

Research Article

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Using ANN for well type identifying and increasing production from Sa'di formation of Halfaya oil field – Iraq

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Abstract: The current study focuses on utilizing artificial intelligence (AI) techniques to identify the optimal locations of production wells and types for achieving the production company's primary objective, which is to increase oil production from the Sa'di carbonate reservoir of the Halfaya oil field in southeast Iraq, with the determination of the optimal scenario of various designs for production wells, which include vertical, horizontal, multi-horizontal, and fishbone lateral wells, for all reservoir production layers. Artificial neural network tool was used to identify the optimal locations for obtaining the highest production from the reservoir layers and the optimal well type. For layer SB1, the average daily production is 291.544 STB/D with the horizontal well, 441.82 STB/D with the multilateral well, and 1298.461 STB/D with the fishbone well type. Also, for the SB2 layer: 197.966, 336.9834, and 924.554 STB/D, and for the SB3 layer: 333.641, 546.6364, and 1187.159 STB/D for the same well type sequence. The cumulative production for each formation layer is 22.440 MMSTB from the horizontal well, 59.05 MMSTB from the multilateral well, and 84.895 MMSTB from the fishbone well types for the SB1 layer; 48.06, 70.1094, and 160.254 MMSTB for SB2; and 75.2764, 111.7325, and 213.1291 MMSTB for SB3 for the same well types.

Keywords: tight formation, increasing oil production, reservoir management, well production types, ANN applications

Abbreviations

AI	artificial intelligent
ANN	artificial neural network
FB	fish bone multilateral well
FDP	field development plan
GOR	gas oil ratio (SCF/STB)
HC	hydrocarbon
Pb	bubble point pressure (Psia)
rw	well bore radius (in)

1 Introduction

The goals of the companies, whether they are operators or producers of oil and gas fields, are almost identical in context, and the result is how to increase production and achieve profits continuously over time while maintaining and prolonging this goal for an extended period to reduce the costs incurred. This can be achieved by employing contemporary technology and novel field techniques.

Carbonate reservoirs are considered one of the most critical producing reservoirs in the world and the Middle East [1–3]. These reservoirs are characterized by complex structure and texture, as well as in their contained and movement of hydrocarbon (HC) fluids. Above all, we may come across oil reservoirs that are almost from low to tight reservoirs, in which the values of permeability are at their best values, less than 1 millidarcy (md) in our case.

Low-permeability to tight supplies has huge improvement potential. Focusing on these kinds of reservoirs by companies has special consideration when it has a decent and critical HC collection with the promising eventual fate of creation. In this manner, applying other strategies and creating office means to increment saves and works with the development of unrefined petroleum in the coming years.

The current reservoir under study is one of these reservoirs classified as carbonate rocks in fields within

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the Mesopotamian for deep and Zagros fold belt in southern and central Iraq, located in Southern East of Iraq. It is considered as one of the main reservoirs in the Halfaya oil field [4,5], in which the original oil in place is estimated at 3.957–4.1 MMMSTB. Still, it suffers from the fact that its permeability could be very low as it ranges from 0.01 to 10 md, as an average with 0.1 md. Some areas are primarily non-existent, which makes the production of vertical well types with the initial daily output of the other vertical well. Horizontal wells are 650 and 1,500 BOPD, respectively [6], after stimulations and activation operations. Therefore, the study uses the method of artificial intelligence to search and predict the most essential commercially accumulated places in which the oil is located and which method is appropriate for increasing production from the reservoir given the well technology type.

Petroleum companies face a real challenge in producing oil and gas from tight and unconventional reservoirs (e.g., tight carbonate reservoirs, extra heavy oil reservoirs, and shale oil reservoirs). Although vertical wells are usually designated in the beginning stages of field development, more than 60% of wells presently being penetrated are horizontal wells. These wells can (i) further develop efficiency, (ii) further develop crossing points with vertical-crack organizations, (iii) lessen gas and water coning, and (iv) increment apparent productivity. Because of the improvement in direction plan, the accessibility of base opening sensors, and the headway of estimating while at the same time (MWD) devices, well directions have become progressively perplexing [7].

So, in terms of technology, horizontal wells can increase productivity, improve area sweep efficiency, minimize water and gas coning and vertical bridge fractures, and prevent asphalt precipitation [8,9]. Although horizontal wells improved production in many fractured reservoirs, the productivity improvement in some cases was not significant compared to other good plans. The main obstacle to horizontal wells is rapid productivity decline due to fracture closure, orientation, and lack of knowledge about reservoir fractures [10–12]; therefore, the technique of drilling wells turned to horizontal wells with multiple arms (multilateral wells) and in different forms to overcome all the previously mentioned production problems.

Multilateral wells are characterized as a well with various branches in the lower bore opening focusing on the compensation zone in a similar layer or multiple layers. Based on the main drag, the multilateral well can be divided into root well and fishbone groups, as shown by Shamkhal [13] in Figure 1. The primary wellbore is vertical for the top-notch, while for the fishbone wells, the laterals are bored out from flat wellbore (Bosworth et al. [14]). The fishbone wells are new creative innovations applied to increment well efficiency and access troublesome land developments and offbeat repositories. More extensive waste regions describe them; therefore, high creation rates can be accomplished. The primary benefits of this innovation over water-powered breaking are the severe cost and decreased activity time. Fishbone-formed multilateral wells demonstrated improved efficiency than multi-broke flat wells in somewhat low penetrable repositories [15].

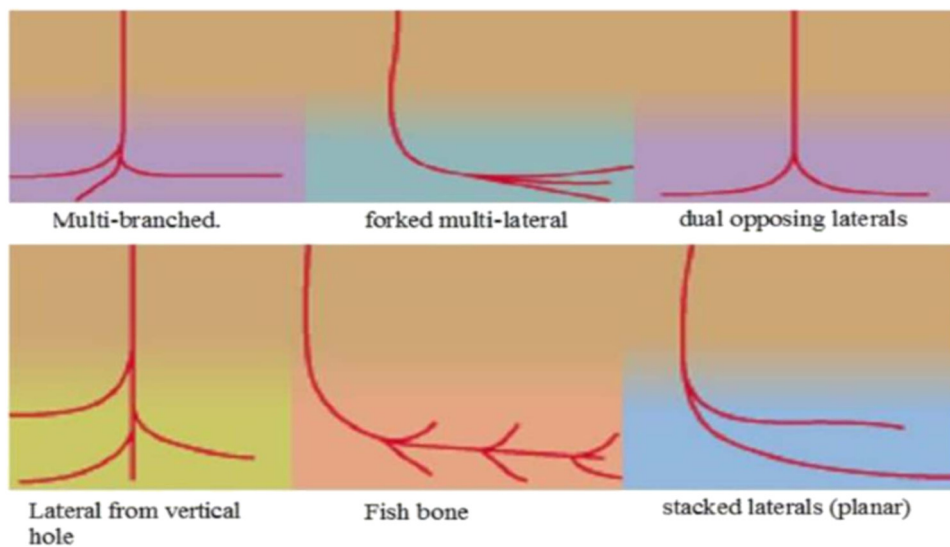


Figure 1: Types of multi-lateral horizontal wells.

Foreseeing good efficiency is a fundamental for considering planning and finishing the creation well, as well as choosing the counterfeit lift and excitement processes. A few methods have been accounted for to examine well execution. Additionally, the more significant part of the detailed techniques is essential and material for limited cases since they ignore the number of rib openings and accept uniform tensions in all laterals. A considerable deviation was seen between the genuine creation of information and the anticipated outcomes.

1.1 Artificial neural network (ANN) in the oil industry

Simulated intelligence is the condition of the workmanship framework, which has heaps of definitions by researchers and architects back in 1945. Two meanings in which the ideal interest characterizes artificial intelligent (AI). Haugeland [16] described AI as “The energizing new work to make PCs think, the machine with minds, in the full and strict sense.” Partridge [17] has characterized AI as “an assortment of calculations that are computationally manageable, satisfactory approximations of unmanageably indicated issues.” Simulated intelligence can sometimes reproduce human insight by taking care of issues, by noticing different boundaries using new techniques or approaches. One of the ways to deal with performing and planning AI is to characterize particular specialists for a specific issue.

Explicit data sources connected with one perspective can be coordinated to address the problem [10–12,18–20].

1.2 Aim of the study

This research aims to find the best critical and candidate areas for production, while determining the best architecture technology that the AI model can use and Sa'di formation of tight carbonate rocks in the Iraqi Halfaya oil field – taking into consideration the influencing area, reservoir, and production factors.

1.3 Area of the study – Halfaya oil field

The Halfaya field is located south of Iraq in Missan province, 35 km southeast of Amara city, Figure 2 is presented by Arjwan et al. [20]. The structure, composed of two domes, runs along an NW–SE direction and is a gentle elongated anticline about 38 km long and 12 km wide. The field comprises a main body of the anticline with a length of 31 km, extending in the NW direction. It was discovered in 1976, and significant oil accumulations have been found in the formations. Halfaya is proven to hold 4.1 billion barrels of recoverable reserve and has a production potential of 200,000–535,000 barrels per day. The China National Petroleum Corporation-led group finished

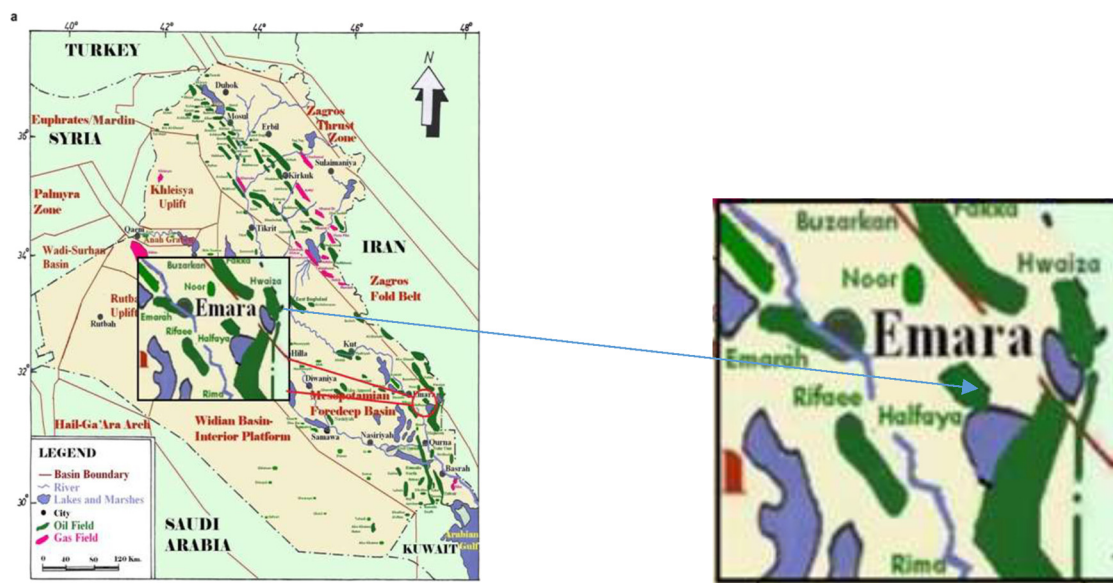


Figure 2: Geographical location of Halfaya oil field.

the first phase in June 2012 and increased the production from 3,000 to 100,000 barrels per day, 15 months ahead of schedule [21]. However, before this date, there were some reports of previous attempts, as in the year 1957, the Halfaya oilfield was found first by the Basrah Oil Company, and it was considered a good design by the National Oil Company who did a seismic study covering the district during the period 1973–1974 who drew a pearl shape for it. In 1956 Smout decided the center Cenomanian–early Turonian Sa'di formation, a significant carbonate supply unit in southern Iraq, was concentrated on utilizing cuttings and wireline logs [5].

1.4 Geology setting of the area

Al-Sudani [5] mentioned that the stratigraphic secession in the Halfaya oilfield area could be represented by the deep oil well HF9 drilled in the center of the Halfaya structure, which penetrated deep into the early Triassic Mirga Mir formation with a total depth of 6,230 m. Jurassic and Cretaceous units are the main target for the Jurassic oil source and the Cretaceous oil reservoirs in the Halfaya field.

Stratigraphically, in Iraq, they are divided into Late Toarcian–Early Tithonian Megasequence (AP7) that were deposited during a period of isolation of the central intra-shelf basin of Mesopotamian from the Neo-Tethyan Ocean,

probably due to renewed rifting along the NE margin of the Arabian plate.

The basin's depletion occurred in a restricted, relatively deep-water environment during the Mid-Jurassic. The bay became evaporitic during the Late Kimmeridgian–Early Tithonian time. The base of the mega sequence in an area of interest started with the basinal formation. The mega sequence's upper evaporitic part comprises the Gotnia formation evaporates. The Late Tithonian–Early Turonian Megasequence (AP8) included the Yamama, Ratawi, Nahr Umr, and Mishrif Formations reservoirs. The Late Turonian–Danian Megasequence (AP9) included the reservoirs of Khatib, Tannuma, Sa'di, and Hartha Formations. Jeribe Formation is the only reservoir in the Tertiary with the upper regional seal of the Fatha (Lower Fars) Formation. Figures 3 and 4 depict these stratigraphic sequences for southern Iraq – as presented by Saber [22] and Tamar and Shahad [23]. Also, the technical reports demonstrate the stratigraphic section in a Halfway oil field when studying the petroleum sample characterization of the area.

1.5 Research methodology

This research follows the steps given below to obtain the best scenario for cumulative oil production from three layers of the Sa'di formation with different production well types.

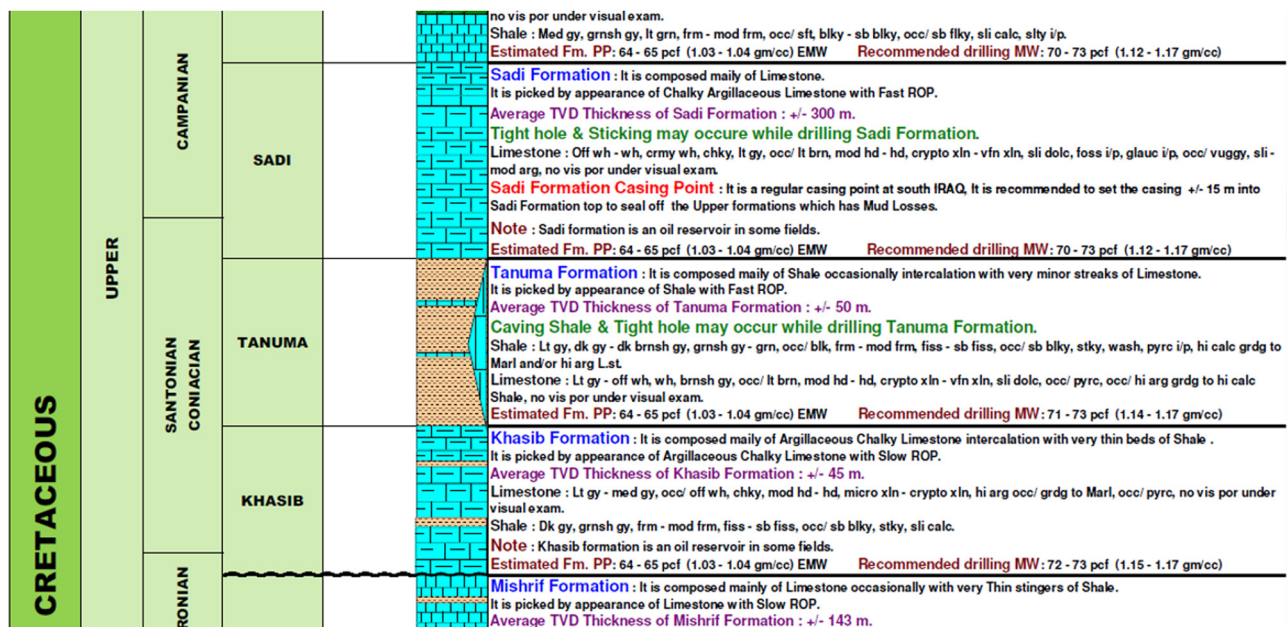


Figure 3: Stratigraphic column in the southern area of Iraq, after Lukoil company. (operational geology), South Iraq operational geology chart.

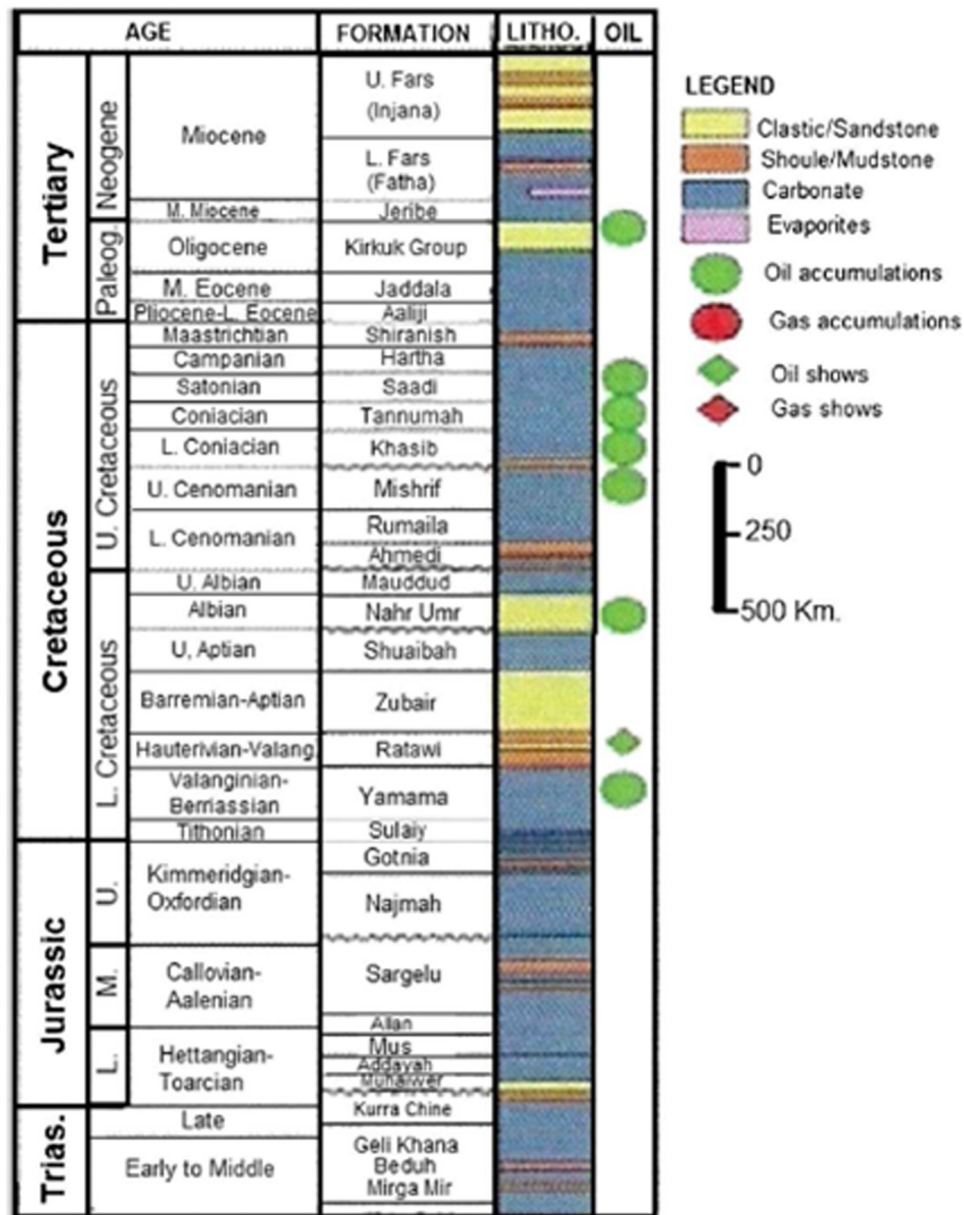


Figure 4: Stratigraphic sections of a stratigraphic column of well HF9 located between HF8 and HF7.

1. Using of available digitized data from previous consent studies according to different layers with petrophysical properties and HC accumulation areas of Sa'di reservoir formation.
2. Constructing ANN using Matlab software with a tool to reach total production as a target of each scenario.
3. Transform the petrophysical properties of formation layers plus thickness as input sets into the input layer of ANN and set the training parameters for choosing NN.
4. A perdition phase of calculation was conducted after trying, training, and validation of ANN to ensure the

right choices of well types and gaining well production from elected areas of layers.

5. Conducting the final decision by comparing base case scenarios of reservoir formation development.

2 Reservoir characteristics and field development

The nature of reservoir rocks containing oil and gas dictates the quantities of fluids trapped within the void space

of these rocks. Two main rock properties are porosity and permeability. So, knowledge of these two properties is essential before questions concerning types, amounts, rates, the flow of the fluid, and fluid recovery estimates can be answered. Other reservoir properties of importance include the texture, the resistivity of the rock and its contained fluids to electrical current, the water content as a function of capillary pressure, and the tortuous nature of the interstices or pore channels.

Changes in water saturation combined with changes in the resistivity of the fluids filling the pores create resistivity profiles in well logs. These profiles help locate HC-bearing formations [8].

Porosity is a vital rock property because it measures the potential storage volume for HCs. Permeability is essential because it is a rock property related to the rate at which HCs can be recovered.

For our concern, values range considerably from less than 0.01 to 10 md. A permeability of 0.1 md is generally considered the minimum for oil production.

Here, we present a case study for a giant Middle Eastern oil field in Iraq, and its characteristics are summarized in Table 1. The table shows that the target reservoir consists of crude oil with 68.44 API, 0.73 cP viscosity, and 864.261 SCF/STB gas-to-oil ratio (GOR) at bubble point pressure (Pb). HCs are produced from three different layers named (SB1, SB2, and SB3).

3 Field development plan (FDP)

For every advancement methodology plan, such new improvements require recognizable proof of the most reasonable well sort (i.e., upward, flat, multi-sidelong, or exceptionally strayed).

As shown in Figure 1, a prediction of the production profile based on the old version of the FDP has been made.

Prediction profile expectation in light of the old rendition of the field advancement plan is shown in Figure 1. As displayed in the figure, the typical creation rate for every individual level was around 1,570 BOPD, which does not see the prediction needs and FDP wants.

The process of developing oil fields takes a wide range of factors and variables that are related to the extractive and productive process. For example, how to maximize reservoir performance (recovery or net present value), we optimize the number of producers and injectors, their types (e.g., vertical, horizontal, or multilateral), locations, and trajectories, as well as their control strategy via smart (intelligent) completions.

Such new developments require the precise identification of the most suitable well type (i.e., vertical, horizontal, multi-lateral, or highly deviated) for each development strategy plan design, and that is what we are thinking of within the Sa'di formation.

4 Build of the model and data used

AI built the adopted model in the study – ANN as a target search tool and using the Matlab software created and prepared by Mathworks company, version 2020. With using approved data available in studies, reports and reliable sources [21,24–26], where the work included (3) models in addition to a vertical one, according to the type of wells proposed for development in comparison with the actual base case that took into account the currently existing vertical wells when to refer to it. It is known that the horizontal wells are the benchmark for comparison with them (calculated and measured), according to the geological nature of the layer concerned with the petrophysical properties.

The first step of this part depends on the available petrophysical maps built from geological models adopted in the study for each formation layer consisting of porosity, permeability, and water saturation. In addition to the thickness, an incomplete picture of the places proposed to distribute those types of wells was generated. The submitted data in the computational models were examined to show the most critical and highest productive areas. Three scenarios models according to the well configuration were built for the desired purpose and according to the number of the variables and stages of each model, which shows the behavior of the network during training and examination of the available data and according to the input variables in the form of ordered pairs of data as shown in Table 2.

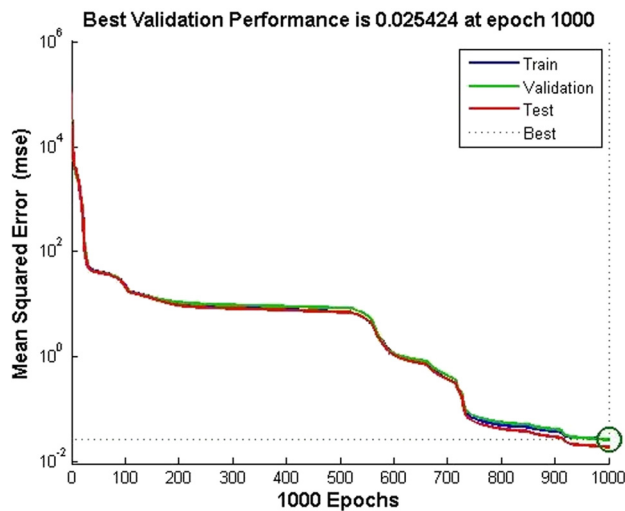
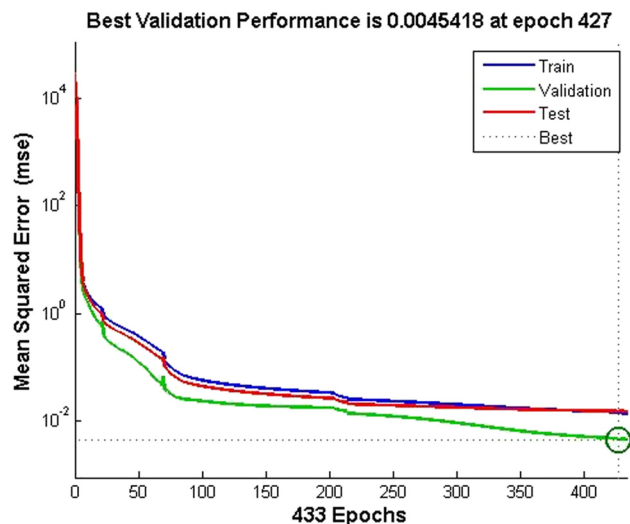
The second step was to analyze the results according to the available data and adopt the best of them as a

Table 1: Sa'di formation characteristics – Halfaya oil field

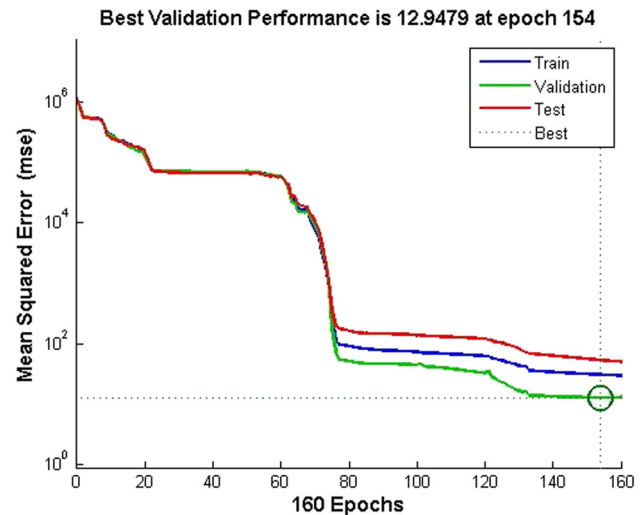
Property	Value
Avg. porosity – (%)	0.1776
Avg. permeability – (md)	146
Reservoir depth (m)	2,600–2,750
Avg. net pay thickness – (m)	125
Oil gravity – (API)	68.44
GOR (SCF/STB)	850
Avg. reservoir pressure (Psia)	4,850
Oil viscosity (cP)	0.73 at Pb

Table 2: Input data sets and its percentages for ANN models

ANN model type	No. of datasets for training	No. of datasets for validation
Horizontal well	$1,416 \times 3$	944×3
Multilateral well	$1,416 \times 3$	944×3
Fishbone well	210×3	140×3

**Figure 5:** Training ANN model for horizontal well.**Figure 6:** Training ANN model for multi-lateral horizontal well type.

developmental step for the reservoir concerned with the study from the concerning field. Figures 5–7 show the behavior of those models that have been built for the desired purpose and according to the stages and variables

**Figure 7:** Training ANN model for fishbone horizontal well type.

of each model, which shows the behavior of the network during training and examination of the available data and according to the variables entered in the form of ordered pairs whose numbers and percentages used are shown in Table 2. Here the concern is with the behavior of the network and its variables.

5 Results and discussion

Once the construction models have been completed, the next step is to validate those models by examining, approving, and implementing them based on the information used with them. In this section, the expected production rates were calculated from three types of wells (horizontal, multi-lateral, and fishbone) for three layers of the Sa'di formation according to the selected areas regarding the reservoir quality region petrophysical properties. It was expected to reach the highest rate of productivity and their cumulative depending on the available data and for the state of the

Table 3: Well type characteristics

Well type	Well characterization
Horizontal	Length = 2,000 ft rw = 0.25
Horizontal – multilateral (2 bore hole)	Length = 2,000 ft rw = 6.5 in – open hole
Horizontal – fishbone (7 ribs)	Rib hole length = 1,000 ft Rib hole spacing = 1,000 ft Rib hole radius – rw = 0.328 ft

Table 4: Comparison of predicted flow rates by ANN with regard to Sa'di formation layers

Layer name	Well type	Maximum Qo STB/D	Minimum Qo STB/D	Average Qo – ANN STB/D	Average Qo – calc. STB/D	AAPE %
SB1	Horizontal well	443.4069	145.1533	291.5698	291.5438	0.00931
	Horizontal multilateral	455.1651	274.8568	355.1829	441.8199	23.8834
	Horizontal – FB	1976.705	648.3597	1300.461	1298.4610	0.16054
SB2	Horizontal well	395.0577	90.74548	197.9919	197.9659	0.01509
	Horizontal multilateral	480.7228	169.9603	287.0392	336.9834	15.2889
	Horizontal – FB	1846.904	425.6843	926.554	924.5540	0.2479
SB3	Horizontal well	547.9084	132.3489	333.6665	333.6405	0.0086
	Horizontal multilateral	581.2562	210.4503	423.3137	546.6364	27.4831
	Horizontal – FB	1951.475	472.8313	1189.159	1187.1590	0.1856

adopted wells. The characteristics of these wells are explained in Table 3. Also, the calculation of the production rates for these types of wells referred above was done through mathematical models published in the scientific literature on this good technique [27,28].

The results from the constructed models based on the use of ANN and calculated mathematically for some of the selected regions are shown in Table 4. This table shows the averages calculated by neural networks and the averages calculated from the mathematical models with an indication of a measure of error (absolute average percentage error [AAPE]), which were adopted in the study, and the proposed areas included in the calculations are shown in Figures 8–10 and Tables 5 and 6. This shows the specific areas of the proposed well sites and the amount of expected daily production.

The following were found:

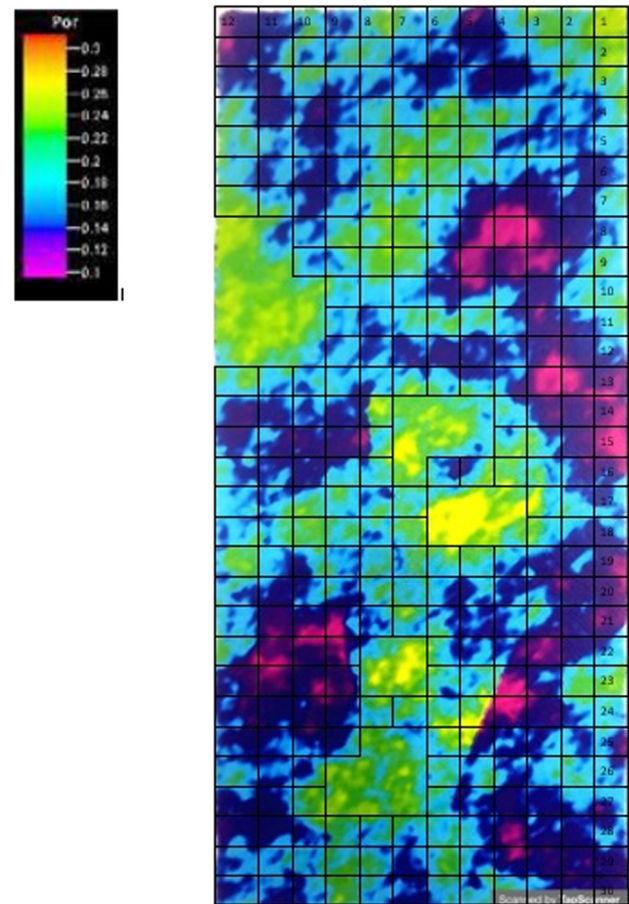
5.1 For horizontal wells

It was found through the prediction process for the model built using ANN. The production rates ranged from 443.41 to 145.2 STB/D for layer SB1, from 395.1 to 90.75 STB/D for layer SB2, and from 547.91 to 132.4 STB/D for layer SB3 for the formation of Sa'dia. The areas selected for each layer were elected on the basis that they show high reserves of HC reserve and the highest oil saturation. The length of the adopted horizontal well was 2,000 ft with a diameter of 0.25 in, and the results are shown in Table 4 – calculation of production per day.

5.2 For multilateral wells

The prediction method was also adopted using the ANN model by examining the selected regions that have high

HC storage and saturation without the other areas, as it ranged from 455.2 to 274.86 STB/D for layer SB1, from 480.7 to 170 STB/D for layer SB2, and from 581.3 to 210.5 STB/D for layer SB3 to form Sa'dia. According to the areas selected for each layer, the adopted well has two arms, which are 2,000 ft long and 0.27 in in diameter. The results are reflected in Table 4 as per day of production.

**Figure 8:** Selected areas with SB1unbordered.

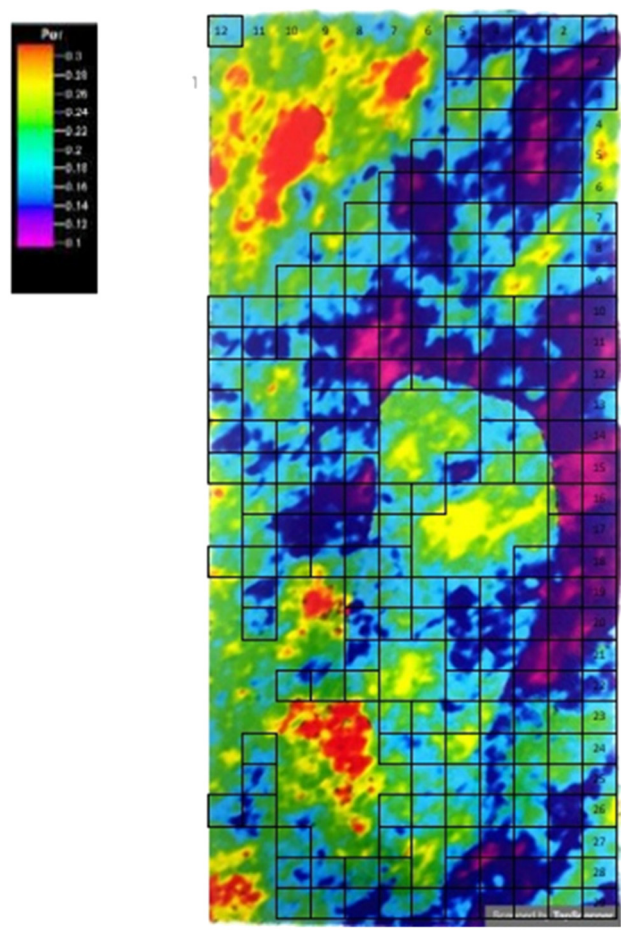


Figure 9: Selected areas with SB2 unordered.

5.3 For fishbone wells

Good high productivity characterizes this technique of wells due to the detection of a larger area of the reservoir and with a lower value of pressure drop. It ranged from 1976.71 to 648.4 STB/D for layer SB1. It went from 1846.9 to 425.7 STB/D for layer SB2 and from 1951.5 to 472.83 STB/D for layer SB3 to form Sa’dia. According to the selected areas for each layer, which were elected on the basis that shows high reserves of HC pool and the highest oil saturation, where a borehole of 1,000 ft long, with seven arms, and 0.328 in diameter was adopted, to compare with the rest of the scenarios used from the wells and for the selected areas from the three layers of the Sa’di formation. The obtained results are shown in Table 4.

5.4 Expected error rate

According to the obtained results, one of the statistical measurements used in research purposes for the validation and

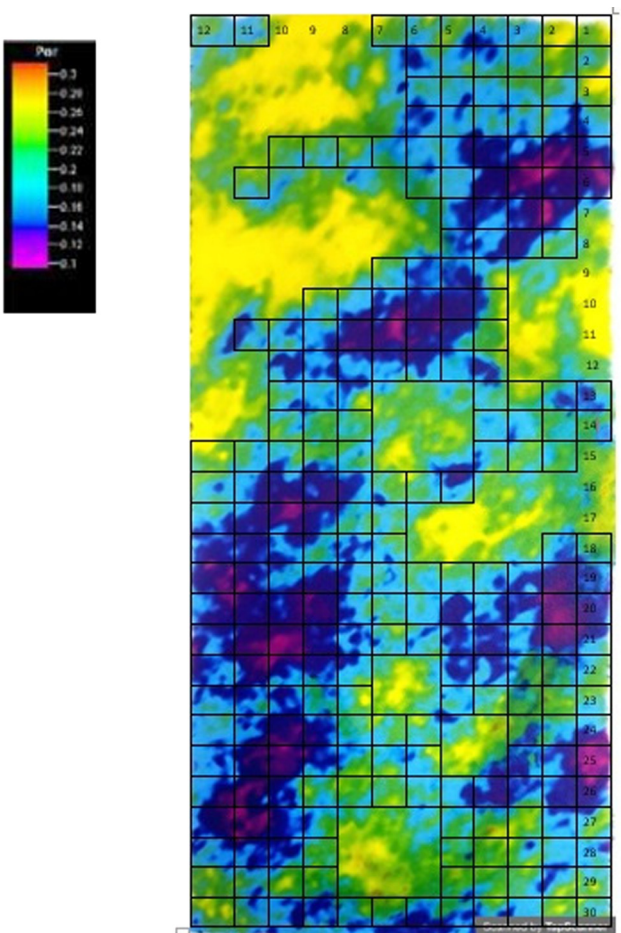


Figure 10: Selected areas with SB3 unordered.

verification, an expected error rate was used. The average error rate was 0.0086% for horizontal wells and 27.48316% for horizontal wells with booms. However, the error rate was 0.18556% for FB-type wells. It is noted that the highest rate recorded is for melt-type wells, which is why these wells have a high rate of error.

6 Expected scenarios for field development

The process of creating or approving the scenarios adopted in the FDP is mainly studied according to the nature of the

Table 5: No. of suggested grids on Sa’di formation layers

Layer name	No. of suggested grids
SB1	39
SB2	111
SB3	114

Table 6: Types and no. of wells distribution on Sa'di formation layers

Well type	Layers								
	SB1			SB2			SB3		
	No. of wells	Avg. daily production STB/D	Cumulative production MM STB	No. of wells	Avg. daily production STB/D	Cumulative production MM STB	No. of wells	Avg. daily production STB/D	Cumulative production MM STB
Horizontal	21*	291.544	22.440	67*	197.966	48.06	55*	333.641	75.2764
Horizontal multilayers	39**	441.82	59.05	57	336.9834	70.1094	56	546.6364	111.7325
Horizontal – fishbone	18	1298.461	84.895	23	924.554	160.254	28	1187.159	213.1291

*Either new horizontal well, or transfer the vertical well into horizontal one.

**New horizontal well.

layers and their petrophysical properties, in addition to defining the selected areas in them, which is expected to give excellent results depending on the layering that determines the storage character of the HCs in them and the excellent permeability there.

The characteristic of the flawless transition between layers and regions of formation, as well as the ratio of pure thickness to total thickness, plays a significant role in this type of reservoir that suffers from decreasing porosity and permeability. Its heterogeneity is substantial, which is shown here in this type of carbon reservoir with high heterogeneity.

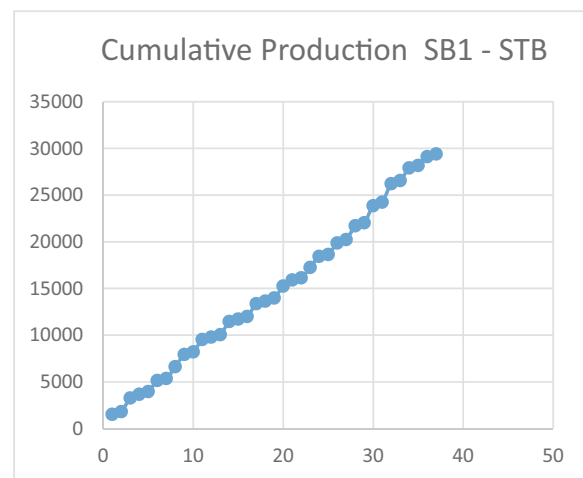
The crest regions are generally characterized by good properties and excellent selected areas, in addition to areas where there is an improvement in porosity toward the southeast parts of the field about the porosity, while developing and improving the permeability toward the southwest regions of the area.

According to the dimensions of the field, which are indicated in paragraph (2.1) of the current research, the areas that will be adopted for development were selected, as their number was 39 in the SB1 layer and 114 in the SB2 layer. In contrast, the SB3 layer was 111, areas with equal dimensions (4,157 ft × 3,281 ft). Based on the available spaces and the ability of the wells to drain and produce, the number and type of each well for each layer were selected; these are detailed in Tables 4 and 5.

Selected scenarios

a. The first scenario will be adopted as a base one for comparison regarding the distribution of the current wells in the field and the currently approved production rates according to the development plan set by the CNPC field operator, which has reached the goal of producing 400 M STB/D for a period of 10 years. Thus the cumulative production rate for 10 years will be 1,460 MM STB/D. This topic has a question. How much is the daily production of Al-Sa'di capacity?

- The second scenario depends on the vertical wells in the field but in the elected areas and calculating the cumulative production from the field, where the daily production of the Sa'di formation and its three layers is 51.255 MSTB/D, so the cumulative annual output for a period of 10 years will be 187.081 MMSTB.
- The third scenario is the adoption of the horizontal wells' technology, whether it is new wells or the adoption of developing the already existing vertical wells and converting them to horizontal wells, where the daily production from the installation is 70.972 MSTB/D and thus the cumulative production for a period of 10 years is 259.0478 MMSTB.
- The fourth scenario is adopting the existing vertical wells' technology with the development of horizontal wells using the multilateral wells' technology and calculating the cumulative production for the same proposed period, where the daily production amounted to 116.324 MSTB/D. Thus, the cumulative production for the same period is 424.583 MMSTB

**Figure 11:** FB and H wells in SB1 – cumulative production.

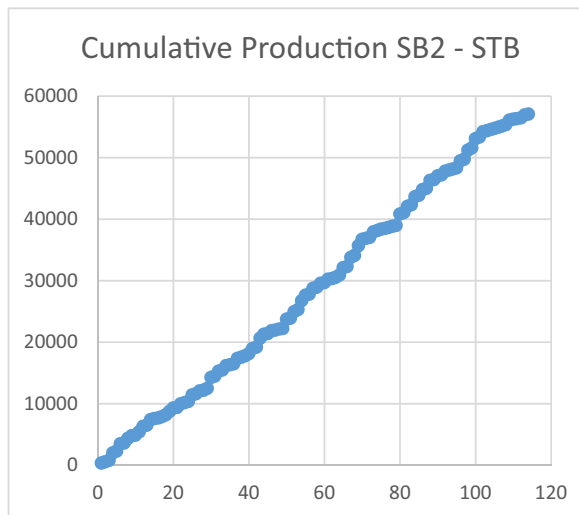


Figure 12: FB and H wells in SB2 – cumulative production.

- e. The fifth scenario is the adoption of the existing vertical wells with the development of horizontal wells using the fishbone technique and the cumulative production for the same proposed period, where the daily production amounted to 287.814 MSTB/D, while the cumulative production for the same period will be 1050.5211 MMSTB
- f. Adoption of the mixed production method from the well's technology adopted in the selected areas and for three layers of the Sa'di formation.

This scenario was based on introducing a trade-off between the proposed well techniques to be used in developing the Sa'di reservoir. It is three layers through the results of the ANN model, wherein in each selected region,

the well will be chosen depending on the amount of production achieved from it without taking into account the vertical wells currently in the field and penetrating the Sa'di formation. The plan developed by the operating company is to reach 400 MSTB/D of each formation, and Table 5 shows us the number and type of wells and the amount of production achieved from each layer of the Sa'di reservoir with the cumulative production for a period of 10 years. Table 5 shows the distribution of those wells in the layers of the reservoir formation with cumulative output for each formation layer. At the same time, Figures 11–13 reflect the cumulative production for 10 years of the prediction period for each layer.

From the comparison of the obtained results in Table 5, it is evident that the Sa'di's formation, although it was of a type tight carbonates formation, but the oil saturation and the nature of the petrophysical characteristics were able to give an indication that, the amount of daily and accumulated production that will be greater with the different using of well type, that is mean that these selected areas have highly potential for exploration, but it needs favorable well types for right exploitation.

7 Conclusions

7.1 Using of AI-ANN as a searching tool for the best

The use of AI-ANN as searching tool for the best candidate areas for productivity and increasing the average daily and

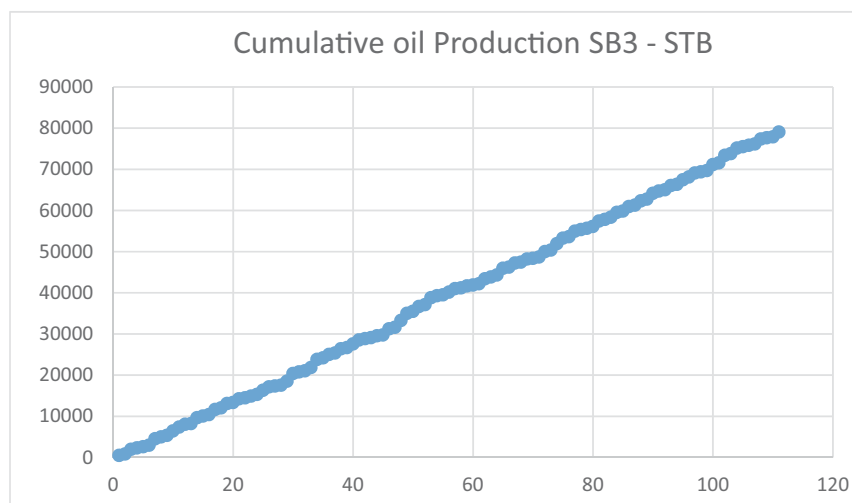


Figure 13: FB and H wells in SB3 – cumulative production.

accumulated production according to the types of wells used in the formation layers under study, and through the results obtained from the present work, the following results were reached: -

1. All the extracted and available data were checked and used in the research, proving their validity and reliability through the error percentage, which amounted to AAPE as in Table 4.
2. All the production rates predicted and calculated using the AI-ANN models were accurate and with an accepted percentage range of error.
3. The values of the predicted production rates from the mathematical models have proven their accuracy and reliability with what was reached by the AI-ANN, especially for horizontal and FB well types.
4. The daily production rates from the selected areas of the three layers of the Sa'di formation were reached, depending on the petrophysical (reservoir quality) properties that were previously modeled and distributed.
5. The established models showed a very acceptable quality, especially in the training and examination phase, with an error percentage of less than 1.
6. Only three variables were adopted to construct the used models and develop products for the formation layers.
7. Using the ANN models, empirical equations were reached, a direct method for calculating production rates and the types of wells approved in the research.
8. The proposed models will assist production engineers in designing and finding the best developmental production plan for the reservoir under study.
9. Regarding the Sa'di formation layers, although it is a type of tight reservoir, it has the willingness and ability for developers to improve production within various techniques of wells.
10. The best production scenario was ascending from SB1 to SB3 for all types of wells according to their cumulative production.

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The other datasets are available on reasonable request from the corresponding author with the attached information.

References

- [1] Ehrenberg SN, Aqrabi AA, Nadeau PH. An overview of reservoir quality in producing Cretaceous strata of the Middle East. *Pet Geosci.* 2008;14:307–18. doi: 10.1144/1354-079308-783.
- [2] Shepherd M. Carbonate reservoirs in M. Shepherd. *Oil field production geology.* AAPG Mem. Vol. 91; 2009. p. 301–9. Copyright 2009 by The American Association of Petroleum Geologists. doi: 10.1306/13161226M913372.
- [3] Kargarpour MA. Carbonate reservoir characterization: an integrated approach. *J Pet Explor Prod Technol.* 2020;10:2655–67. doi: 10.1007/s13202-020-00946-w.
- [4] Noori AK, Lazim SA, Ramadhan AA. Geological model of the tight reservoir Sadi Reservoir-Southern of Iraq. *J Eng.* 2019;25(6):30–43. <http://creativecommons.org/licenses/by-nc/4.0>.
- [5] Al-Sudani H. Evaluation of petrophysical properties of Sa'di Formation. South of Iraq; November 2019. Research study.
- [6] Yang J, Zhu G, An Y, Li N, Xu W, Wan L, et al. Integrated reservoir model and differential stimulation modes of low permeability porous carbonate reservoir: a case study of S Reservoir in X Oilfield in Iraq. *Processes.* 2022;10:1179. <https://www.mdpi.com/2227-9717/10/6/1179>.
- [7] Garrouch AA, Lababidi HM, Ebrahim AS. An integrated approach for the planning and completion of horizontal and multilateral wells. *J Pet Sci Eng.* 2004;44(3–4):283–301.
- [8] Hu J, Zhang C, Rui Z, Yu Y, Chen Z. Fractured horizontal well productivity prediction in tight oil reservoirs. *J Pet Sci Eng.* 2017;151:159–68.
- [9] Wang H, Guo J, Zhang L. A semi-analytical model for multilateral horizontal wells in low-permeability naturally fractured reservoirs. *J Pet Sci Eng.* 2017;149:564–78. <https://www.sciencedirect.com/science/article/pii/S0920410516309202>.
- [10] Hassan A, Abdulaheem A, Elkhatny S, Ahmed M. New approach to quantify productivity of fishbone multilateral well; October 2017. SPE – 187458-MS doi: 10.2118/187458-MS.
- [11] Hassan A, Elkhatny S, Abdulaheem A. Application of artificial intelligence techniques to predict the well productivity of fishbone wells. *Sustainability.* 2019;11:6083. doi: 10.3390/su11216083.
- [12] Hassan A, Mahmoud M, Al-Majed A, Abdulaheem A. A new technique to quantify the productivity of complex wells using artificial intelligence tools. 2016 November 7–10, IPTC-19706, UAE. SPE -183508; 2016. <https://doi.org/10.2523/IPTC-19706-Abstract>.
- [13] Shamkhal M. Selection of technologies for multilateral wells' completion in the Achimov Formations of Yamburg Field. M.Sc thesis. Montana University; July 2020.
- [14] Bosworth S, El-Sayed HS, Ismail G, Ohmer H, Stracke M, West C, et al. Key issues in multilateral technology. *Oilfield Rev.* 1998;10(4):14–28.
- [15] Xing G, Guo F, Song C, Sun Y, Yu J, Wang G. Fishbone well drilling and completion technology in ultra-thin reservoir. Paper presented at the IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition, Tianjin, China, Paper Number: SPE-155958-MS; July 2012. doi: 10.2118/155958-MS.
- [16] Haugeland J. *Artificial intelligence: The very idea.* Cambridge, MA: MIT Press; 1985. p. 287.

- [17] Partridge D. A new guide to artificial intelligence. Intellect books; 1991. p. 200.
- [18] Buhulaigah A, Al-Mashhad AS, Al-Arifi SA, Al-Kadem MS, Al-Dabbous MS. Multilateral wells evaluation utilizing artificial intelligence. SPE-183688-MS; 2017.
- [19] Al-Marsomy SW, Al-Ameri TK. Petroleum system modeling of Halfaya oil field south of Iraq. 2015 Iraqi J Sci. 56(2B):1446–56.
- [20] Fayadh AH, Mad'hat EN. 3D geological model for Khasib, Tanuma, and Sa'di formations of Halfaya Oil Field in Missan Governorate-Southern Iraq. Iraqi J Sci. 2018;59(2B):875–85. doi: 10.24996/ij.s.2018.59.2B.8.
- [21] Ehrenberg SN, Aqrabi AA, Nadeau PH. An overview of reservoir quality in producing Cretaceous strata of the Middle East. Petrol Geosci. 2008;14:307–18. 1354-0793/08/\$15.00 _ 2008 EAGE/ Geological Society of London. doi: 10.1144/1354-079308-783.
- [22] Saber A. Stratigraphic chart – South Iraq operational geology chart. Missan Oil Company, Petroleum engineer. 2008. https://www.academia.edu/10193944/South_iraq_operational_geology_chart.
- [23] Al-Ameri TK, Al-Marsoumi SW, Al-Musawi FA. Crude oil characterization, molecular affinity and migration pathways of Halfaya oil field in Mesan Governorate, South Iraq. Arab J Geosci. 2015;8:7041–58. doi: 10.1007/s12517-014-1733-z.
- [24] Buhulaigah A, Al-Mashhad AS, Al-Arifi SA, Al-Kadem MS, Al-Dabbous MS. Multilateral wells evaluation utilizing artificial intelligence. 2017. SPE 183508-S. https://www.researchgate.net/publication/315779433_Multilateral_Wells_Evaluation_Utilizing_Artificial_Intelligence.
- [25] Noori AK, Lazim SA, Ramadhan AA. Geological model of the Tight Reservoir-Sa'di Reservoir-Southern of Iraq. J Eng. 2019;25(6):30–43.
- [26] Technical reports. MOC; 2014. special issues.
- [27] Guo B, Sun K, Ghalambor A. Well productivity hand book; 1st edn. Houston, TX, USA: Gulf Publishing Company; 2008 August.
- [28] Hill AD, Zhu D, Economides MJ. Multi-lateral wells. Society of Petroleum Engineering. Richardson, Texas, USA: January Society of Petroleum Engineers; 2008. doi: 10.2118/183688-MS.