Hindawi
Journal of Engineering
Volume 2022, Article ID 6148337, 8 pages
https://doi.org/10.1155/2022/6148337

Research Article

Production Step-Up of an Oil Well through Nodal Analysis

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Received 12 January 2022; Revised 28 August 2022; Accepted 13 September 2022; Published 6 October 2022

Academic Editor: Sohaib Z. Khan

A nodal analysis technique is used in this paper to optimize the production of oil in the well "*X*-3" located in the Rio del Rey basin. Several wells in that basin are facing a low productivity problem. That problem represents the key problem of this paper. The goals of this paper are to quantify the effects of four parameters (tubing size, flowline size, wellhead pressure, and skin) on production; to determine the causes of abnormally reduced productivity; and to choose optimal values to enhance the well flow rate. To achieve these goals, it is necessary to use well pressure volume temperature (PVT) and reservoir data and the nodal analysis technique. The nodal analysis method is applied at two main node points (wellbore and wellhead), where inflow and outflow performances are carefully reviewed with sensitivity analysis. The two nodal points are selected because of the high-pressure drops they observe. The analysis results showed that the selection of some wrong equipment diameters (production tubing and surface flowline) and values (wellhead pressure and skin) strongly influenced (badly) the flow rate. In fact, the increase in tubing and flowline diameters positively influenced the flow velocity, while the diminution in the wellhead pressure increased the flow rate as well. The production of the well increased from about 800 to 1000 barrels per day. Although nodal analysis remains an effective method to determine the causes of low productivity, it is limited compared to transient tests and production logging.

1. Introduction

Petroleum production engineering is a part of petroleum engineering that attempts to maximize and optimize oil and gas production in a cost-effective manner [1–5]. Every producing well is drilled and completed in order to move the oil and/or gas from the reservoir (which is their natural location) up to the surface into stock tanks or sales lines [6–10]. But during this particular phase of oil and gas production, several problems which tend to decrease the amount of produced hydrocarbons may occur. The most common of these problems encompass low productivity, significant decline of the desirable production fluid, or rapid increase of the undesirable fluid [11–15]. Reduced productivity is known as one of the most challenging issues. While experiencing this particular problem, production optimization methods ought to be implemented. To the best of our understanding, production optimization means determination and implementation of the optimum values of parameters in the production system to maximize hydrocarbon production rate (or discounted revenue) or to minimize operating costs under various technical and economic constraints [1]. The technique used in this paper is nodal analysis.

Nodal analysis, also referred to as the systems analysis approach, represents a method for analyzing a well which allows the determination of the producing capacity for any combination of components (reservoir pressure, well productivity, wellbore completion, tubing string, surface choke, flow line, and separator) [15–17]. The essential principle of this method is to determine locations or nodes of pressure drop or excessive flow resistance in any part of the well system [6]. This paper deals with a production well named *X*-3, which is subject to low productivity. This well, in which there are considerable reserves, is located in the Rio del Rey Basin in Cameroon [18, 19]. However, concerning that problem, some hypotheses are formulated to try to understand this abnormally low productivity: it could be due to an ineffective completion job or the setting of in-optimal data such as wellhead pressure, tubing size, and flow line size. It could also be due to an increase in the value of the initial reservoir skin. These hypotheses make the well *X*-3 an ideal candidate for performing nodal analysis to optimize its hydrocarbon production rate. The key objectives of this work are to analyze the production system to detect the problem by employing nodal analysis, perform a sensitivity analysis to determine the optimum sizes of equipment, and analyze the production after selecting those optimum sizes.

This paper is subdivided into three sections: section two introduces the presentation of materials and methods used in this piece of work, section three provides results obtained and discussions, and section four presents the conclusion.

2. Materials and Methods

To achieve the goals of this paper, it is necessary to use data (pressure volume and temperature, reservoirs, and well data), tools (PIPESIM software) [20], and methodology: nodal analysis with inflow and outflow performance at various nodes.

2.1. Data. Most of the following data are obtained during well testing and drilling operations. These data are subdivided into three kinds: pressure volume and temperature, well data, and reservoirs data. The pressure volume and temperature are linked to the fluids present in the reservoir and they are summarized in Table 1.

The well has been drilled up to 9000 feet and slightly deviated (20°). Most of the well data are presented in Figure 1 and in Table 2.

The reservoir is located at 8000 ft MD. Additional data are highlighted in Table 3.

2.2. Methods. Nodal analysis is used to achieve the goals of this paper in such a way that a sensitivity analysis is performed on the main components at two particular nodes (wellbore and wellhead): production tubing diameter, surface flow line diameter, wellhead pressure, and skin. Those sensitivity analyses at different nodes will be done with one of the most powerful Schlumberger software (PIPESIM 2017), which is the only one used for this study. The results obtained from such an analysis will help to determine where the problem is located in order to provide an accurate solution.

Table 1: PVT data.

Parameters	Value
Oil density (°API)	45
Gas oil ratio (scf/STB)	500
Formation volume factor (bbl/stb)	1.25
Oil viscosity (cp)	0.66
Water cut (%)	15

2.2.1. Sensitivity Analysis on the Production Tubing Size. From the wellbore node, performing a sensitivity analysis on the size of the installed tubing will help to appreciate, on one hand, its influence on production rate and, on the other hand, select the most appropriate size for an optimal flow rate. It is merely a simulation of conflicting values of tubing size (selected according to standard values and in an economical manner) in function of the well deliverability at nodal points.

2.2.2. Sensitivity Analysis on the Surface Flowline Size. The size of the surface flowline may affect the flow rate. The Bernoulli principle of fluid flow clearly explains it. Production performance analysis at the well head node will allow finding the optimal flowline size corresponding to the desired flow rate.

2.2.3. Sensitivity Analysis on the Wellhead Pressure. The pressure at the wellhead is constantly monitored to maintain an ideal flow rate. Four values were selected from the initial wellhead pressure with an increment of 50 PSI. It is good to highlight the fact that an increase in wellhead pressure entails an addition of bottom hole pressure as well. A sensitivity analysis is then required at the top node to determine the most appropriate pressure, thereby ensuring a high flow.

2.2.4. Sensitivity Analysis on Skin. The skin factor (dimensionless) is a value that quantifies damage in the wellbore vicinity. It could be due to completion (limited entry), particle deposition during formation, fine migration, or other factors. An increase in this value directly implies a decrease in fluid production. Determining the influence of skin (at the wellbore node) on production requires the analysis of productivity indexes, or PI (the higher the PI is, the smaller the skin).

3. Results and Discussions

The purpose of this section is initially to present the results obtained from the data, tools, and methodologies used in this paper. Moreover, discussions of the obtained results are presented.

3.1. Results. The major results of the study encompass the influence of tubing size, flow line size, wellhead pressure and skin on the general well production. Before presenting the main results, it is necessary to indicate the initial state of

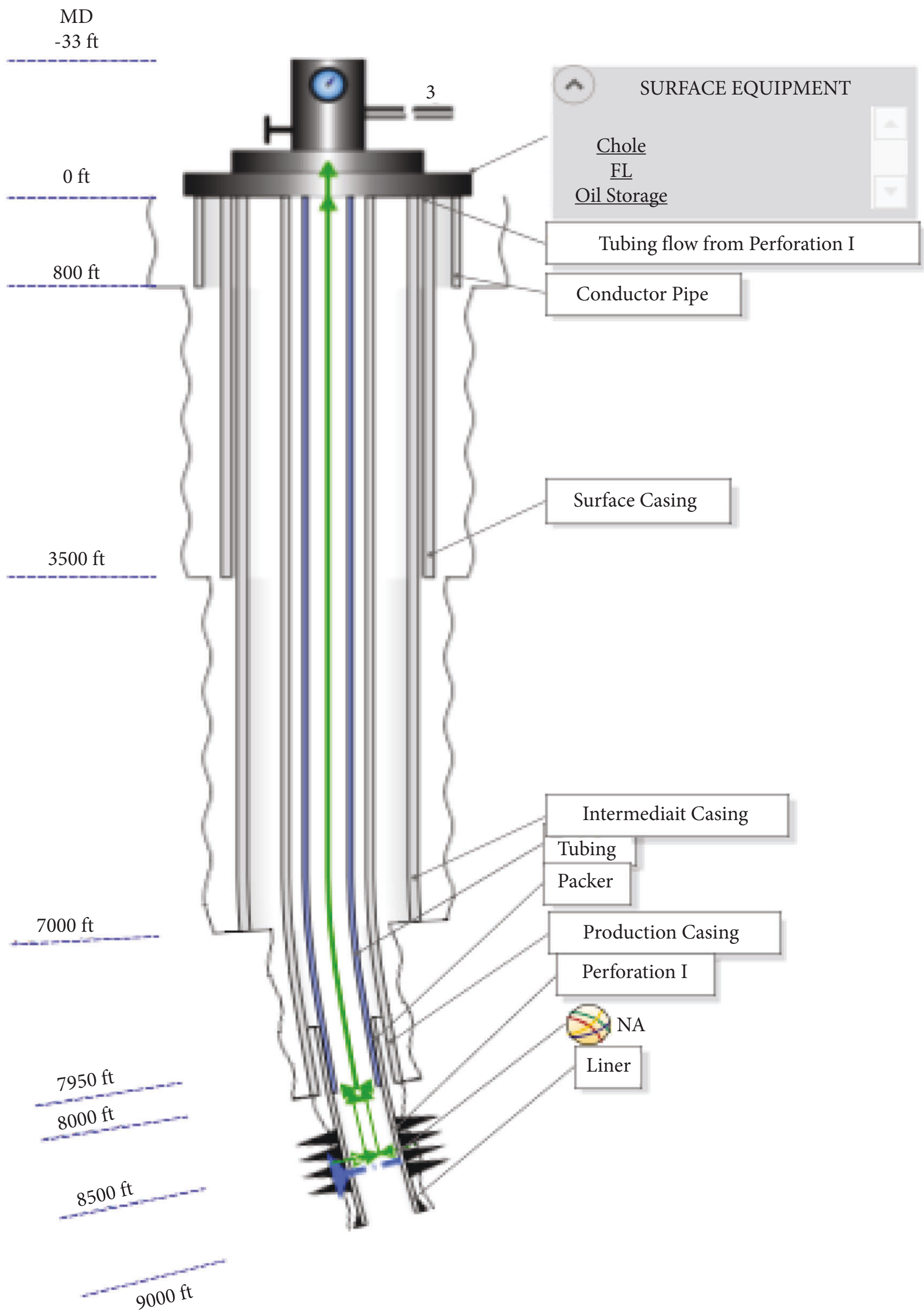

Figure 1: Well profile.

Table 2: Well data.

Parameters	Value
Wellhead pressure (psia)	50
Wellhead temperature (°F)	65
Productivity index (STB/*d*/psi)	1.5

Table 3: Reservoir data.

Parameters	Value
Porosity (%)	22
Permeability (md)	50
Skin	1
Temperature (°F)	200
Reservoir initial pressure (psia)	2800
Drainage radius (ft)	1500

production in terms of its deliverability, which means the relationship between inflow performance (IPR) and outflow performance (VFP). Figure 2 illustrates the IPR (representing what the reservoir can deliver in terms of oil or gas quantity) vs. VFP (representing what the well can deliver in terms of fluid quantity) relationship.

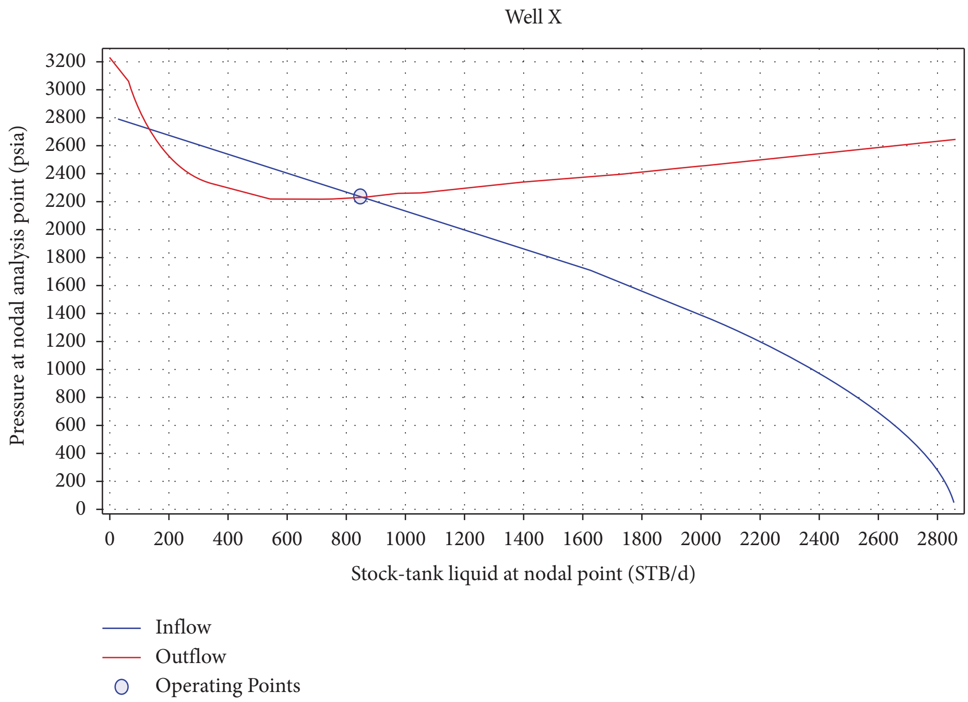

Figure 2: Initial well performance analysis.

In Figure 2, the blue line represents the inflow performance and the red one represents the well vertical flow performance. The cross point of those two lines represents the operating point, which represents the flow rate the well is able to deliver. This analysis shows that the well is producing 820 barrels per day with tubing and flow line diameters of 3.5 and 3 inches, respectively, and with 100 psia at the wellhead.

3.1.1. Sensitivity analysis on Production Tubing Size. To quantify the influence of the production tubing size, a sensitivity analysis is performed by choosing three standard values between 2 and 4 inches, with an increment of 1 inch. Figure 3 clearly illustrates the results of sensitivity analysis on tubing.

Figure 3 illustrates the influence of different tubing diameters on production. It can be observed that the flow rate is increasing with an inside diameter value of 4 inches (orange) rather than other diameter values. So, an increase in the diameter of the tubing results in an increase in the flow rate up to 820 bpd in this specific case.

3.1.2. Sensitivity Analysis on Surface Flowline Size. The flowline can also have an effect on the well overall production, and Figure 4 depicts that effect.

In Figure 4, it can be seen that the surface flowline has a crucial effect on production. The higher the diameter of the flowline, the higher the flow rate. A flowline diameter of 4 inches (orange line) provides about 950 barrels daily. So, to step up the production requires a change in the surface flowline diameter.

3.1.3. Sensitivity Analysis on Wellhead Pressure. The wellhead pressure has a direct influence on downhole or bottom hole pressure by the hydrostatic principle. Figure 5 shows the relationship between the wellhead pressure and the well deliverability.

According to Figure 5, it instantly appears that the well head pressure is inversely proportional to the overall production. This can be explained by the fact that increasing well head pressure implies an increase in downhole or bottom pressure. An optimal flow rate requires a significant depreciation (difference between reservoir pressure and bottom hole pressure). The value of interest on wellhead pressure here is 50 psia, which can supply up to 990 bpd.

3.1.4. Sensitivity Analysis on Skin. As mentioned in Section 2.2.4, the contribution of skin on production can be seen through the productivity index (PI) with PIPESIM software. Figure 6 resumes that contribution:

From Figure 6, which shows the relationship between PI and well deliverability, it can be perceived that the well is producing at 1000 BPD with a PI of 2 bpd/psi. It should be noted that the skin is inversely proportional to the PI. It is necessary to increase the PI from its initial value (1, 5 bpd/psi) up to 2. This can be obtained by lowering the skin through various processes (matrix acidizing, increasing the perforation density, optimizing the completion).

3.1.5. Deliverability after Adjustments. The core objectives of this work were to comprehend why the well *X*-3 had an abnormally low production performance by employing nodal analysis and to provide an optimal solution. It appears that the selection of some wrong equipment diameters (production tubing and surface flowline) and values (wellhead pressure and skin) strongly influenced (badly) the flow rate. To properly optimize the performance of the well *X*-3,

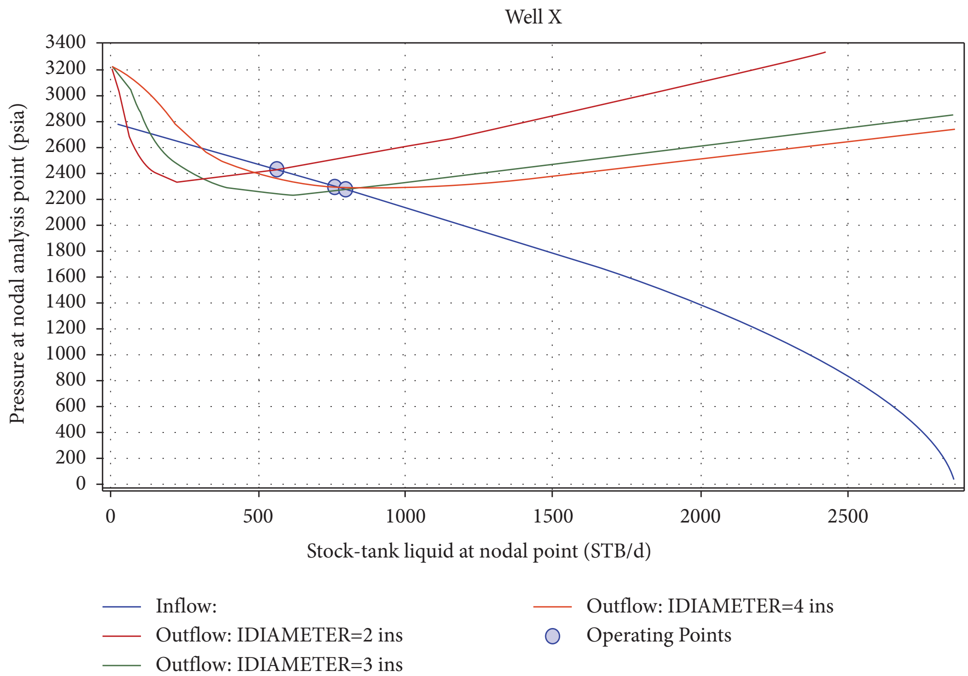

Figure 3: Sensitivity analysis on tubing.

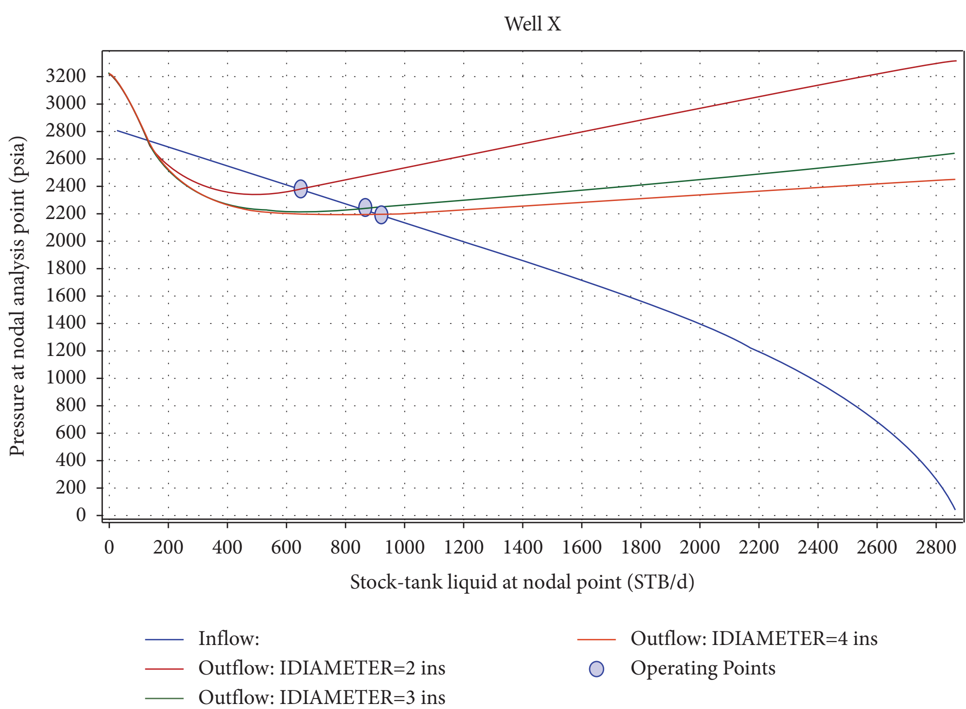

Figure 4: Sensitivity analysis on flowline.

specific values based on upwards sensitivity analyses are chosen and illustrated in Figure 7 and Table 4.

Figure 7 indicates a significant increase in flow rate from an initial value of 800 bpd up to 1000 bpd. Further analysis could greatly increase that value. These adjustments could be handled depending on an economic analysis. It is recommended to adopt the most economical solution among those presented.

3.2. Discussions. The objectives of this paper are to quantify the influences of four parameters (tubing size, flowline size, wellhead pressure, and skin) on production, determine the causes of abnormally small-scale production, and choose optimal values to enhance the well flow rate. Hypotheses are made for this purpose: the setting of in-optimal data such as well wellhead pressure, tubing size, and flowline dimensions; an increase in the value of the initial reservoir skin; near

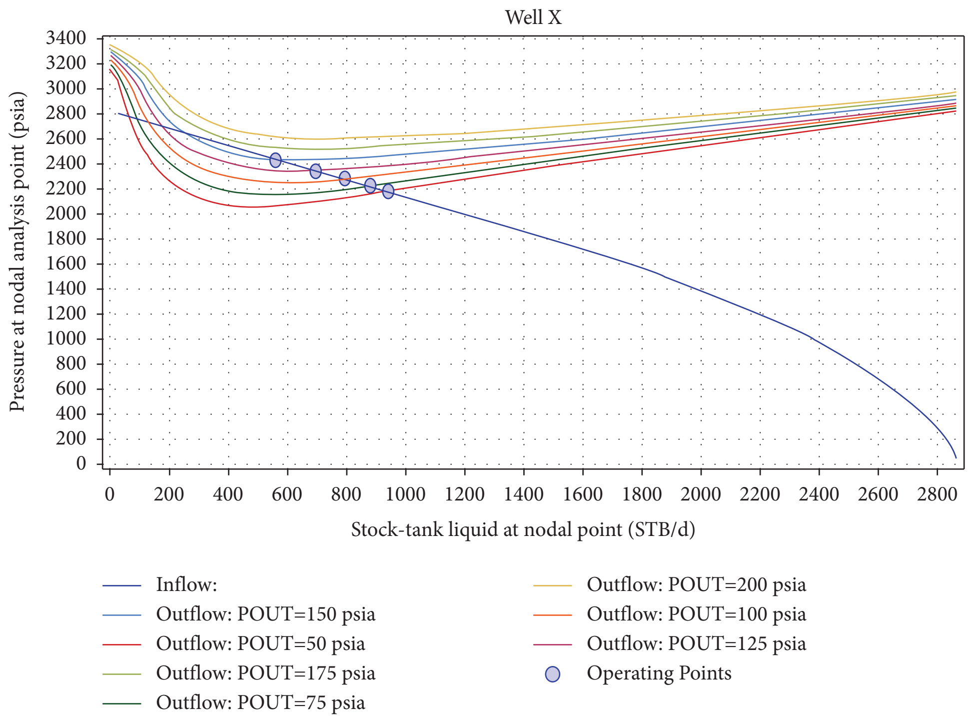

FIGURE 5: Sensitivity analysis on wellhead pressure.

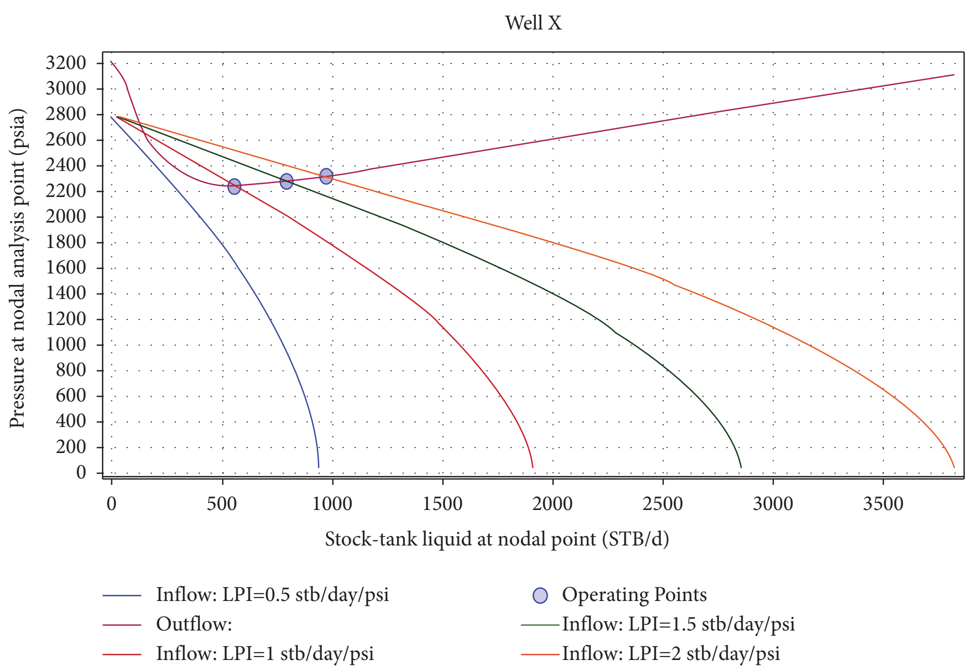

FIGURE 6: Sensitivity analysis on skin.

wellbore damage (formation damage); or restrictions in the wellbore. It is seen that two of these hypotheses are validated. In fact, more problems related to reduced productivity are due to the selection of the wrong equipment diameter. The delivery system is subdivided into two main parts: the flow of hydrocarbons from the reservoir into the wellbore and from the wellbore up to the surface. Selecting inadequate equipment diameter will always lead to a decrease in the flow rate. Many assumptions or hypotheses could be made when low productivity is noticed, but the most likely ones are related to completion and wellbore restrictions. Most researchers have been confronted with such problems, and they used different methods or techniques on one hand and the same ones on the other hand to overcome them.

In 2020, Elbrir worked on nodal analysis in the *X* field, which typically consists of 18 wells, and four of them were

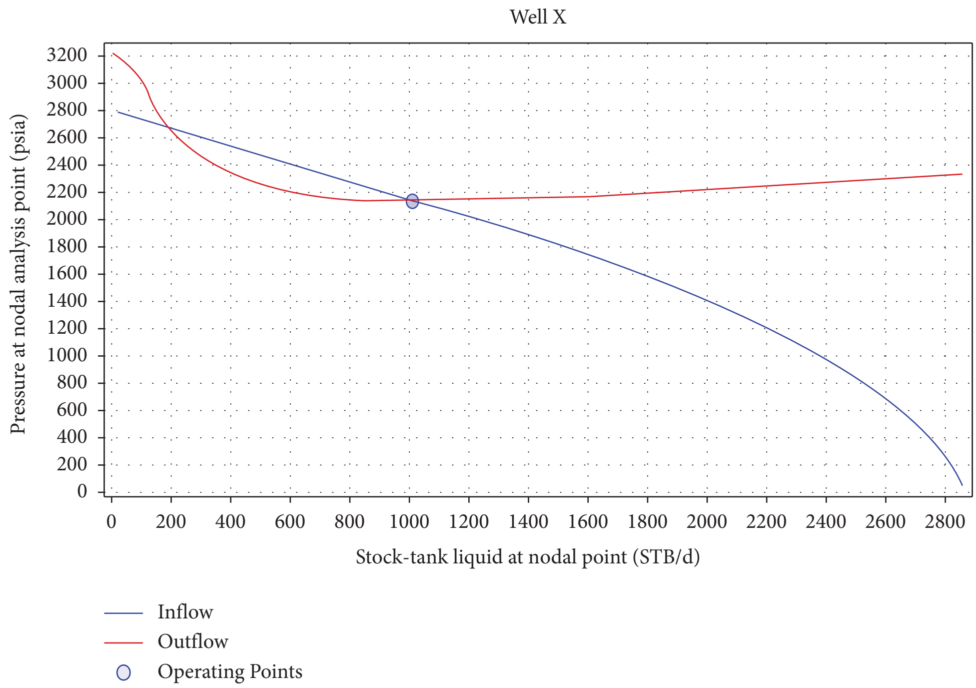

FIGURE 7: Nodal analysis after adjustments.

TABLE 4: Optimized parameter values.

Parameter	Initial value	Final value
Tubing diameter (inch)	3.5	4
Flowline diameter (inch)	3	4
Wellhead pressure (PSI)	100	50
Skin	1	−1

selected for the analysis, namely X NW-1, X NW-2, X NW-3, and X NW-4 [21]. In order to get the production forecast, she conducted sensitivity analyses on wellhead pressures, water cuts, and layer pressures. Concerning the wellhead pressure, which is common with this current work, she came to the conclusion that the well performance improves as the wellhead pressure decreases. These results corroborate those obtained in this current paper.

Sardam et al. [22] worked on nodal analysis to detect the effect of each parameter on the pressure drop and flow rate at different nodes in the production system. Their work was carried out in the oil and gas fields in Kurdistan and Iraq. Similarly, in this current paper, Sardam et al. also did a sensitivity analysis on skin and production tubing diameter. In accordance with the results acquired in this paper, they derived the conclusion that positive skin indicates less flow to the bottom hole and more pressure drop. Likewise, a negative skin means less pressure drop and more flow to the bottom hole. Concerning tubing diameter, they used different ranges (between 4.00 and 5.5 inches) to know which diameter is more helpful for obtaining better production in the petroleum field. They observed that the changes in tubing diameter only had effects on the VFP curve, and the lower tubing diameter gave a lower level of the VFP curve. These results strongly confirm those obtained in this paper.

Most companies, instead of nodal analysis, can perform transient well testing or use production logging tools, which are more accurate but costly. Ilozobhie and Ikechukwu worked on the determination and prediction of the individual contributions of layers to combined production in a well in the Niger Delta, Nigeria [23]. They tried to solve a low productivity problem in a well that crossed 5 reservoir layers. They were dealing with five layered reservoirs in the same well and wanted to determine the shallowest productive layer. To achieve this tedious task, they utilized MBAL software and obtained accurate performances as well as production predictions for each layer. But most of the production results, like productivity indexes of each reservoir, have been obtained. Unlike the method employed in this work, the method used by Ilozobhie and Ikechukwu required detailed petrophysics and sedimentary data for five layers. This is to show some limitations of nodal analysis compared to other methods.

4. Conclusion

To sum up, the problem addressed in this paper was to optimize the production of oil in the well "*X*-3" located in the Rio del Rey basin. The objectives were then to quantify the influence of four criteria (tubing size, flowline size, wellhead pressure, and skin) on production, determine the causes of abnormally low production, and select optimal values to enhance the well flow rate. Nodal analysis with sensitivity analyses was used to determine which parameters mostly influenced the production to solve the abnormally low production problem. The nodal analysis method is applied at two main node points (wellbore and wellhead). As a result, it was adjudged that the surface flowline diameter and tubing diameter had a great influence on production. In fact, the increase in tubing and flowline diameters (from 3.5” to 4” and 3” to 4”, respectively) positively influenced the flow rate, while the decline in the wellhead pressure increased the flow rate as well. The production of the well increased from about 800 to 1000 barrels per day. It was equally noted that this problem is due to a likely fine migration. It was recommended that the less costly solution, whether changing tubing diameter or flowline diameter or decreasing the skin by acidizing, should be chosen. An economic analysis of this work should be a fascinating topic of research.

Data Availability

Data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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