the ranges of the adjusted PVT data, providing valuable insights into the performance of the reservoir. The bubble point pressure exhibited a wide range, varying from 165 to 7142 psia, indicating significant variations in reservoir conditions. Similarly, the temperature ranged from 80 to 280 °F, indicating diverse thermal characteristics across the reservoir. The formation volume factor (FVF), which indicates the expansion and contraction of the fluid, ranged from 1.025 to 2.59 bbl/STB (barrels per stock tank barrel), further highlighting the variations in fluid behavior. The gas-oil ratio (GOR) displayed a range of 2.54 to 74.7 m^3/STB, indicating different gas-to-liquid ratios within the reservoir. The oil gravity ranged from 22.3 to 48.1 °API (788 to 920 kg/m^3), and the gas gravity ranged from 0.65 to 1.276, demonstrating differences in gas properties. The separator pressure and temperature were determined as 2.86 MPa and 52 °C, providing crucial boundary conditions for the analysis. Additionally, the ranges for both oil and oblique viscosity were provided, offering insights into the flow characteristics of the reservoir fluid.

Based on the adjusted PVT data, the study proceeded to establish the inflow performance relationship (IPR) using the selected PI model. This step is crucial in understanding how the reservoir fluids flow into the wellbore and affect the overall performance of the system. By establishing the IPR, the study can further evaluate the productivity and performance of the ESP system under different reservoir conditions and operating parameters. The comprehensive analysis of the adjusted PVT data and the establishment of the IPR form a solid foundation for evaluating the inflow performance and optimizing the productivity of the ESP system. These insights will contribute to the overall understanding of the reservoir behavior and assist in making informed decisions regarding the design and operation of the artificial lift system.

The production parameters chosen were an IP of 0.539 STB/day/psi and an Absolute Open Flow (AOF) of 869.301 STB/day. These parameters represent the productivity potential of the well under consideration. To evaluate the efficiency of the system, the CanSystem downhole equipment was installed. It is important to note that Prosper does not provide an encapsulation option. Therefore, a casing section with the same outer diameter was designed to simulate the effect of the casing with the casing joint. This simulated casing section allows for an assessment of the system performance in the presence of the CanSystem equipment.

By utilizing the VLP (Vertical Lift Performance) and IPR (Inflow Performance Relationship) matching, the correlation between multiphase flow and the pressure parameters obtained from AutographPC was successfully adjusted. A graphical comparison of tubing correlations showed a better fit with Petroleum Expert 2 for the wellhead pressure, intake pressure, and discharge pressure.

Table 1: Ranges of PVT data

Parameters	Glasso correlation
Bubble Point, (MPa)	16.5 – 71.42
Temperature, (°C)	26.7 – 137.8
Formation Volume Factor, (bbl/STB)	1.025 – 2.59
Gas Oil Ratio, (m^3/STB)	2.54 – 74.7
Oil Gravity, (kg/m^3)	788 – 920
Gas Gravity	0.65 – 1.276
Separator Pressure, (MPa)	2.86
Separator Temperature, (°C)	52
Oblique Oil viscosity: µob (mPa.s)	0.142 – 127*
Oil viscosity: µo (mPa.s)	0.16 – 315*

Table 2 presents a comprehensive overview of the main productivity variables obtained from both the CanSystem and traditional systems. Upon analyzing the productivity results displayed in Table 2, it becomes evident that while the CanSystem and traditional system exhibit similar supplied pressures (P) and wellhead pressures, there are notable differences in other crucial productivity parameters. In terms of flow rate (Q), the CanSystem outperforms the traditional system by achieving a higher value of 750 STB/day, compared to 702 STB/day achieved by the traditional system. This signifies that the CanSystem enables increased production of fluid from the well, showcasing its superior efficiency in fluid extraction.

The productivity index (PI), which measures the efficiency of fluid production per unit of pressure drawdown, demonstrates a slight advantage for the CanSystem. The CanSystem exhibits a PI value of 13.97 m^3/day/MPa, while the traditional system achieves a PI value of 12.50 m^3/day/MPa. This indicates that the CanSystem's configuration enhances the efficiency of fluid production, allowing for more effective utilization of the pressure drawdown. Another important variable, the total dynamic head (TDH), represents the vertical distance between the pump and the discharge point. In this aspect, the CanSystem showcases a lower TDH value of 844.3 m and the traditional system requires a slightly higher TDH value of 868.7 m. This discrepancy implies that the CanSystem demands less energy to lift the fluid to the desired discharge point, reducing energy consumption and enhancing overall operational efficiency (Al Munif et al., 2021).

The results obtained from the comprehensive comparison and analysis of these productivity variables provide compelling evidence of the numerous advantages associated with the implementation of CanSystem technology in artificial lift systems. By harnessing its unique capabilities, the CanSystem technology has demonstrated its ability to achieve significantly higher flow rates, enhance the productivity index, and reduce the total dynamic head, establishing itself as a superior choice for optimizing the performance of artificial lift systems in the oil production industry. These findings not only contribute to the expanding body of knowledge but also underscore the immense potential and efficacy of CanSystem technology, solidifying its position as a transformative solution in the quest for improved productivity and operational efficiency in the oil and gas sector.

Table 2: Ranges of PVT data

System	P (MPa)	Q (m^3/day)	PI (m^3/day/MPa)	TDH (m)
CanSystem	9.65	119.2	13.97	844.3
Traditional system	9.65	111.6	12.50	868.7

4. Conclusions

The use of the CanSystem has shown significant improvements in key performance indicators. The productivity index was enhanced by 6.83 %, accompanied by a 6.83 % increase in flow rate and a 2.8 % improvement in the total dynamic head when using an Electrical Submersible Pump with 325 stages. However, it is important to note that the optimal flow is not achieved at pressures below 9.65 MPa, emphasizing the dependence of production pressure and gas behaviour on the specific characteristics of each well. The CanSystem proves to be a suitable solution for wells facing challenges such as corrosion, water intrusion, and technical or economic difficulties with secondary cementing. Its application can address these issues effectively. For a comprehensive analysis and future work, it is crucial to consider different operating conditions and evaluate overall performance for various scenarios. This includes assessing volumetric flow, pressure, and temperature for the equipment, allowing for a more informed decision-making process. These conclusions demonstrate the potential of the CanSystem as a valuable tool in optimizing well performance. The observed improvements in productivity index, flow rate, and total dynamic head highlight its effectiveness in enhancing fluid production and system efficiency. However, further validation through field testing and additional analyses under diverse operational conditions is recommended to confirm and expand upon these findings. By conducting comprehensive evaluations and providing accurate data, the CanSystem can contribute to more informed decision-making processes in the oil and gas industry.

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