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Optimization of Separator Size and Operating Pressure for Three-phase Separators in the West Qurna1 Oil Field

Ammar Falah Hasan [a], Ghanim M. Farman [a, *]

a Department of Petroleum Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

Abstract

An optimization study was conducted to determine the optimal operating pressure for the oil and gas separation vessels in the West Qurna 1 oil field. The ASPEN HYSYS software was employed as an effective tool to analyze the optimal pressure for the second and third-stage separators while maintaining a constant operating pressure for the first stage. The analysis involved 10 cases for each separation stage, revealing that the operating pressure of 3.0 Kg/cm^2 and 0.7 Kg/cm^2 for the second and third stages, respectively, yielded the optimum oil recovery to the flow tank. These pressure set points were selected based on serval factors including API gravity, oil formation volume factor, and gas-oil ratio from the flow tank.

To improve the optimization process for separator sizes, a Python code was developed, combining the Newton Raphson Method (NRM), and Lang Cost Method (LCM), with Retention time calculations. In this process, total purchase cost was the objective function. Two design scenarios were examined, corresponding to throughput of 105,000 KBPD and 52,500 KBPD respectively. In the first scenario, the NRM, LCM, and Retention time methods within the Python code were employed, resulting in a three-stage separation train with costs of $1,534,630 for the first stage, $1,438,239 for the second stage and $1,025,978 for the third stage. The Total purchase cost for the separation train was $3,988,847. In the second scenario, utilizing two separators for each stage to process the same throughput resulted in lower costs, totaling $823,851.5 per stage and a total purchase cost of $2,471,553. These costs were calculated using the Lang Cost method, which included the material cost and utilized a Lang factor of 3.1 to determine the total purchase cost after adding shipping, installation, commissioning, and start-up expenses.

The first scenario resulted in larger separators and higher costs, while the second scenario showed lower costs, although it required two vessels per stage to process the same throughput. It was observed that the separator efficiencies were influenced by retention time, with increased retention time leading to improved separator efficiency.

Keywords: Operating Pressure; API gravity; Production Optimization; Separator Sizing; Gas Oil Ratio.

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1- Introduction

Production units are a significant segment in the upstream energy industries. When designing production units, the design of surface facilities—including separators—is crucial. The layout of central processing facilities is planned to produce the highest number of liquid barrels from a given feed at a constant volume. Additionally, by boosting oil production, the limited amount of intermediate liquid components like butane and propane are converted to gas, leaving the heavy components in the liquid. Light and intermediate components vaporize when the feed is subjected to a larger pressure drop. The maximum liquid level in the plant flow tanks and the higher number of barrels of expensive hydrocarbon components in the oil phase will thus come from changing the proper pressure at the right stage [1].

And since the whole system of the oil and gas industry could be highly improved by optimization of the CPF central processing facility's operating conditions. Most oil-producing fields produce a mixture of oil and water droplets called emulsions that need to be processed. Additionally, this water typically has dissolved salts in it, primarily sodium, calcium, and magnesium chlorides. When crude oil is not processed, and when salts are refined, it can lead to a number of operational and maintenance issues [2].

Flash equilibrations take place in a number of vessels that make up these separation facilities. The correct (EOS) equation of state can be used to determine the amount of each component in each phase based on the vessel's pressure set point and temperature set point [3]. Ambient conditions like temperature, which determines the temperature of the separator, cannot be controlled economically which needs more investments CAPEX &OPEX for heaters and heat exchangers. As a result, the only element influencing the equilibrium condition will be the separator pressure [4].

When the pressure continuously drops from the full well stream header pressure to the ambient pressure in the flow tank in a multi-stage separation system. Gas oil ratio (GOR), crude rundown API, RVP Reid vapor pressure,

*Corresponding Author: Email: ghanimzubaidy@uobaghdad.edu.iq

TVP true vapor pressure and OFVF oil formation volume factor are factors considered, the goal of optimization is to increase the quantity of stabilized liquid by decreasing the GOR and Bo and maximizing the °API [4]. The pressure of the second vessel in a multi-stage separation train was optimized as one of the earliest pressure optimization techniques. Without any equilibrium calculations, it was pretty straightforward [5, 6].

The Natco Company offered a highly well-liked technique for maximizing the pressure of separators, which employed a constant ratio to determine the optimum pressure set point of the second vessel [6]. This technique is referred to as the constant-ratio approach because of the way it works. Due to the straightforward calculations required for pressure adjustment, many manufacturing units adopt this quick but erroneous approach. Bahadori provided precise techniques for optimizing separation train vessel pressure, using a sequence of flash calculations to optimize the pressure of each separation step [7, 8].

In addition to flash calculations for equilibrium, certain empirical formulae that were appropriate to a specific situation and could not be applied widely have been developed in the past ten years; in fact, using them in conditions other than the fundamental correlation criteria may result in inaccuracy. The number of steps in each separation vessel is used to classify the correlations that are shown. About 6,000 simulation case runs were studied to create these relationships, which encompass a range of characteristics under varied circumstances. The other stream constituents are not taken into account in these correlations, the variables are the operating temperature of the vessels and the proportions of specific components, such as CH_4, N_2, CO_2, and H_2S, in the full well stream [8-10].

The vessel operating pressure is used as an independent variable, and the number of oil barrels in the flow tank is chosen as the objective function. Some constraints on variables should be taken into account throughout the optimization process since the instruments and facilities lead to a pressure drop. The first restriction is for the first separator's maximum allowable operating pressure to be either higher or equal to the inlet pressure. The minimum operating pressure set point of the low-pressure LP separator before the flow tank, which should be higher than 0.5 Kg/cm^2, is the second restriction, this restriction results from the pressure decrease in downstream equipment's like elbows, LCV level control valves and friction in pipes after the vessel, which need to be treated as a hydraulic constraint to reach the flow tank's atmospheric conditions. The flow tank's constant pressure, which must be 0.38 Kg/cm^2 is the last constraint [11-13].

The first stage separator is then subjected to optimization while taking into consideration the set constraints. The second stage separator is optimized when the first separator's pressure has converged, and the process is repeated for the remaining separators. The same process is done as well after reaching the last separator in order to achieve complete convergence. It should be noted that when maximizing each separator's pressure, the pressure is set at the separators' previously optimal pressure levels for that separator [14].

Increasing the number of stages might lead to more oil recovery in the tanks which means just optimizing the operating condition of the separators or increasing the separator sizes might not be the only solution, in other words, to get the optimum results, just pressure optimization in the separators is not enough. The number of separators may also have a great effect on the results. Theoretically, adding more separators should result in more barrels in the flow tank, however, CAPEX and OPEX considerations plus facility layout area are the limitations that have restricted the number of separators in the manufacturing units. Additionally, if the number of separators is increased above a certain point, the additional oil barrels in the flow tank decline. To get the optimum results, it is necessary to combine pressure optimization with a technique for calculating the number of separator stages [15-17].

The West Qurna1 oil field contains multiple production formations, including Mishrif, Zubair, Maudood, and Saadi. Among these, Mishrif stands out as the main production formation, contributing up to 90% of the total production. This formation is characterized by various sedimentary facies, with limestone which is the dominant lithology. Composed mainly of calcium carbonate ($CaCO_3$), limestone plays an essential role in the formation's composition. In addition, dolomite, a component of magnesium ($CaMg(CO_3)_2$).

The sedimentary rocks are the main components of Zubair formation such as sandstone, shale, and siltstone. The Saadi formation is mainly composed of alternating layers of sandstone shale and siltstone. Maudood formation mainly consists of sandstone with less amounts of shales and siltstones [18-21]. Fig. 1 shows a constructed separation train in a HYSYS flowsheet.

2- Methods

Steps taken to obtain the optimum results of both operating pressure and vessels sizes are elaborated in Fig. 2 which shows the flow chart of this study. HYSYS software was used for pressure optimization and the sizing optimization a Python code was developed to calculate the optimum results.

2.1. Pressure Optimization HYSYS Model

Incorporating the operating pressure to HYSYS was done by creating a new case in HYSYS then the appropriate fluid package for the simulation for this study was selected here Peng-Robinson fluid package was used [22-23]. Input data such as wells flow rate and the fluid conditions that were collected from BOC were added to the full well stream. Then the separation vessel types and numbers were selected and added to the flow sheet. The first stage three phase separator operating pressure in the West Qurna 1 oil field is set at 11.8 kg/cm^2 while the tank's operating pressure is set at 0.03 kg/cm^2. Table 1 contains the exported oil required specifications.

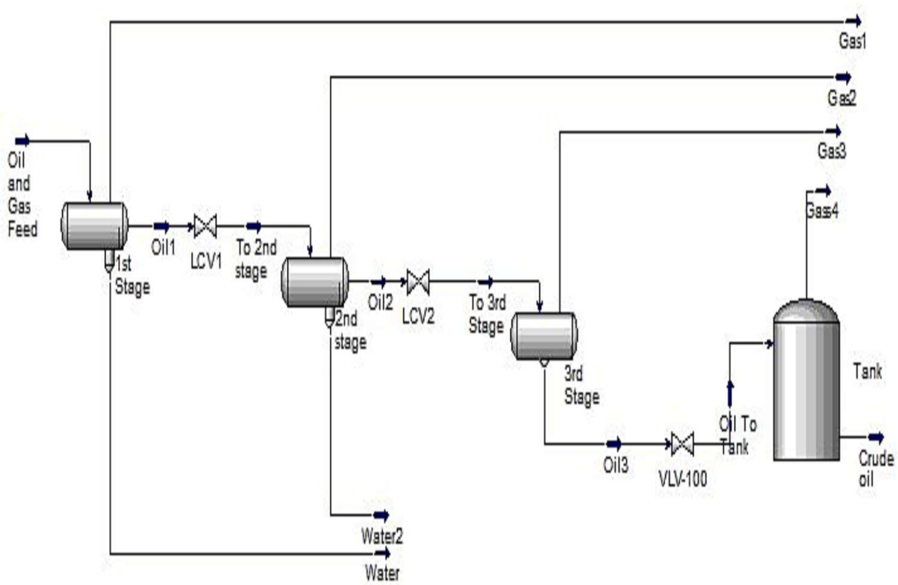

Fig. 1. Full Train Overview 105 KBPD by HYSYS

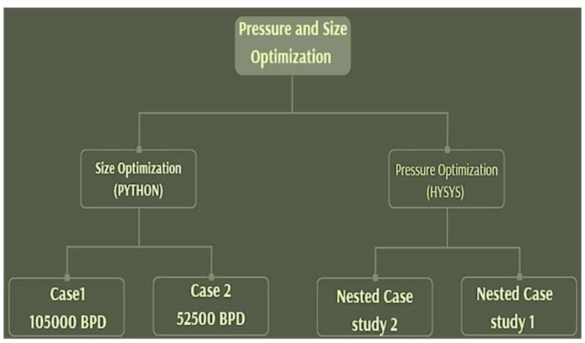

Fig. 2. Study Flow Chart

Table 1. Required Exported Oil Specifications [3]

Conditions	Requirements
Salt content	Less than 30 PTB
Water content	0.1 vol%
Reid vapor pressure 37.8°C	Under 13 psi

2.2. Size Optimization (Python Code)

The code preparations started with empty list animalization for the results storing for every calculation step, then we used a while loop that allowed us to enter different diameters and lengths and the inlet flow rates. Then the code has to calculate the separator surface area and the total weight of the separator W1+W2 all this should be done by using the LF method [24, 25]. then the next step was to calculate the cost of the material and the total cost using the results from the weigh calculations the cost factor was assumed 1.5 $ for the material unit size, in addition to that by using the entered diameters and lengths the code calculate the retention time for each stage Then the results was appended in a list and when all calculations are done a table will be printed out for results summarization for all the input values then it ask the user to end the steps or continue. When the user enters n meaning no which will be an order for the code to end the process the code will print out a list of the calculations and compare between the cases that have been studied and then it shows the optimum value. Fig. 3 shows the Python code flow chart.

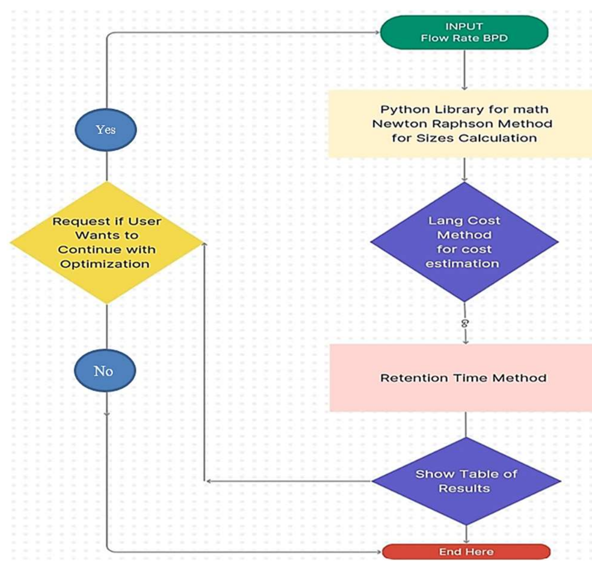

Fig. 3. Python Code Flow Chart

3- Results and Discussions

Since West Qurna1 oil field gas oil ratio GOR is high and ranges between (500-1000 SCF/bbl.) and high wellhead pressure (500 psi) and the area are available, so three-phase horizontal separators are the best choice to deal with because it is less expensive and easy to shipping, install, and maintenance. The result of the calculation for optimum separator size and optimum separator pressure for the West Qurna 1 oil field. Firstly, the separator type is chosen then the number of stages that give the highest stock-tank oil recovery is selected. After that flash calculations were computed and simulated to determine optimum separators pressure. Finally, the separator size for each stage is calculated using a developed Python code.

3.1. Separator operating pressure

For West Qurna 1 first stage separator operating pressure is fixed and cannot be manipulated due to several constraints, therefore, the operating pressures of second stage vessel and third-stage vessel were optimized, and the results were 3.00 Kg/cm^2 operating pressure set point for the second stage separator and 0.7 Kg/cm^2 operating pressure set point for the third stage vessel and for the flow tanks operating pressure was 0.038 Kg/cm^2, the above settings were chosen based on max API gravity to the tanks and minimum Bo (OFVF) and minimum GOR to tanks which give the best results with maximum oil recovery to the tanks and intermediate components stabilization. Table 2 shows the optimum set points.

a) Second stage

Optimum operating pressure for the second stage separator was selected based on API gravity, oil formation volume factor, and gas oil ratios in addition to the system profile pressure, this set point was chosen to increase the stabilized barrels number of intermediate components, HYSYS simulation resulted in the required set of data that led to the identification of the second stage optimum operating pressure set point. GOR is a representation of the fraction of produced gas to the produced liquid volume and for the separator pressure optimization it's a crucial parameter as well as the API gravity which is the measure of the density of the oil, and it is considered crucial in identifying the oil shrinkage during the process.

During the optimization process of the separation vessels' operating pressure, it's important to consider the system pressure profile, which refers to the pressure variation inside the system. Several factors can affect this pressure profile, such as throughput, full-well stream fluid composition, and the dimensions of the separation vessels.

To determine the optimal pressure value to be set at the second stage, various pressure values were tested in the HYSYS simulation. An analysis was then conducted to identify the value that produced the maximum performance. This analysis considered various factors such as the stabilized volume of the intermediate component, system profile pressure, and the mass flow rate. The simulation results show that a pressure set point of 3.0 Kg/cm^2 provided the maximum level of stabilization at the second stage. This pressure value resulted in the maximum number of stabilized intermediate components compared to the other runs. It is essential to thoroughly analyze and verify the simulation results before implementation. Considering the expected impacts on overall performance and the cost of implementing the changes is also crucial. Fig. 4 shows the optimal pressure set point for the second stage.

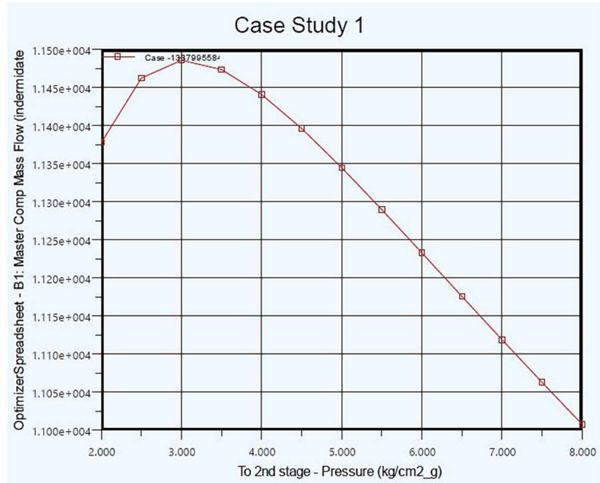

Fig. 4. Second Stage Optimal Pressure Vs. Mass Flow Rate for the Intermediate Components

b) Third stage

After applying the optimization steps of the second stage, the third stage set point of the optimum operating pressure for the optimum operation pressure was selected based on factors such as API gravity, oil formation volume factor and gas oil ratios, and system profile pressure. This set point was carefully selected to increase the production of stabilized barrels of intermediate components. Through HYSYS simulation, the required set of data was obtained, leading to the identification of the optimal operation pressure set point for the second stage.

GOR is a key indicator of the ratio of gas to liquid volume produced. It plays a crucial role in optimizing separator pressure, along with the API gravity, which measures the density of the oil and helps identify oil shrinkage during processing. When optimizing the operating pressure of separation vessels, it is important to consider the system pressure profile, which refers to pressure variation inside the system. Factors such as throughput, full-well stream fluid composition, and vessel dimensions can impact this pressure profile.

To select the optimum pressure set point for the third stage, various pressure values were determined using HYSYS simulation. After performing the analysis, the performance of maximum produced value was identified including various factors such as the stabilized volume of intermediate component, system profile pressure, and the mass flow rate. From the simulation results 0.70 Kg/cm^2 pressure set point provided maximum stabilization at the third stage as this value of pressure led to a maximum number of the stabilized intermediate components at a value in comparison with the remaining run values. Fig. 5 shows the third stage optimum pressure set point.

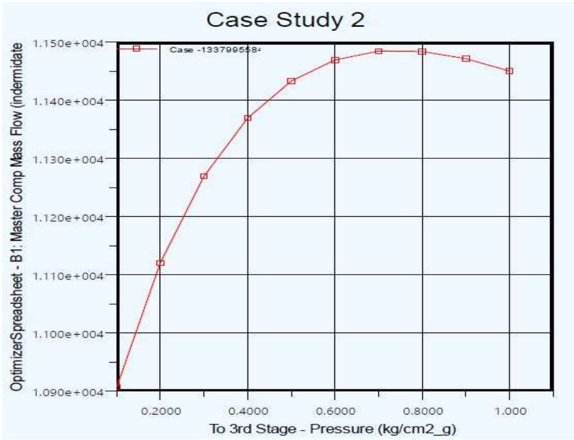

Fig. 5. Third Stage Operating Pressure VS Mass Flow Rate for Intermediate Components

The optimal pressure set points for the flow tank, three separation vessels, and the GOR, Bo, and stock-tank oil API gravity values are presented in Table 2. The selection of these optimal pressure set points was determined by considering a maximum API of the crude oil rundown to the flow tank (increased profitability), minimal values of Bo to reduce shrinkage, and minimal values of GOR. These values were chosen based on the highest points in the curves shown in Fig. 4 and Fig. 2.

1. For the First stage separator pressure is 11.79 Kg/cm^2 fixed pressure and cannot be changed.
2. For the second stage separator, the optimum operating pressure is 3.0 Kg/cm^2 with total GOR, Bo, and stock-tank oil API gravity. Figure 4 shows the pressure SP which results in the highest number of intermediate components stabilization at the specific pressure compared with other pressures, the optimum SP is 3 Kg/cm^2 with 11485.6 Kg/hr of mass flow rate.
3. For the third stage separator, the optimum operating pressure is 0.7 Kg/cm^2 with total GOR, Bo, and stock-tank oil API gravity. Fig. 5 shows the pressure SP which results in the highest number of intermediate components stabilization at the specific pressure compared with other pressures, the optimum SP 0.7 Kg/cm^2 with 11457.5 Kg/hr of mass flow rate.

Table 2. Optimum Separators Pressure

Vessel	Pressure Kg/cm^2	API	GOR	OFVF (Bo)
First Stage	11.79	24.7	497	1.28
Second Stage	3	24.7	497	1.28
Third Stage	0.7	24.7	497	1.28
Tank	0.038	24.7	497	1.28

3.2. Separation Vessels Sizes

A combination of Newton Raphson Method and Lang Cost Method and the retention time calculations were the base for a code written in Python to help in the separator sizes optimization process and the total purchase cost was the objective function. And in this study two design scenarios were taken in order to investigate the optimum separator size with a production rate of 105,000 KBPD and 52,500 KBPD respectively and the optimum solutions are shown in Table 3 and Table 4.

a) The First scenario 105,000 KPBD

For the first scenario, the optimization process showed that the optimum size for the first stage three-phase separator is a length equal to 16.5 meters and a diameter equal to 3.5 meters, and for the second stage three-phase separator the length equal to 15 meters and the diameter is equal 3.5 meters and for the third stage two phase separator the optimum length was equal to 12.3 meters and the diameter equal to 3 meters.

Then the retention time was calculated for each stage and vessel individually to be used in the optimization decision and the result was the retention time for the first stage separator was equal to 6.8 minutes and for the second stage separator the retention time was equal to 6.2 minutes and lastly for the third stage separator the retention time was equal to 3.7 minute. The retention times for each stage were also calculated and were found to be 6.8 minutes for the first stage, 6.2 minutes for the second stage, and 3.7 minutes for the third stage.

The total purchase cost for the first case scenario was as follows, for the first stage separator which is the biggest vessel in terms of size and material was equal to $1,534,630, and for the second stage separator the estimated cost was $1,438,239, and for the two phases three phase separator the total purchase cost was $1,025,978, these costs were calculated using Lang Cost method which took the material cost in consideration and Lang factor 3.1 to calculated the total purchase cost after adding the shipping, installation, commissioning and startup expenses.

Table 3. Optimum Separators Sizes 1st Scenario

Stage	Diameter m	Length m	Total cost $	Retention Time minute
First	3.5	16.5	1,534,630	6.8
Second	3.5	15	1,438,239	6.2
Third	3	12.3	1,025,978	3.7

b) The Second Scenario 52,500 KPBD

In this scenario, we used an approach that was different from the first scenario as the length and diameter of each stage were reduced leading to the cost reduction but two separators at each stage were needed to process the 105000 KBPD. The optimum separator size was equal for all the stages and equal to 7-meter vessel length and 2-meter diameter, and this is a significant reduction in size compared to the sizes of the first design case but that size reduction requires two vessels at each stage.

The need for two separators for every single stage was taken into consideration for the total cost of the second scenario which is $823,851.50 for the single stage and that is much less than the cost resulting from the first design case that was equal to $1,534,630 and for the second stage separator the estimated cost was $1,438,239 and for the two-phase three phase separator, the total purchase cost was $1,025,978 the fewer sizes lead to lower costs.

The results of retention time calculations for each stage were 1.89 minutes, although it's less than the retention time from the first design case but it is still within acceptable limits. It is worth noting that the second design case results might not be fit for all conditions as using two separated trains with vessels less in size could not be the perfect choice for another full well stream.

Table 4. Optimum Separators Sizes 2nd Scenario

Stage	Diameter m	Length m	Total cost $	Retention Time minute
First	2	7	411,925.75	1.894
Second	2	7	411925.75	1.894
Third	2	7	411925.75	1.894

4- Conclusions

To achieve optimal pressure levels**,** utilizing a single train with three-stage separators and carefully selected set points can significantly increase volume by stabilizing intermediate components. The recommended set points for the three stages in the separation train are 11.79 Kg/cm^2, 3.0 Kg/cm^2, and 0.7 Kg/cm^2, as they have the most economical choices. The optimized separation vessels offer several advantages that are not available with the non-optimized version, including increased crude volume capacity in the flow tank, higher API, and reduced flared gas emission. When considering the optimal sizes for separators, the comparison between the cases studied shows a trade-off between separator size and cost. The first case design had a longer retention time compared to the second case design resulting in a larger separator and higher cost. In contrast, the second case design required two vessels per stage to process the same throughput, ultimately leading to lower costs. Separator efficiencies are affected by the retention time, with longer retention times leading to improved separator efficiency. Therefore, increasing retention time can positively impact the overall performance of the separators.

Nomenclature and Abbreviations

(CAPEX)	Capital Expenditure
(OPEX)	Operational Expenditure
(S.P)	Set Point
(OPSP)	Optimum Pressure Set Point
(FVF)	Formation Volume Factor
(GOR)	Gas Oil Ratio
(W.C)	Water Cut
(WQ1)	West Qurna1
(SCF)	Standard Cubic Feet
(API)	American Petroleum Institute
(KBPD)	Kilo Barrel Per Day
(WOR)	Water Oil Ratio
(Bo)	Oil Formation Volume Factor
(EOR)	Enhanced Oil Recovery
(IOR)	Improved Oil Recovery
(μo)	Oil Viscosity
(μg)	Gas Viscosity
(kro)	Oil Relative Permeability
(krg)	Gas Relative Permeability
(EOS)	Equation of State
(CPF)	Central Processing Facility
(STB)	Stock Tank Barrel
(LCV)	Level Control Valve

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تحسين حجم العازلة والضغط التشغيلي للعازلات الثلاثية الطور في حقل غرب القرنة ١

عمار فلاح حسن [١]، غانم مديح فرمان [١، *]

١ قسم هندسة النفط، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

تمت الدراسة لتحديد افضل ضغط تشغيلي لعازلات النفط ثلاثية الطور في حقل غرب القرنه ١. استخدمت هذه الدراسة برنامج ASPEN HYSYS لدراسة ضغط عازلات النفط للمراحل الثانية والثالثة، مع الحفاظ على ضغط التشغيل ثابتًا في المرحلة الأولى. شملت الدراسة تحليل ١٠ حالات لكل مرحلة، وكشفت أن الضغط التشغيلي المساوي ل ٣,٠ كجم/سم٢ و ٠,٧ كجم/سم٢ للمرحلتين الثانية والثالثة على التوالي، أدى إلى أعلى استرداد للنفط في خزان التصدير. تم اختيار هذه القيم بناءًا على عدة عوامل مثل الـAPI، Oil formation Volume Factor ونسبة الغاز إلى النفط في الخزان.

تم تطوير برنامج مكتوب بلغة Python لتسهيل عملية تحسين أحجام عازلات النفط، تم استخدام طريقة نيوتن رافسونNR طريقة لانج لحساب التكلفة وحسابات زمن المكوث. كانت دالة الهدف هي تكلفة الشراء الإجمالية. تم اعتبار سيناريوين تصميمين يتناسبان مع معدلات إنتاج تبلغ ١٠٥,٠٠٠ برميل يوميًا و ٥٢,٥٠٠ برميل يوميًا على التوالي. في الحالة الأولى، تم استخدام طريقتي نيوتن رافسون ولانج للتكلفة، و كانت النتيجة ضفة عزل ثلاثي المراحل بتكاليف فردية قدرها ١,٥٣٤,٦٣٠ دولار للمرحلة الأولى، ١,٤٣٨,٢٣٩ دولار للمرحلة الثانية، و ١,٠٢٥,٩٧٨ دولار للمرحلة الثالثة. تكلفة بناء ضفة العزل الكلية لثلاث عازلات تساوي ٣,٩٨٨,٨٤٧ دولار. في الحالة الثانية، تم استخدام عازلتين لكل مرحلة للتعامل مع نفس معدل الانتاج، مما نتج عنة تكاليف اقل من السيناريو الأول. حيث بلغت التكاليف الإجمالية ٨٢٣,٨٥١,٥ دولار لكل مرحلة تكلفة بناء ضفة العزل الكلية لثلاث عازلات تساوي ٢,٤٧١,٥٥٣ دولار.تم حساب الكلف بأستخدام طريقه لانج و بمعامل ٣,١ لحساب الكفلة الكلية بعد اضافة الكلف التخمينيه للنقل و التنصيب و الفحص و التشغيل.

أما تصميم الحالة الأولى فأنة انتج عازلات أكبر وتكاليف أعلى، بينما أظهر تصميم الحالة الثانية تكاليف أقل، على الرغم من أنه يتطلب وجود عزلتين لكل مرحلة لمعالجة نفس معدلات الإنتاج. لوحظ أن كفاءة العازلات تتأثر بزمن المكوث، حيث يؤدي زيادة زمن المكوث إلى تحسين كفاءة العزلات.

الكلمات الدالة: الضغط التشغيلي، API الكثافة النوعية للنفط، تحسين الانتاج، أحجام العازلات، نسبة الغاز الى النفط.