Available online at http://ijcpe.uobaghdad.edu.iq and www.iasj.net
Iraqi Journal of Chemical and Petroleum Engineering
Vol. 24 No.3 (September 2023) 45 – 54
EISSN: 2618-0707, PISSN: 1997-4884

Optimization of Gas Lifting Design in Mishrif Formation of Halfaya Oil Field

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Abstract

The optimization of artificial gas lift techniques plays a crucial role in the advancement of oil field development. This study focuses on investigating the impact of gas lift design and optimization on production outcomes within the Mishrif formation of the Halfaya oil field. A comprehensive production network nodal analysis model was formulated using a PIPESIM Optimizer-based Genetic Algorithm and meticulously calibrated utilizing field-collected data from a network comprising seven wells. This well group encompasses three directional wells currently employing gas lift and four naturally producing vertical wells. To augment productivity and optimize network performance, a novel gas lift design strategy was proposed. The optimization of gas allocation was executed to maximize oil production rates while minimizing the injected gas volume, thus achieving optimal oil production levels at the most effective gas injection volume for the designated network. The utilization of the PIPESIM Optimizer, founded on genetic algorithm principles, facilitated the attainment of these optimal parameters. The culmination of this study yielded an optimal oil production rate of 18,814 STB/d, accompanied by a gas lift injection rate of 7.56 MMscf/d. This research underscores the significance of strategic gas lift design and optimization in enhancing oil recovery and operational efficiency in complex reservoir systems like the Mishrif formation within the Halfaya oil field.

Keywords: Gas lift, Optimization, genetic algorithm, PIPESIM, Halfaya oil field, Mishrif formation.

Received on 05/10/2022, Received in Revised Form on 26/02/2023, Accepted on 27/02/2023, Published on 30/09/2023

https://doi.org/10.31699/IJCPE.2023.3.5

1- Introduction

Commonly, during the oil production process, oil naturally flows through the well-tubing. As a result of primary oil recovery, that includes a natural driving mechanism that lift oil from the perforation at the bottomhole to the well surface without the use of an artificial method [1, 2]. However, in the majority of cases, primary oil recovery; oil production based on natural reservoir mechanism; won't commonly continue to flow naturally for a long period due to declining reservoir pressure [3, 4]. Consequently, the natural production process is inefficient. In addition, there is a lot of hydrocarbons remaining in the oil reservoir, which is the reason for a common field problem. To produce the oil that still remains in the reservoir, it is necessary to consider future well/reservoir improvements, studies, and techniques, such as gas injection and water injection for secondary oil recovery or gas lift as an artificial lift technique [1, 5]. Based on the status of the reservoir driving mechanisms, several artificial lift techniques are constructed which include electrical submersible pumps, hydraulic and sucker pumps, and gas lift technics, which can be utilized to lift the oil to surface production facilities [6-8]. Gas lifting techniques are one of the efficient artificial lifting methods [9-11]. The methodology of gas-lifting techniques is based on the injection of gas from the annulus into the bottom of the production tube of production, where the injected gas is mixed with the oil produced to decrease the fluid density in the tubing, so the hydrostatic pressure of fluid in the well will be decreased [12, 13].

In the oil production sector, gas lifting is the most prevalent artificial lift method because it is used in the most reservoirs that have high gas-oil ratio and solid content production as well as it is used in wells that produced high water cut. These wells are not easy to be handled by other methods of artificial lifting [14]. If there is enough gas available, it is possible to apply the gas lift technique to decrease the required flowing bottomhole pressure to attain an economic flow rate. The most popular technique for activating wells is gas-lift [1, 15]. The concept of gas lifting can be explained by the introduction of an external energy source, such as natural gas, through a casing-annular and into the tubing with the assistance of subsurface gas lifting valves. Gas lift techniques are used in several giant fields to boost economic production levels. For a large field to increase field productivity, the gas lift is thought to be the most cost-effective artificial lift technique [16, 17].

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The gas is injected at a high pressure into the deepest point of the production tubing in order to lower the fluid's mixing density. This lowers the oil hydraulic pressure, thus the oil lifted through the tubing to the surface. As the pressure in the production tubing decreases, oil flows from the reservoir to the sandface. This means that as the pressure in the bottom hole decreases, oil production will be easily produced. This method uses both equipment on the surface and equipment below the surface. Production facilities are the ones responsible for separating oil and gas into their respective streams, and the surface equipment is designated for the gas source [18, 19]. After being dried out by specialized dehydration units or filters, this gas is then compressed by the compressor station at a certain pressure based on the required injection pressure to reach the operating valve [20, 21]. A gas injection manifold and gas pipelines are shown in (Fig. 1) as being used to transport the gas to the wellheads after it has been treated and compressed.

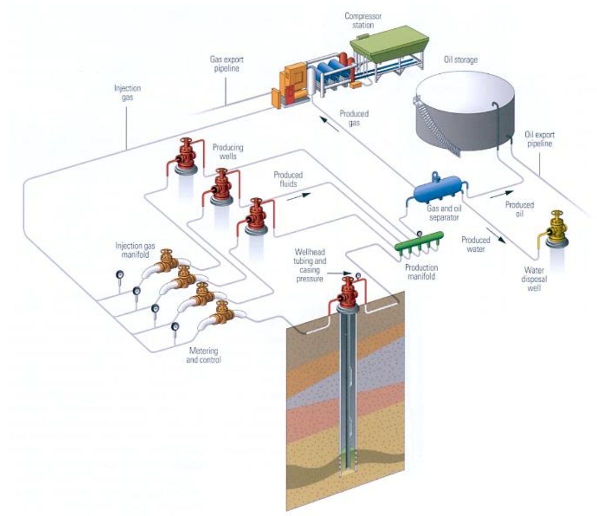

Fig. 1. Gas Lifting Components [22]

The field of study known as optimization seeks to identify courses of action that not only conform to the parameters of a problem but also bring about the best possible outcome. When it comes to engineering, constraints can be caused by both physical limitations and technical specifications. When it comes to business, however, constraints are typically associated with resources, such as labor, equipment, money, and time. In nonlinear decision models, where multiple solutions exist, many of which are sub-optimal, finding the "best viable" one is a common goal of utilizing global optimization (local) [16]. Due to a lack of tools for global optimization, engineers and scientists often settle for feasible solutions with values that will produce the best results for the most efficient and effective solutions.

Gas lift systems are used to increase oil production rates by injecting compressed gas into the lower section of tubing. The optimization of gas lift allocation is crucial in order to maximize oil production rates; as excessive gas injection can reduce oil production [23-25]. In this study, the gas lift allocation was optimized using a genetic algorithm under the constraints of the gas lift system. The goal was to maximize the oil production rate, and the optimized gas lift allocation was used to predict the oil production rate. To ensure accurate predictions, a reservoir simulator was integrated with a multiphase flow simulator. The results demonstrated that optimizing the gas lift allocation can improve oil production, and the oil production rate can be estimated using the optimized gas lift allocation for the gas lift system.

- Area of the case study

The Halfaya Oilfield is situated in the southern part of Iraq, specifically in the Maysan governorate, which is 35 km southeast of Amarah City [26, 27]. The oilfield is one of the biggest in Iraq and is operated by PetroChina. The location of the Halfaya oil field is shown in Fig. 2 [28]. It has a proven reserve of 4.1 billion barrels and a production potential of 200,000-535,000 barrels per day. Generally, Mishrif is one of the main Cretaceous reservoirs in the Mesopotamian Basin and Middle East [29, 30]. The Mishrif Formation, which is the primary producing zone in the Halfaya Oilfield, is approximately 400 meters thick and is characterized by the development of grain shoal reservoirs [28, 31]. These reservoirs can be further divided into 15 sublayers [31]. The Mishrif reservoir primarily consists of rudstone, grainstone, and packstone, with well-developed intergranular and dissolved pores, contributing to its porosity [31]. The formation is connected to the Arabian shield in the south and has a regional structural location adjacent to sub-basin deepwater facies in the southwest [28]. The geological features and reservoir architecture of the Mishrif Formation in the Halfaya Oilfield provide valuable insights for the development of similar reservoirs in the Middle East. The thickness of the Mishrif Formation ranges from 350 to 400 meters. Understanding the characteristics and properties of the Mishrif Formation is crucial for effective reservoir engineering and production optimization in the Halfaya Oilfield [28, 32].

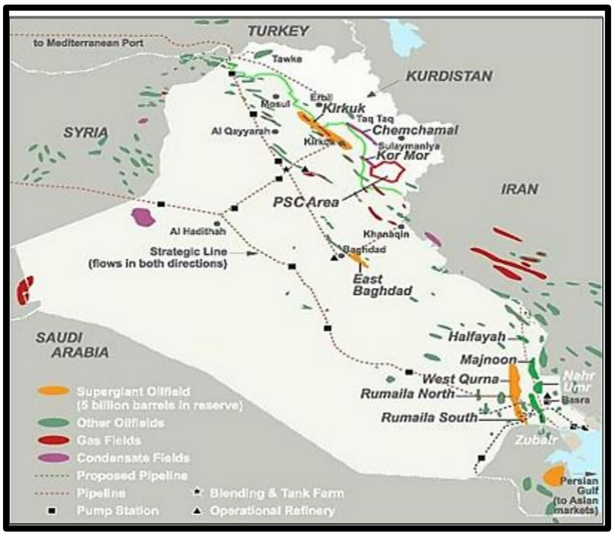

Fig. 2. Location Map of the Studied Wells along with Oilfields [33]

2- Literature Review

Historically, a number of investigations have been carried out to establish optimal gas injection rates. Mayhill [34] conducted research to investigate the connection between the rate of gas injection and the rate of oil production. He dubbed the resulting graph a "gas lift performance curve," which can be seen in Fig. 3. He determined that the rate at which an additional expenditure for gas injection was equal to some percentage of the incremental income earned at that gas injection rate was the rate that he deemed to be the most efficient for injecting gas into the well.

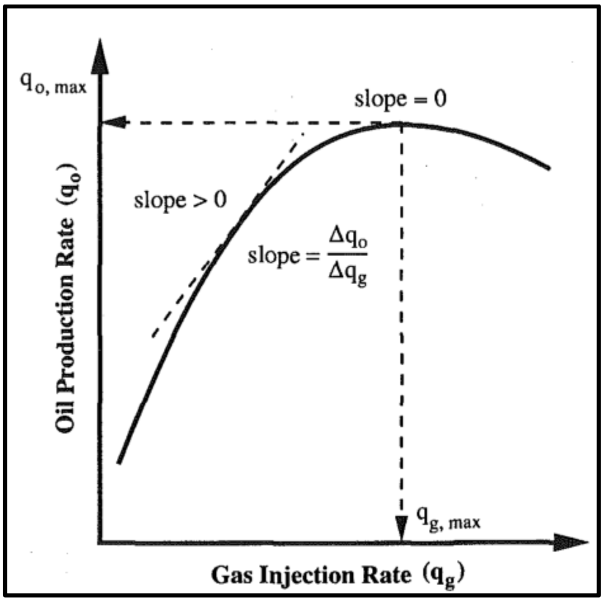

Fig. 3. A Typical Gas-Lift Performance Curve

Redden et al. [35] provided a method for determining the most profitable method of gas distribution to wells in a continuous flow gas lift system. They created a computer program to perform gas allocation calculations, and it was successfully implemented in a Venezuelan field with 30 wells.

Gomez et al. [36] provided a method for generating the gas lift performance curve and created a computer program that fitted the second-degree polynomial to each gas lift performance curve. This polynomial was then used to calculate which well would produce the highest oil when each well was injected with an equal amount of incremental gas. An extra quantity of gas would subsequently be assigned to this well, and this operation would continue until all the available injection gas volume had been consumed.

Hong et al. [37] conducted research to investigate the impact that a variety of factors have on continuous-flow gas lift systems. Hong and co-authors worked to improve the system functionality, which included six gas lift wells and surface flow lines.

Kanu et al. [38] developed the "equal slope allocation" approach for both limitless and constrained gas supplies. They proposed the formulation of the economic slope and the use of this slope to distribute the total quantity of gas at the optimal economic point for a set of wells.

In 2017, H. Ben Mahmud and A. Abdullah [39] looked at the effectiveness of gas condensate wells. They have carried out an appropriate optimization that can lower operational expenses, maximize hydrocarbon recovery, and raise net present value. They have improved the wellhead, tubing size, and skin factor, among other good parameters. Utilizing the PROSPER simulation program and a real field in the Thrace Basin, all these elements have been researched. Following period adjustments, the future performance estimate for the same reservoir deliverability is identified using validated history matching data. In order to give the finest production practices, anticipated outcomes are compared to and validated with measured field data. Additionally, the findings demonstrate that the skin component significantly affects the production rate by 45%. The production rate dramatically drops because of the decrease in reservoir pressure, which results in a 70% decrease. While changing the tubing size, the wellhead pressure shows a slight reduction compared to the production rate, which exhibits no discernible change.

Mohammed et al. [40] treated one of the wells in the Mishrif reservoir, the Nasiriyah oil field with a gas lifting technology. In order to find the most accurate correlation for computing the pressure gradient in the wellbore, a mathematical model has been constructed and validated with the help of the PIPESIM program and the corresponding data set of the PIPESIM program. Through an analysis of the well's performance, researchers were able to study the impact on the production rate that was caused by a reduction in average reservoir pressure as well as an increase in the water cut. When the reservoir pressure reached 2,750 psi, the output rate was lowered to 1917 STB/d, and the flow rate was lowered to 1210 STB/d when the water cut increased to 60%. As a result, artificial lift techniques were utilized in to boost oil production rates. The findings revealed that the gas lift system contributed to the rise in production rate, which was measured at 3,198 STB/d while the reservoir pressure was equivalent to 2,750 psi.

Saleh et al. [41] conducted research to check the feasibility of a gas lift application to boost the production of the Noor Oil field. The continuous gas lift was designed using the PROSPER program to determine the highest possible oil production rate. The design was created after comparing the well head pressure that was initially measured with the pressure that was calculated. The optimal location and injection rate of the gas had been determined, and other design parameters had been calculated to determine the maximum oil production rate, the number and depth of valves that were required for gas injection, and the pressure needed to control the opening and closing of each valve The results from the gas lifting design indicate that the maximum oil production rate 1,000 STB/d, and the best gas injection rate is 2.6) MMscf/d. There is also an operating pressure of 1700 psi available at the casing head, while the minimum bottom hole following pressure is 1,501.5 psi.

Al Juboori et al. [10] elaborated on the Genetic Algorithm as an optimization technique for improving the oil production rate by implementing gas lift in a large Iraqi oil field. Their developed optimization model was presented step by step; therefore, it can easily be followed, and be used as a guide, especially by frontline production engineers involved in designing and developing a gas-lift system towards optimal allocation of gas injection rate for each individual well in a network system for a field with limited gas injection volume.

Miresmaeili et al. [11] focused on the optimization of gas allocation for continuous-flow gas-lift systems to maximize oil production. The study investigates the potential application of an Artificial Neural Network (ANN) using Bayesian Regularization (BR) for modeling gas-lift operations and compares the results with the Levenberg–Marquardt (LM) back-propagation training algorithm. The Teaching–Learning-Based Optimization (TLBO) algorithm is applied to solve the well-rate and gas-lift allocation problems under the injection capacity constraint. The performance of the TLBO algorithm is compared with the Genetic Algorithm (GA) based on convergence rate and the best solution. The proposed prediction and optimization model is tested in a gas-lift system for a given period of reservoir life. The results showed that the BR model is more robust and efficient than the LM model, and the TLBO algorithm outperforms GA in the gas allocation mapping for continuous gas-lift systems. The simulation results demonstrate the effectiveness of the proposed model on continuous flow gas-lift operations. The research uses extensive published data in model development and comparison, and the prediction accuracy produced by the BRNN and the LMNN were 99.9% and 99.5%, respectively. The study highlights the importance of gas allocation optimization in continuous-flow gas-lift systems and the potential of ANN and TLBO algorithms in modeling and optimization.

Al-Janabi et al. [16] studied the application of the gas lift technique at the Buzurgan oil field, which contains 43 wells and has a production rate of 73,380 STB/d. Utilizing the entire network with a gas lift system and applying the optimization using a Genetic Algorithm were the tasks that needed to be completed for the study. The task at hand was the allocation of injected gas. In the development of oil field projects, the optimization of gas lift plays a vital role in the production process and in optimizing the net present value of the investments made in those projects. The implementation of optimization techniques in the gas lift project is extremely difficult since the gas lift optimization problem involves many decision variables, objective functions, and restrictions. Nevertheless, the gas lift and optimization proved to have a significant increase in the production of the field to reach 187,759 STB/d despite having a limited volume of injected gas with 82 MMscf/d.

Gas lift techniques are commonly used in the oil industry to enhance oil production rates, but the optimization of gas lift design and allocation remains a complex challenge, especially in reservoirs with varying characteristics like the Mishrif formation of the Halfaya oil field. Despite existing research on gas lift optimization, there is a lack of studies that comprehensively address the optimization of gas lift design and allocation for a heterogeneous well network, considering both directional and vertical wells. This study aims to bridge this gap by investigating the impact of gas lift design and allocation on production outcomes in the Mishrif formation of the Halfaya oil field and proposing an integrated methodology for optimizing gas lift operations. The proposed methodology involves an integrated experiment/modeling study encompassing various stages. Initially, field data from the Mishrif formation in the Halfaya oil field will be collected, encompassing well production rates, fluid properties, reservoir pressure, and temperature, followed by a comprehensive reservoir characterization to gain insights into reservoir heterogeneity, fluid behavior, and production challenges. Subsequently, a production network nodal analysis model will be developed through the utilization of PIPESIM software, incorporating seven wells, including directional gas lift wells and naturally producing vertical wells. This model will define parameters spanning wellbore and surface networks, encompassing tubing, casing, wellhead chokes, and separator conditions. Employing a Genetic Algorithm, the gas lift allocation for the well network will be optimized within the PIPESIM model, with the objective of maximizing oil production rates while minimizing injected gas volume, adhering to operational limits and system capabilities. The model will then be calibrated with historical data and validated against real-world production data. A novel gas lift design strategy, considering the unique characteristics of the Mishrif formation and mixed well types, will be formulated. Subsequent to this, the Genetic Algorithm optimization will be executed across diverse scenarios, evaluating distinct constraints, reservoir conditions, and production objectives to identify the optimal gas lift allocation scenario that maximizes oil production while minimizing gas usage. Furthermore, the integration of a reservoir simulator into the production network model will account for transient reservoir behavior and validate optimization outcomes. Finally, a comprehensive evaluation will compare optimized gas lift allocation scenarios with the current strategy, assessing the impact of the proposed gas lift design strategy on oil and gas injection rates, and overall field efficiency. The study will conclude by highlighting the significance of gas lift optimization in intricate reservoirs like the Mishrif formation, elucidating its potential benefits for oil field development.

3- Methodology

This section describes the process of constructing a well model located in the Halfaya oilfield and the effects of gas lift design and optimization on the selected network model performance. The network model was designed using SLB PIPESIM 2019, which is a steady-state simulator built on the principle of nodal system analysis

to mimic the production petroleum system .The PIPESIM simulator models multiphase flow from the reservoir to the wellhead and considers artificial lift systems, including rod pumps, ESP, and gas lift. Well models can be created using the interactive graphical schematic and templates of the PIPESIM simulator, which enables users to design optimal well completions and artificial lift systems, diagnose problems that are limiting well production potential, and optimize production from existing wells by quantifying actions to increase flow rates. Fig. 4 shows the steps applied to model and optimize the gas lift application for the Halfaya oilfield.
The nodal analysis-based design is used to improve gas lift-based oil production well. The proposed optimization model is tested in a gas-lift system for a given period of reservoir life. The results demonstrate the effectiveness of the proposed model on continuous flow gas-lift operations.

Fig. 4. Flow Diagram of the Methodology

4- Results and Discussion

4.1. Model Construction

The network model (Fig. 5) consists of seven wells of which five are deviated wells of which three wells are already being produced by the gas lift technique (Fig. 6). These wells are distributed along three manifolds connected to the central processing unit.

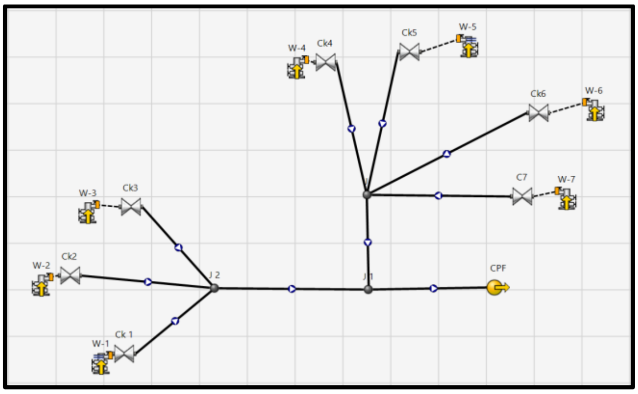

Fig. 5. The Studied Network of Wells in the Halfaya Oilfield

MB1 is the main reservoir unit in the Mishrif formation. Table 1 lists the main fluid properties of this unit. Calibrating the black oil fluid model is based on the concept of calibration constant. When measured values vary from calculated values in the black oil model, a calibration constant can be used to modify all subsequent calculations. The black oil model is a simplified model that is widely used in the oil and gas industry to predict the behavior of reservoir fluids. It assumes that the reservoir fluid can be divided into three phases: oil, gas, and water. The black oil model is calibrated using laboratory measurements or calculated through flash calculations of the reservoir fluid as explained in Al-Fatlawi et al research [1]. The calibration constant is used to adjust the model to match the measured values. This is an important step in the design of a gas lift system in the Mishrif Formation Halfaya oilfield, as it ensures that the model accurately represents the behavior of the reservoir fluid.

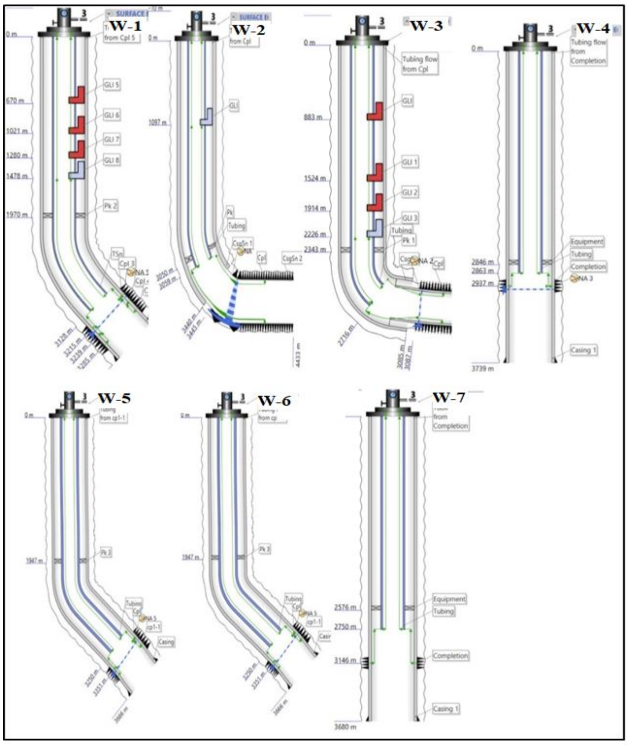

Fig. 6. Studied Wells' Completion

Iraqi crude oils have unique properties that require specific correlations to accurately predict their behavior. Therefore, this study has used the following correlations, which have been explained in this section. A viscosity correlation was developed using extensive experimental data on oil viscosities collected from different samples of Iraqi oil reservoirs [42]. Other studies developed a correlation between the solution gas-oil ratio and oil formation factor of Iraqi oils, respectively [43, 44]. These correlations are important in the design of a gas lift system in the Mishrif Formation Halfaya oilfield, as they can be used to calculate various oil properties such as bubble point pressure, solution gas-oil ratio, oil FVF, and dead oil viscosity. The calculated oil properties are listed in Table 1.

Table 1. MB1 Fluid Properties

Fluid Properties	
GOR (Scf/STB)	629
Bubble point pressure (psi)	2765
B_{ob}	1.384
API	22
μ_{ob} (cp)	1.381

The gas volumes that are required in the gas lifting process are provided by other wells producing with a high gas-oil ratio. The gas used should be immiscible and be easily separated at the surface and reused again for gas lift. The gas behavior model opted for are MB Standing and DL Katz [45], as determined through the process of gas behavior model selection conducted by Al-Fatlawi et al. [46].

4.2. Base Case

Gas lift installation is a method of artificial lift that uses an external source of high-pressure gas to supplement formation gas to lift the well fluids. By injecting gas into the tubing, the density of the fluids in the tubing is reduced, and the bubbles have a "scrubbing" action on the liquids, which lowers the flowing bottomhole pressure (BHP) at the bottom of the tubing. Gas lift installation can add more active wells to the network by enabling production above the bubble point pressure. However, some wells may have a low productivity index due to the reservoir fluid density and high-pressure drop, making it impossible to produce without gas lift. In this case, comprehensive analysis can be applied to the entire network using PIPESIM network simulation models, which enables full simulation of the effect of each well on the other, and estimates the required injected gas volumes for each well. Table 2 provides a comparison of the network performance before and after the addition of a gas lift to the system, which clearly shows the benefits of the gas lift approach on the field performance.

Table 2. Results of Wells Production (before and after Gas Lifting)

Well Name	Before Gas Lift Design		After Gas Lift Design	
	Gas lift rate (MMscf/d)	**Oil rate (STB/d)**	**Gas lift rate (MMscf/d)**	**Oil rate (STB/d)**
W-1	1	2681	1	2681
W-2	1.193	1216	1.193	1216
W-3	0.7655	3554	0.7655	3554
W-4	0	3256	5	3535
W-5	0	2640	3	2929
W-6	0	0	3	2053
W-7	0	0	1	2365
Total	**2.9585**	**13347**	**14.96**	**18332**

The optimization of injected gas volume will be tailored to each well's response to enhance oil production through gas lift. In instances where a well demonstrates a significant gas lift volume but minimal improvement in oil production, a strategic approach will involve reducing gas quantities specifically for these wells. This targeted adjustment arises from network optimization, ensuring the most efficient allocation of resources.

4.3. Gas Lift Optimization

In this section, the PIPESIM Optimizer Based Genetic Algorithm was utilized to allocate injected gas lift rates to each well with the aim of maximizing the total oil production rate. The problem was constrained with an upper bound of 10 MMscf/d for injected gas in the selected wells and a total field injection rate of 20 MMscf/d while the lower bound was set at 0 MMscf/d. These constraints were estimated based on the total gas lift rate presented in Table 1, except for well W-4, which showed a low improvement in oil production. The high limit of 10 MMscf/d was chosen to generate Gas Lift Performance Curves (GLPCs) with a wide range for each well in the PIPESIM Optimizer. Fig. 7 illustrates the generated GLPC for the entire network. The figure clearly demonstrates the efficiency of the optimization process in terms of increasing the oil production rate (18,814 STB/d) with a reduced gas injection rate of 7.56 MMscf/d compared to the base case.

The utilization of the PIPESIM Optimizer Based Genetic Algorithm in gas lift allocation optimization is a novel approach that addresses the challenge of maximizing hydrocarbon production with limited gas lift resources. By optimizing the gas injection flow rates, the financial performance of the well pad or offshore platform can be maximized. This approach is particularly beneficial when dealing with multiple wells that require gas lift stimulation and a limited supply of natural gas. The integration of the genetic algorithm with the PIPESIM simulator allows for accurate modeling and optimization of gas lift operations, leading to improved production rates.

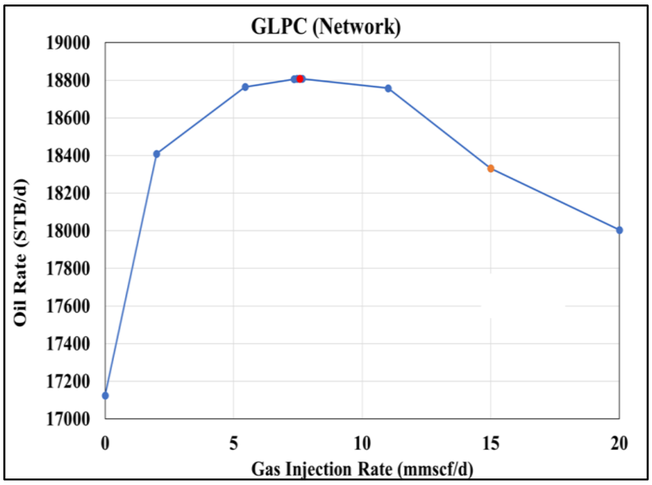

Fig. 7. GLPC for the Network Generated by PIPESIM Optimizer

5- Conclusions

This section is dedicated to highlighting the main outcomes of this paper:
The design of a gas lift system in the Mishrif Formation Halfaya oilfield was the main focus of this work because of the importance of this field and reservoir fluid specifications, in which the gas lift optimization showed

promising results in enhancing the production of the operation and closed wells.

A gas lift design scheme was proposed to improve productivity based on the optimization of the volume of required injected gas used for the lifting process. The genetic algorithm is an efficient optimization technique for performing gas lift for the full scale of a field network.

Nomenclature

GA: Genetic Algorithm
GL: Gas Lift
GLPC: Gas Lift Performance Curve
GLV: Gas Lifting Valve
Qgi: Injection gas rate in gas lifting
CPF: Central Provident Fund
PK: Packer
CPL: Well Completion
GLI: Gas lift Injection valve

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استخدام الرفع بالغاز في حقل حلفايه النفطي

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الخلاصة

يعد استخدام الرفع الاصطناعي والتصميم والتنفيذ مرحلة أساسية في تطوير حقول النفط والغاز. يكرس هذا العمل لدراسة آثار تصميم وتحسين رفع الغاز على أداء حقل حلفايا النفطي. تم بناء نموذج عقدي لشبكة الإنتاج بواسطة برنامج SLB PIPESIM الذي تمت معايرته وفقا للبيانات المقاسة المتاحة لشبكة متكونه من ٧ آبار.

تتكون هذه المجموعة من الآبار من ٣ آبار اتجاهية تنتج بالفعل عن طريق رفع الغاز و٤ آبار عموديه تنتج بشكل طبيعي ٢ منها تم إغلاقها بسبب انخفاض الضغط إلى ما دون نقطة الفقاعة. وبالتالي، تم اقتراح مخطط تصميم رفع بالغاز لتعزيز الإنتاج. تم إجراء تحسين مشكلة توزيع رفع الغاز لتعزيز أداء الشبكة وزيادة معدل إنتاج النفط.

تم إجراء تحسين مشكلة توزيع رفع الغاز لتعزيز أداء الشبكة وزيادة معدل إنتاج النفط. يتم استخدام **PIPESIM Optimizer الذي** يعتمد على الخوارزمية الجينية، وكان معدل إنتاج النفط الأمثل الناتج ١٨٨١٤ برميل/يوم مع معدل حقن الغاز ٧,٥٦ مليون قدم/يوم.

الكلمات الدالة: الرفع بالغاز، تحسين، الخوارزمية الجينية، بايبسم، حقل الحلفايا النفطي، تكوين مشرف.