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Comparative Study between Different Oil Production Enhancement Scenarios in an Iraqi Tight Oil Reservoir

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Abstract

This paper presents a comparative study between different oil production enhancement scenarios in the Saadi tight oil reservoir located in the Halfaya Iraqi oil field. The reservoir exhibits poor petrophysical characteristics, including medium pore size, low permeability (reaching zero in some areas), and high porosity of up to 25%. Previous stimulation techniques such as acid fracturing and matrix acidizing have yielded low oil production in this reservoir. Therefore, the feasibility of hydraulic fracturing stimulation and/or horizontal well drilling scenarios was assessed to increase the production rate. While horizontal drilling and hydraulic fracturing can improve well performance, they come with high costs, often accounting for up to 100% of the total well cost. To ensure economically viable flow rates and achieve maximum ultimate oil recovery, a technical and economic comparative study was conducted. The results indicate that hydraulic fracturing offers promising outcomes, with a total oil production of 153,816 Mbbl over 30 years from 25 fractured wells, resulting in a final Net Present Value (NPV) of 3,583.32 MM$.

In contrast, the planned two horizontal wells exhibit lower eventual production and NPV compared to the majority of fractured wells. However, the 2000 m lateral section of well HF00Y-S00YH shows a slightly higher NPV. Considering the operational benefits and profitability, hydraulic fracturing should be seriously considered for the further development of the Saadi reservoir.

This comparative study provides valuable insights into the most effective approach for enhancing oil production in tight reservoirs like Saadi, balancing the technical feasibility and economic viability of different stimulation scenarios. The findings can guide decision-making processes and contribute to maximizing oil recovery in similar challenging reservoirs.

Keywords: hydraulic fracturing; horizontal wells; stimulation; oil recovery; Saadi reservoir.

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1- Introduction

The oil industry is constantly evaluating and creating new oil and gas reservoirs to meet the increasing claim for oil components. Unconventional reservoirs, which span a large area and utilize special techniques or extensive stimulation treatments to extract significant amounts of hydrocarbons, are now the primary focus for resource development [1].

There are various techniques and treatments to enhance the oil recovery from tight oil reservoirs including: acid fracturing, hydraulic fracturing, fishbone wells, horizontal wells, deviated wells and matrix acidizing. Acid fracturing of vertical wells was less effective in stimulating production in tight oil reservoirs since this method results in shorter fracture height and length [2, 3]. Although, fishbone wells outperforms horizontal and deviated wells in Saadi reservoir as it gives higher oil production rates for extended period. the complexity of drilling fishbone wells makes it difficult to be achieved [4]. Also, deviated wells need high kickoff points and it is usually being drilled instead of vertical wells in areas where there is difficulty to drill vertical wells [5]. In addition, the production of hydrocarbons from unconventional reservoirs is not primarily influenced by the properties of the rock matrix, but rather by the presence of secondary fractures and, in some cases, an enhanced permeability zone created through stimulation techniques [6]. The initial performance of the wells that penetrates Saadi reservoir was high after the treatments, suggesting a favorable effect of the implemented treatments. The performance of the wells decreased quickly by 65% after 3 months. During this time, there was intermittent oil production and some of the wells were shut-in. As a result, and because of the poor petrophysical characteristics of Saadi reservoir, matrix acidizing failed in enhancing production from such tight oil reservoirs [7]. Therefore, to bypass the complexity of fishbone and deviated wells and the underwhelmed production of acid fracturing and matrix acidizing treatments, hydraulic fracturing of vertical wells and drilling horizontal wells scenarios are proposed for developing Saadi reservoir. There are several advantages and restrictions associated with each option. Thus, hydraulic fracturing and horizontal wells methods must be closely examined to choose the better scenario, since they have a big impact on how the reservoir will perform.

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The focus of this study is the Saadi formation, located in the Halfaya oil field, which is the thickest and most widespread formation within the Late Turonian-Early Campanian Sequence. It consists of two units, the non-reservoir Saadi A and the reservoir Saadi B, which is the primary tight oil reservoir in the field with a thickness of 77 meters. The Saadi formation is deposited over the Tanuma formation and below the Hartha formation, and is predominantly composed of limestone [8]. Although it is a carbonate oil reservoir with medium-sized pores and narrow pore throats, it has poor petrophysical characteristics. The Saadi formation forms an anticline structure (Fig. 1). It is clear that top of the reservoir is approximately at 2775 m. The permeability (k) of Saadi reservoir is (0.02-5) md, while the porosity is (0.08-0.25). The original oil in place (OOIP) is estimated to be 4585 MMbbl, which represents 22.5% of Halfaya field's OOIP. However, only 412 MMbbl of this OOIP is stored in the reservoir where k > 2 md; and 187 MMbbl when k > 5 md, which represents only 3% of Halfaya field OOIP. The remaining 3986 MMbbl of the OOIP is accumulated in Saadi reservoir where k < 1.3 md and represents 19.5% of Halfaya field's OOIP. The average oil recovery factor of Saadi reservoir is 1.3% [9].

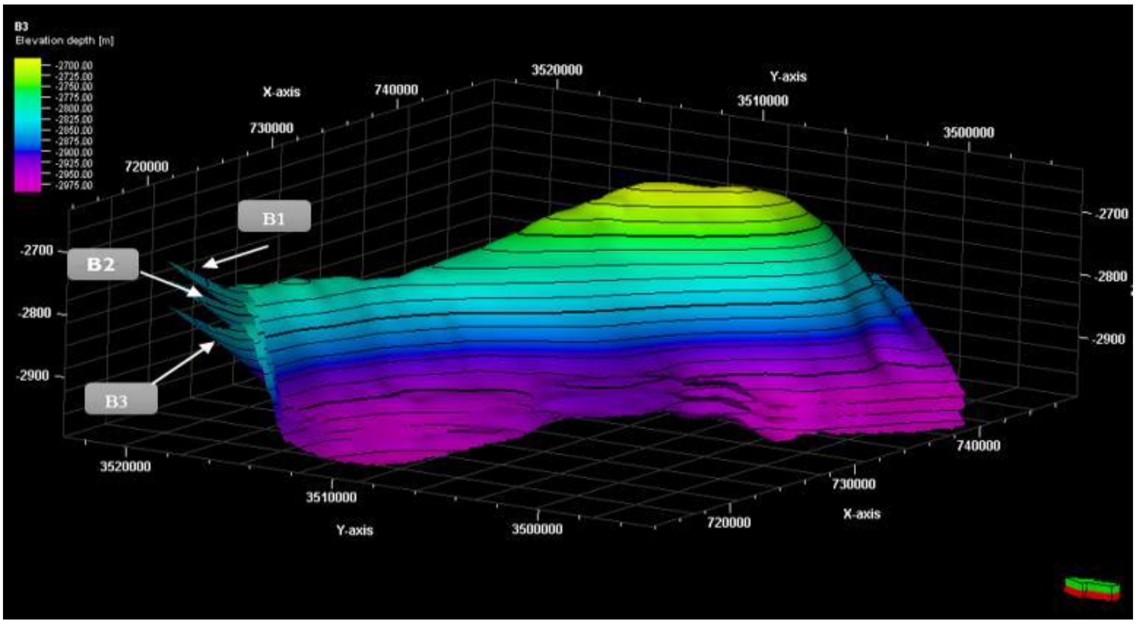

Fig. 1. 3D Surface Map for Top of Saadi B [7]

2- Materials and Methods

2.1. Hydraulic fracturing

The standard hydraulic fracture treatment is designed to maximize well stimulation by providing optimal fracture length and conductivity. The process of hydraulic fracturing involves carefully considering various design parameters such as the type and size of fracturing fluid, the type and concentration of proppant, and the pumping rate [9]. When designing a hydraulic fracturing treatment, it is important to prioritize the contact with the reservoir's capacity over the generated fracture half-length or conductivity. The length of the fracture produced has an impact on the effective fracture length and due to the complexity of the porosity-permeability and fracturing system, accurate flow modeling is critical for efficient treatment [6, 10].

a. Selection of fracturing fluids

The selection of the fracturing fluid utilized is dependent on the brittleness and permeability of the formation. Formations with high permeability are typically stimulated with viscous fracturing fluids to create wider fractures. On the other hand, low-permeability formations can impede fluid flow, leading to unfractured rocks. In addition, increased rock ductility or reduced brittleness require larger fracture openings to maintain the fractures' permeability once pressure is removed. Brittle reservoirs with poor permeability require more aggressive fracturing. It is important to note that any deposition in the reservoir will reduce permeability [11], necessitating the injection of greater fluid volume with lower viscosity, such as slick-water or Guar fluid [12]. Increasing the amount of fracturing fluid used causes an increase in fracture length [13]. The viscosity and temperature of the Saadi formation are compatible with Gel fracturing fluid like Guar_200 F° and Slickwater_180 F° (where Guar and Slickwater are types of fracturing fluid operating at different reservoir temperature).

b. Selection of proppants

To keep the fracture open and provide a pathway for reservoir fluids to reach the wellbore, sand (proppant) is injected with fluid. The size of the proppant has a significant impact on the fracture's permeability, and a homogeneous and larger proppant size achieves higher permeability [13, 14].

The proppant's transportability and strength also influence the fracture permeability, as higher transportability allows for deeper proppant distribution, while proppant strength is critical to avoid smashing under fracture closure stress. Ceramic proppants with varying densities, compressive strengths, and size and shape control are used to create extremely homogeneous grains [15]. The viscosity of the fluid and friction against the pipe walls also affect energy loss in fluid and proppant transmission in pipelines, leading to more pumping power consumption [16].

A typical trend in fracture fluid types, volumes, and complexity based on rock characteristics is shown in Fig. 2. When rock brittleness increases, permeability decreases, and the rock is highly fractured, low viscosity, high-volume, and pumping rate fracturing fluids are recommended, with lower proppant volume and concentration [17]. Asymmetrical fractures with smaller openings tend to be more complex, and the chosen low-density and high-density ceramic proppants provide the highest conductivity for stresses over 6000 psi.

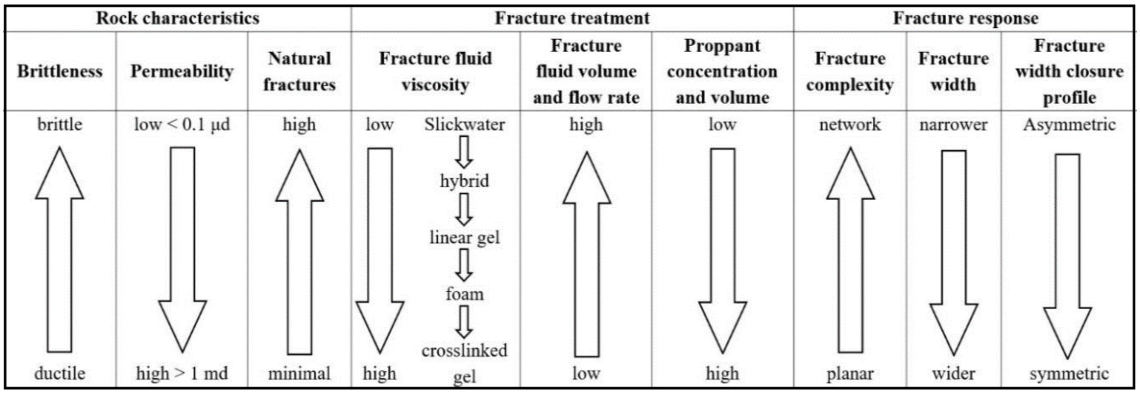

Fig. 2. Rock Characteristics, Fracturing Treatment, and Fracture Response [17]

c. Selection of fracturing fluids pumping rates

Fracturing fluid pumping rates from 18 to 44 bpm were employed. Fig. 3 illustrates the optimal pumping rate utilizing the Guar fracturing fluid. It can be noticed that the longest fracture is generated at pumping rate equal to 31.5 bmp. As the pumping rate goes above 31.5 bpm, the fracture is shortened enabling additional vertical propagation. Therefore, pumping rate of 31.5 is the optimal rate.

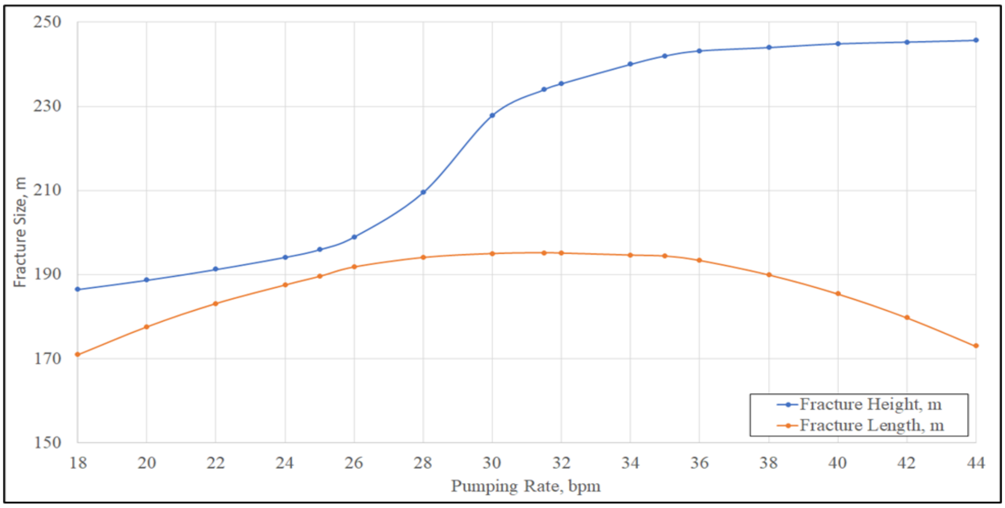

Fig. 3. Optimized Pumping Rate

d. Hydraulic fracturing designs

The study employs two hydraulic fracturing designs to evaluate hydrocarbon production in 25 wells within the study region.

- Design A uses Guar_200 F° fracturing fluid with high-density ceramic proppants at a pumping rate of 31.5 bpm.
- Design B utilizes Slickwater_180 F° fracturing fluid with low-density ceramic proppants at the same pumping rate.

e. Productivity of fractured wells

The steady-state flow oil rate for fractured wells is found as per Eq. 1 [5].

$$q = \frac{kh(p_e - p_{wf})}{141.2B_o\mu_o(\ln\frac{r_e}{r_w} + S_f)} \tag{1}$$

Where q is flow rate, k is permeability, h is height of fracture, pe is reservoir pressure at re, pwf is bottom hole flowing pressure, Bo is oil formation volume factor, μo is oil viscosity, re is drainage radius, rw is well-bore radius and Sf is skin factor.

2.2. Horizontal wells

Increasingly, horizontal wells have been employed in low-permeability reservoirs due to the advancement of drilling technology as well as the decrease in drilling costs [18]. Each horizontal well drains a large portion of the reservoir, resulting in higher output from pay zones. The well's orientation, lateral section length, pay zone thickness, petrophysical characteristics, compressibility and boundary conditions all influence the output of a horizontal well. However, the length of the horizontal wellbore is the most important factor in determining horizontal well performance [19]. The horizontal well's lateral length may enable contact with numerous fractures, significantly increasing production [20]. Two horizontal wells namely HF00X-S00XH and HF00Y-S00YH are proposed to be drilled in Halfaya oil field with target in Saadi formation. To evaluate the production performance and economics outcomes of various lateral unfractured horizontal wells, the oil rate is fixed at the same plateau oil rate of the fractured wells to compare the outcomes of the fractured vertical wells and horizontal wells more precisely. The supposed lateral lengths are 500, 750, 1000, 1500 and 2000 m for each well.

- Productivity of horizontal wells

Many equations to estimate the productivity of horizontal wells were presented in the literature. The modified Joshi equation is used to evaluate the production rate of horizontal wells [21, 22].

$$q = \frac{k_H h(p_e - p_{wf})}{141.2B_o\mu_o\left\{ln\left[\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right] + \frac{\sqrt{\frac{k_H}{k_V}}h}{L}ln\left[\frac{\sqrt{\frac{k_H}{k_V}}h}{r_w\left(\sqrt{\frac{k_H}{k_V}}+1\right)}\right] + S\right\}}.F_o \tag{2}$$

Where h is pay zone thickness, k_H is horizontal permeability, k_V is vertical permeability, L is lateral length, a is modified Joshi factor, S is skin factor and Fo is frictional pressure correction factor.

2.3. Economic comparison

When making a choice on a project, the economic analysis is critical. Net cash flow (NCF, MM$) is a function of cumulative hydrocarbon production over the entire project period, capital expenditure (CAPEX, MM$) and operational expenditure (OPEX, MM$). In the context of a particular CAPEX composed of drilling cost plus the fracturing treatment cost and OPEX which is the monthly well cost over the entire production period, the NCF may be seen as a function of the cumulative hydrocarbon production. Also, cumulative hydrocarbon production is a function of the fracture length, the fracture height and lateral section length. Hence, NCF of the fractured wells is a function of the fracture geometry whereas NCF of horizontal wells is a function of lateral section length [23].

The entire cost in this study is made up of drilling costs, including completion costs, and stimulation costs. The cost of vertical wells is constant for each well, however the cost of lateral drilling varies according to the lateral length specified for the horizontal well section. It is composed of a fixed cost component and a variable cost component. Due to small variation in total depth of all other wells in the project, vertical wells drilling and completion costs are fixed to 5 MM$. Fracturing fluid unit and proppant unit costs are 1 $/gal and 0.4 $/lb, respectively. Fixed fracturing job cost is assumed to be 400000 $. Cost of horizontal well with lateral length of 500 m is 6.5 MM$ and increasing 0.35 MM$ every 500 m of extra lateral length. Monthly well cost is assumed at 1500 $/month. Oil price and gas price are 60 $/bbl and 4$/MScf, respectively. Production forecasting for 10950 days (30 years) is estimated. The NPV for each well and design in the project is estimated assuming the discount rate at 15%. The two scenarios are compared based on cumulative production and NPV results. The greater the cumulative production, and hence the greater the NPV, the more favorable the potential scenario. The net present value (NPV) of fractured vertical wells for N years is calculated using Eqs. 3 through 11. For horizontal wells, these equations are used realizing that the CAPEX is the well drilling cost including all associated operations cost [23].

$$NPV = \sum_{i=1}^{N}\left[\frac{NCF}{(1-Discount\ Rate)^i}\right]_i \tag{3}$$

NCF = Gross Revenue - Total Cost, (4)

Gross Revenue = Cumulative Production × Price, (5)

Total Cost = OPEX + CAPEX, (6)

OPEX = Monthy Well Cost × No. of Months, (7)

CAPEX = Drilling Cost + Fracturing Cost, (8)

Fracturing Cost = Fracturing Fluid Cost + Proppant Cost + Fixed Job Cost, (9)

Fracturing Fluid Cost = Fracturing Fluid Volume × Price Per Fracturing Fluid Volume Unit, (10)

Proppant Cost = Proppant Mass × Price Per Proppant Mass Unit, (11)

3- Results

Design A involved pumping a total of 53,475.9 gallons of clean fluid, 55,870.5 gallons of slurry, and 72,013 pounds of proppant through the perforations. The resulting fracture had a half-length of 220 meters, a height of 178 meters, an average width of 0.054 inches, and a maximum width of 0.129 inches. Design B required pumping a total of 53,354.4 gallons of clean fluid, 56,404.5 gallons of slurry, and 72,013 pounds of proppant through the perforations, resulting in a fracture with a half-length of 208.8 meters, a height of 98 meters, an average width of 0.047 inches, and a maximum width of 0.113 inches. Fig. 4 and Fig. 5 illustrate the proppant concentration for Designs A and B, respectively, for well HF-55.

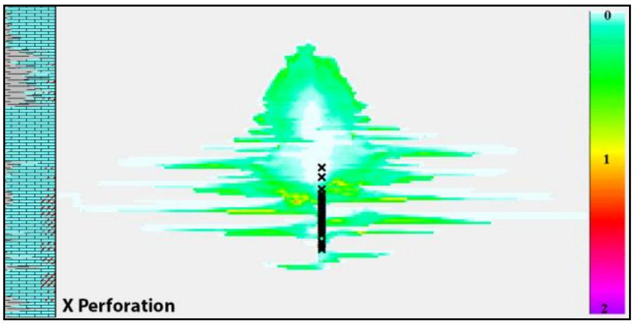

Fig. 4. Proppant Concentration (lb/ft2) for Design A of Well HF-55

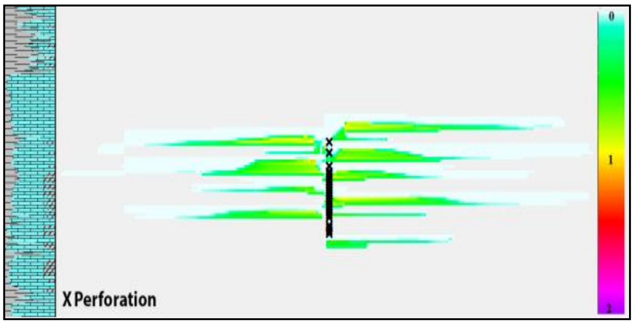

Fig. 5. Proppant Concentration (lb/ft2) for Design B of Well HF-55

3.1. Production forecast for fractured wells and horizontal wells

The oil rates for each fractured vertical wells in the project over 30 years are illustrated in Fig. 6 and Fig. 7 for designs A and B, respectively. Also, the oil rates for horizontal wells are presented in Fig. 8.

According to the findings of the fracturing models, the plateau oil rate for the majority of the wells was 1239 bbl/day. As a result, the horizontal wells are compelled to produce largely at this rate. When compared to fractured wells, the horizontal wells will only be able to produce at the plateau rate for a short period of time which not exceeds 2 years at the longest lateral section. Even with all tested lateral lengths of HF00Y-S00YH and HF00X-S00XH, the total oil volume is less than 1000 Mbbl at an average daily rate less than 60 bbl/day. Since the oil produced is less than the majority of fractured wells, it follows that the gas produced is less, too.

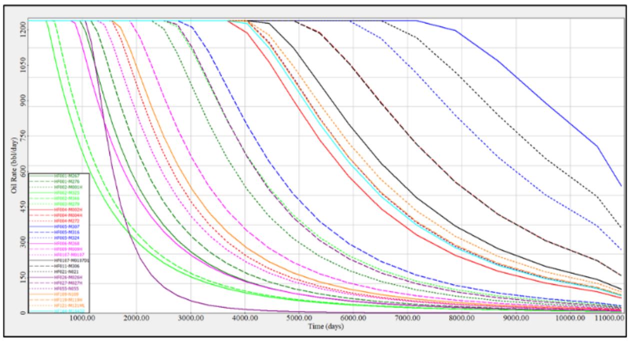

Fig. 6. Oil Rates for Fractured Vertical Wells Design A

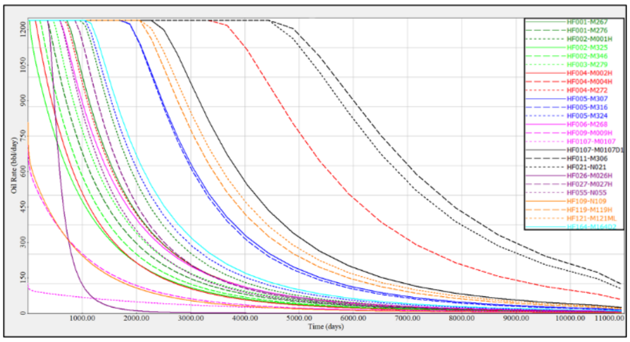

Fig. 7. Oil Rates for Fractured Vertical Wells Design B

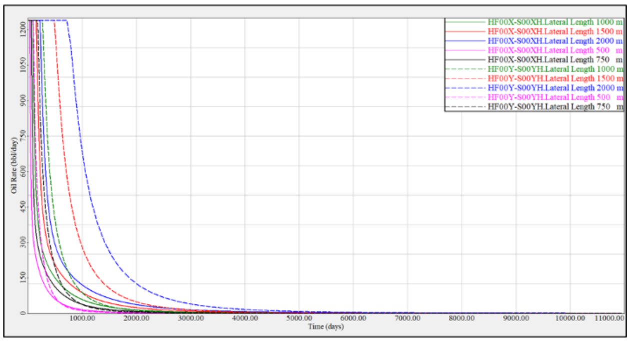

Fig. 8. Oil Rate for Horizontal Wells

The stacked histogram in Fig. 9 depicts the project's cumulative oil volumes and NPV for all wells analyzed at various treatment configurations.

4- Discussion

The results of design (A) for well HF-55 indicate that the fracture height propagated upward towards the Hartha formation and downward towards the Tanuma formation and yields the highest rates and cumulative volumes of oil and gas over the entire 10950 days (30 years) of the production forecasting. The design's final oil was 7858.360 Mbbl, with a plateau peak oil rate of 1239 bbl/day over 4044 days and an average oil rate of 718 bbl/day. Furthermore, the NPV analysis reveals that design (A) yields 170.356 MM$. The design (B) for well HF-55, in which better fracture height confinement has been gained; results in final oil volume of 2171.720 Mbbl, with a plateau peak oil rate of 1239 bbl/day over 593 days and an average oil rate of 198 bbl/day. Likewise, the NPV analysis reveals that design (B) yields 82.032 MM$. The hydrocarbon production and NPVs for 25 wells show promising results since utilizing the design (A) gives 153816 Mbbl total oil production over 30 years from 25 wells with a final NPV of 3583.32 MM$. On the other hand, a total of 79957.7 Mbbl of oil with a final NPV of 2373.772 MM$ is achieved when the design (B) is being used. The planned horizontal wells have a lower eventual production and NPV than the majority of fractured wells, with the exception of the 2000 m lateral section of well HF00Y-S00YH, which has a slightly higher NPV. The results of fractured vertical wells show accepted oil production and NPV in view of previous researches and actual well production data of Saadi reservoir. These findings assist in circumventing the intricacy of fishbone and deviated wells, as well as the disappointing output of acid fracturing and matrix acidizing treatments. Therefore, hydraulically fractured wells outperform horizontal wells and should be considered for further development of Saadi reservoir keeping the operational benefits and profitability in balance.

Recognizing the significance of extended horizontal wells and hydraulic fracturing of vertical wells in enhancing production of Halfaya oil field, acid and hydraulic fracturing of horizontal wells will be the emphasis of the future phases for optimizing output from the field, particularly from the Saadi reservoir.

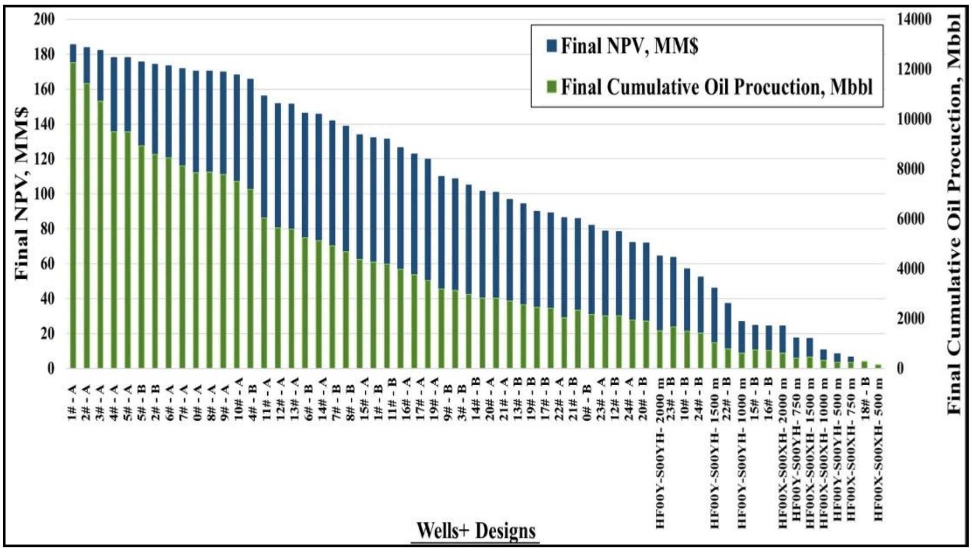

Fig. 9. Horizontal Wells and Fractured Vertical Wells Final Cumulative Oil Production and NPV Comparison

5- Conclusions

Investigation for treatments and solutions are necessary in order to obtain and maintain commercial production in a tight oil reservoir like Saadi reservoir which was this study scope. Optimal treatment designs created for horizontal wells and fractured vertical wells. The following are concluded:

- Production forecast for fractured wells show dramatic increase in hydrocarbon rates and cumulative production in comparison with unfractured wells.
- Longer plateau could be conserved with higher cumulative hydrocarbon output for majority of the fractured vertical wells.
- Also, the economic analysis gives promising results of high NPV for majority of the fractured vertical wells in the project area.
- The proposed unfractured horizontal wells at various lateral section lengths show that hydrocarbon rate and plateau periods are much smaller than fractured vertical wells. Hence the wells reach very low production rates very fast.
- The NPV of the horizontal wells show that for 2000 m lateral sections the well could be economical. Otherwise, these wells are abounded fast and the NPV are not accepted economically.
- Comparing the two scenarios, the majority of the fractured vertical wells shows higher plateau rate, period and NPV’s than all proposed horizontal wells.
- Therefore, the optimal strategy for developing such a low permeability reservoir is to employ fractured vertical wells rather than drilling horizontal wells.

Abbreviations and Nomenclatures

OOIP, original oil in place, MMbbl; k, Permeability, md; k_H, Horizontal permeability, md; k_V, Vertical permeability, md; q, Production rate, bpm; h, Height of fracture, m; pe, Reservoir pressure, psi; pwf, Bottom hole flowing pressure, psi; Bo, Oil formation volume factor, reservoir bbl/ standard bbl; μo, Oil viscosity, cp; re, drainage radius, m; rw, well-bore radius, inches; Sf, skin factor, dimensionless; L, Lateral length, m; Fo, Frictional pressure correction factor; a, modified Joshi factor; NCF, Net cash flow, MM$; NPV, net present value, MM$; Scf, standard cubic feet; gal, gallons; lb, pounds; HF, Halfaya wells prefix; CAPEX, Capital expenditure, MM$; OPEX, Operational expenditure, MM$.

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دراسة مقارنة بين سيناريوهات تعزيز إنتاج النفط المختلفة في حقل نفطي عراقي ضيق

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٢ شركة نفط الشمال، كركوك، العراق

الخلاصة

يعتبر خيار تشقيق آبار النفط وحفر الآبار الأفقية من الخيارات المتاحة لتحسين أداء الآبار في المكامن ذات الخصائص البتروفيزيائية الضعيفة والمكامن ذات العمود الهيدروكربوني الصغير. في هذه الدراسة، تم اختيار مكمن السعدي النفطي في حقل الحلفاية العراقي كمكمن نفطي ذو مواصفات غير جيدة. يصنف تكوين السعدي كمكمن كاربوني ذو فجوات متوسطة الحجم ومنخفض النفاذية وحلقات فجوات صغيرة مع خصائص بتروفيزيائية ضعيفة. أدت الاختيارات السابقة لإنعاش المكمن، مثل التشقيق بالحامض والانعاش بالتحميض، التي تم إجراؤها لهذا المكمن، إلى الدفع باتجاه تنفيذ سيناريو التكسير الهيروليكي أو حفر الآبار الأفقية. لقد أدت الخصائص البتروفيزيائية الضعيفة إلى تقليل مساهمة مكمن السعدي في الإنتاج إلى أقل من ١٪ من إجمالي إنتاج الحقل على الرغم من أن النفط الأصلي في مكمن السعدي يشكل ٢٢,٥٪ من إجمالي النفط الأصلي في حقل الحلفاية. تعتبر تكلفة حفر الآبار الأفقية مرتفعة، والتكسير الهيدروليكي هو أيضًا مكلف ويصل في بعض الحالات إلى ١٠٠٪ من إجمالي تكلفة البئر. لذلك، تم إجراء هذه الدراسة المقارنة التقنية والاقتصادية لجعل الآبار تتدفق بمعدل اقتصادي وتحقيق أقصى استرداد للنفط. من أجل المقارنة، يكون أداء الآبار التي تمت معالجتها بالتشقيق الهيدروليكي أفضل بشكل عام من الآبار الأفقية، ويجب النظر فيها لمزيد من التطوير لتكوين السعدي والحفاظ على التوازن بين المزايا التشغيلية والربحية.

الكلمات الدالة: التشقيق الهيدروليكي، الآبار الأفقية؛ إنعاش الآبار، استخلاص النفط؛ مكمن السعدي.