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Comparative evaluation of hydraulic fracturing performance in vertical and horizontal wells using pipesim software

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Abstract

This research paper uses pipesim software to reproduce and evaluate well performance, comparing vertical and horizontal wells using hydraulic fracturing. It examines the impact of key parameters, such as fracture length, width, permeability, and fracture number, on production improvement. In low-permeability reservoirs, simulation studies indicate that horizontal wells often achieve higher production rates than vertical wells, largely due to improved reservoir and fracture connectivity. Productivity in the vertical well increased to 300(stb/d), while in the horizontal well, it increased to over 9,000 (stb/d) after using hydraulic fracturing. The results indicate that fracture width has less of an impact on the performance of vertical wells than horizontal wells, although fracture length and fracture number significantly influence horizontal well productivity. This disparity underscores the need for strategic fracture design and well selection to optimize oil production under changing reservoir conditions. The research paper emphasizes the need to use advanced modeling tools such as PIPESIM to accurately predict well performance and guide decision-making in hydraulic fracturing operations. Tailor-made fracturing techniques based on reservoir properties can significantly enhance continuous production efficiency and extend well life.

Keywords: Halfaya oil field; hydraulic fracturing; horizontal wells; vertical wells.

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1- Introduction

Hydraulic fracturing is a fundamental technique employed to enhance oil production, particularly in low-permeability reservoirs and unconventional formations as shown in Fig. 1. The efficacy of this method relies on a combination of geological and technological factors, namely the dimensions of the induced fractures (length, width, and number), alongside reservoir characteristics like as permeability and porosity [1-3]. The efficacy of the fracturing procedure is significantly influenced by the well design, as the reservoir's response may vary considerably between vertical and horizontal wells [3-5].

This study aims to provide a quantitative and analytical comparison of vertical and horizontal wells regarding hydraulic fracturing effectiveness and its impact on enhancing oil production rates, utilising the Pipesim petroleum simulation program. pipesim provides an advanced framework for modelling optimal performance across various reservoir conditions [5]. The study primarily focuses on the influence of fracture length on the drainage area, fracture width on flow rate, and the number of fractures in multilayer formations [6]. It also examines how reservoir reactions following fracturing differ based on permeability and porosity [7].

Results indicate that horizontal wells, when exposed to multi-stage hydraulic fracturing, yield greater reservoir contact and generate longer, wider cracks compared to vertical wells, as shown in Fig. 2. As a result, substantially elevated oil production rates, frequently multiple times greater than those achieved by vertical wells, ensue from this [8-10].

This comparison relies on a series of simulation scenarios developed in Pipesim, in which design parameters and geological settings were systematically altered to achieve an accurate evaluation of the performance of both well types under uniform reservoir circumstances [10-12].

- **Area of study**

The current research is conducted at the Halfaya Oil Field, one of the largest oil fields in southeastern Iraq, located in Maysan Governorate, approximately 35 km southeast of Amarah City, as shown in Fig. 3.

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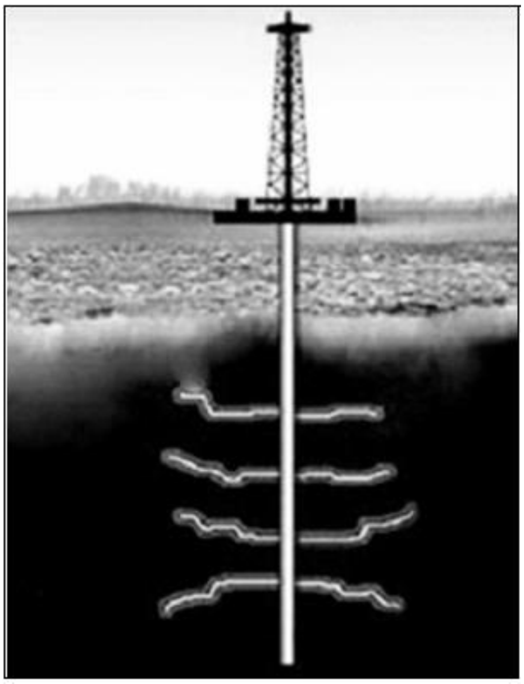

Fig. 1. Fracturing the rock formation for production

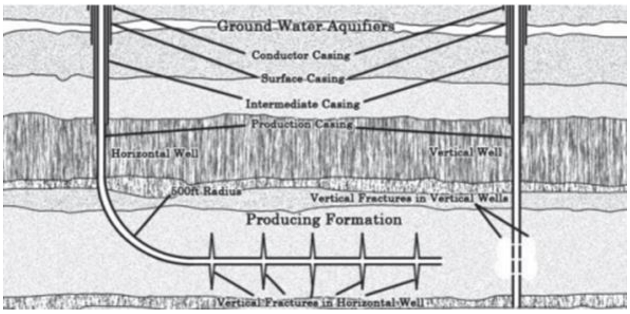

Fig. 2. Compare the fracturing for vertical and horizontal well

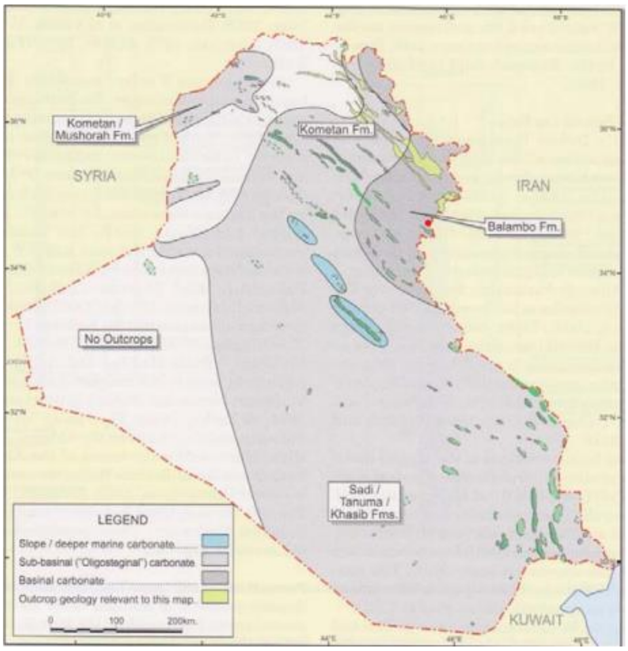

Fig. 3. Late Turonian-early Campanian palaeogeography of Iraq

Halfaya is a colossal oil field with estimated crude oil reserves of 4.1 billion barrels. The primary producing formations, characterised by carbonate and sandstone lithologies, are the Mishrif, Yamama, and Zubair reservoirs, exhibiting varying permeability and porosity conditions [12-19].

The field development plan stipulates vertical and horizontal drilling in conjunction with hydraulic fracturing in designated regions to enhance recovery. The intricate reservoir dynamics of Halfaya, particularly in the deeper, low-permeability regions, render the selection of well design and stimulation techniques essential [19-25].

This study seeks to identify the optimal fracturing strategy for the specific geological and petrophysical characteristics of the Halfaya formations by focusing on representative well models from the field to simulate and evaluate the performance of vertical and horizontal wells utilising Pipesim [26].

2- Methodology

This study evaluates and compares hydraulic fracturing in a vertical well HF002 and a horizontal well HF007 in the Halfaya oil field with Pipesim, a well performance modeling tool developed by Schlumberger.

The methodology adheres to the following phases:

A. Data acquisition and reservoir characterization

Reservoir data obtained from publicly available sources regarding the Halfaya Field, together with field reports:
Pressure and temperature gradients; porosity and permeability metrics.

Oil viscosity, gas-oil ratio (GOR), and formation volume factor (Bo) are classified as fluid characteristics.
Typical fracture half-length, breadth, and conductivity constitute assumptions regarding fracture geometry.

B. Construction of pipesim's model

Two comprehensive models were developed Single-stage fracturing in a vertical well; multi-stage fracturing in a horizontal well; pipesim simulated flow performance by utilising data on well completions, reservoir parameters, and fracture characteristics. In sensitivity analysis, fracture parameters -length, width, and quantity- were modified to evaluate their impact on well production.

C. Simulation scenarios

Multiple simulation scenarios were conducted utilising various.

- Fracture length (e.g., 50 meters to 300 meters)
- fracture width (0.5 cm to 2 cm)
- Single vs. 5–10 stage fracture count
- permeability and porosity to reflect reservoir heterogeneity

Under identical settings, each scenario was executed both vertically and horizontally.

D. Performance metrics

Key performance metrics were evaluated, including: Pressure drawdown and flow efficiency; oil production rate (STB/day).

E. Examination and contrast

The findings were compared under various fracture and reservoir situations to evaluate the effectiveness of each kind of well. The influence of reservoir characteristics and fracture geometry on production outcomes was illustrated using graphs and tables [27].

3- Results and discussion

3.1. Effect length of the fracture

The performance curves of the horizontal well in Fig. 4 and the vertical well in Fig. 5 were studied at different hydraulic fracture lengths (XF). The performance of the horizontal well is shown first, followed by the vertical well. Increasing the fracture length in a horizontal well results in a significant improvement in production performance.

This is demonstrated by increased fluid flow rates from the reservoir to the reservoir at certain system outlet pressures. Especially at increasing flow rates, the performance difference between wells becomes more obvious as the fracture length rises from 164.04 feet to 4921.3 feet. Longer fracture lengths clearly help horizontal wells, particularly in low-permeability deposits.

The patterns for the vertical well are somewhat different. Although growing fracture length increases production rates, the variations across cases are less noticeable than in the horizontal well.

Furthermore, the tendency of the curves to flatten out at larger fracture lengths points to declining returns beyond a given length. For example, the performance increase between XF=4921.3ft and XF = 3280.84ft is really small.

These results imply that, especially in reservoirs with large lateral extents, horizontal wells may be more efficient in maximising production and more sensitive to changes in fracture length. By contrast, vertical wells clearly enhance only up to a specific fracture length; after that, the additional advantage decreases.

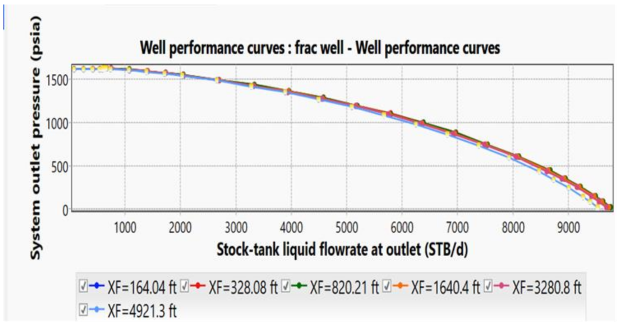

Fig. 4. Effect of fracture length on productivity in horizontal well

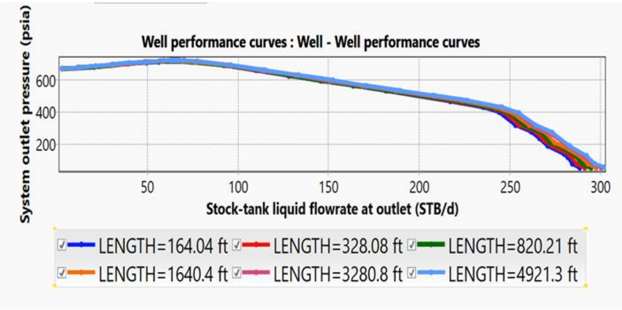

Fig. 5. Effect of fracture length on productivity in vertical well

3.2. Effect width of the fracture

In Fig. 6, the curves show that the hydraulic performance of the well clearly improves with a widening of the crack. The well with the largest fracture keeps a greater outlet pressure at a given flow rate, so reflecting lower pressure losses and better formation conductivity. Still, given what can be accomplished in horizontal wells -especially at greater flow rates- the total impact is really small.

In Fig. 7, three different fracture widths ranging from 3.937 inches to 31.49606 inches were evaluated, showing the performance curves of a horizontal well drilled in a low permeability reservoir. As fracture width rises, the curves flatten and stretch farther, signifying notable production performance gain. The study shows that improving the output of horizontal wells directly and critically depends on the width of fractures.

Larger widths—e.g., 19.68504 and 31.49606 inches—cause notable improvements in flow rates while retaining high outlet pressures, therefore indicating improved connectivity between the formation and the wellbore, and more effective drainage. Although the width of fractures influences both well types, the impact is much more in horizontal wells.

This is ascribed to the horizontal section's longer lateral length, which magnificuates the effect of fragmentation by so increasing the contact area with the reservoir. Designing fractures with enough breadth in horizontal wells is clearly a key factor in maximising production performance compared to vertical wells, which remain more constrained in reservoir contact even after stimulation.

Thus, with regard to increasing fracture width to attain maximum hydraulic and economic efficiency, field applications should give optimal fracture designs in horizontal completions first priority.

3.3. Effect of fracture permeability

The figures below show the performance curves. The results reveal a fundamental variation in the response of each well type to permeability changes in the case of a vertical well in Fig. 8; moderate improvement in performance results from higher permeability. Variations in the performance curves become evident mostly at higher flow rates (over 250 STB/d), where the system outlet pressure starts to decline rapidly. Particularly at low to moderate permeability values, this behavior is ascribed to the limited contact area between the wellbore and the reservoir in vertical wells, therefore limiting the efficient use of rock features.

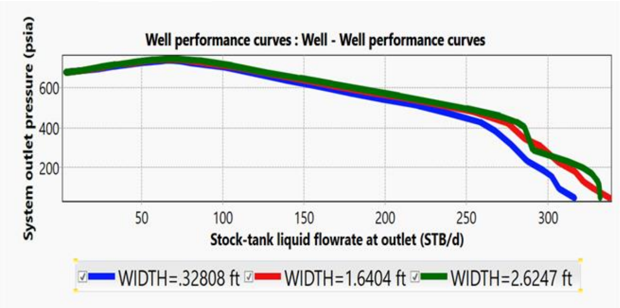

Fig. 6. Effect of fracture width on productivity in vertical well

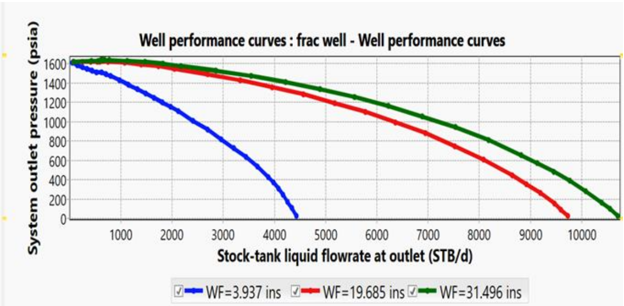

Fig. 7. Effect of fracture width on productivity in horizontal well

By comparison, the effect of permeability on the horizontal well in Fig. 9 is much more evident.

The performance curves, even at smaller flow rates, differ greatly from one another; as permeability rises, the productivity grows in a practically exponential way.

Comparatively to less than 2000 STB/d at 50 Md, production rates at 1000 Md exceed 9000 STB/d.

Furthermore, the pressure drop at the wellhead reflects the improved drainage efficiency made possible by horizontal wells because of their extended contact with the reservoir. Permeability increases this process more gradually.

This comparison emphasises that although permeability is a fundamental factor influencing well performance in both circumstances, its impact is rather more effective in horizontal wells. Particularly in high-permeability formations, this is a result of horizontal wells' increased lateral exposure to the reservoir, which increases drainage efficiency and greatly raises production.

3.4. Effect of the number of fractures

Fig. 10 shows the fluid flow rate from the primary reservoir to the outlet (STB/d) and the system outlet pressure (psia) in a hydraulically fractured horizontal well, and the relationship between them. The findings demonstrate a distinct influence of the quantity of hydraulic fractures (NF) on well performance . At low NF values (e.g., 10), a pronounced decline in outlet pressure occurs with rising flow rate, signifying suboptimal production performance.

As the quantity of hydraulic cracks escalates to elevated levels (e.g., 2000), performance markedly enhances, exhibiting a diminished decline in pressure at elevated flow rates.

This enhancement is due to the augmented surface area exposed to flow within the hydraulic fracture zone, which diminishes hydraulic resistance and facilitates improved output.

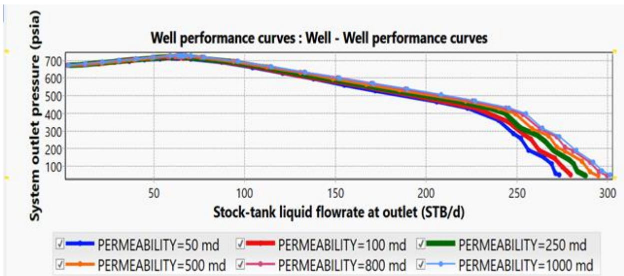

Fig. 8. Effect of fracture permeability on productivity in vertical well

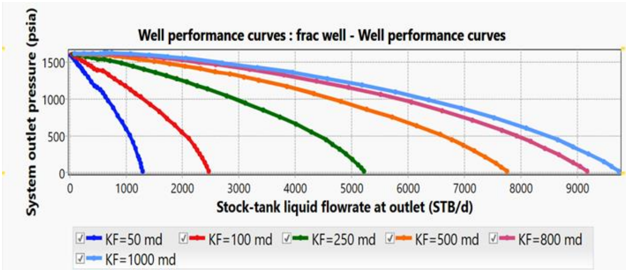

Fig. 9. Effect of fracture permeability on productivity in horizontal well

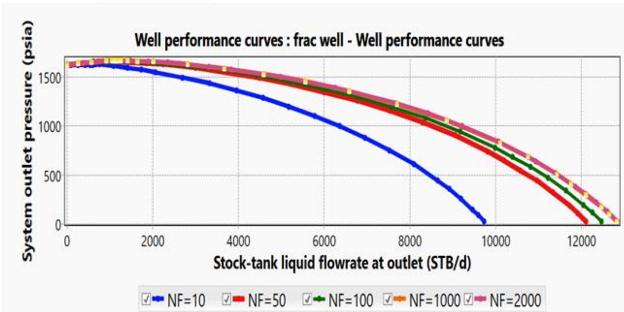

Fig. 10. Effect of the number of fractures on productivity in horizontal well

While the pipeSim software lacks the capability to assess the impact of hydraulic fracture quantity in a vertical well, this can be inferred from the flow characteristics inherent to both well types.

The horizontal well features an extensive horizontal reach that increases the probability of efficient interaction with hydrocarbon-bearing strata. Consequently, augmenting the quantity of hydraulic fractures leads to a significant enhancement in production.

Conversely, fluid movement in a vertical well predominantly occurs radially towards the wellbore.

Consequently, generating a substantial quantity of hydraulic cracks in this instance does not markedly improve performance. The lack of activation of this option in pipesim may be attributed to the comparatively little influence it has compared to horizontal wells, where the radial flow characteristics reduce the efficacy of many fractures.

4- Conclusion

- Horizontal wells provide greater performance compared to vertical wells in low-permeability reservoirs due to their enhanced reservoir contact and the prolonged impact of the fracture network.
- In horizontal wells, fracture length is a critical factor in the linkage between the well and the reservoir, hence affecting output. Its influence in vertical wells is relatively limited.
- Although its effect was much more evident in horizontal wells, where bigger fractures improved flow conductivity across a greater contact area, Fracture width had a considerable positive influence on flow capacity in both well types. The hydraulic fracturing operation is heavily reliant on fracture permeability. Significantly, elevated fracture permeability enhances the flow capacity of fractures; still, horizontal wells are more advantageous due to their extensive fracture network.
- The flow performance was much influenced by formation permeability. In tight or low-permeability reservoirs, horizontal wells proved greater sensitivity to permeability changes, hence more effective.
- The quantity of fractures significantly influences horizontal wells by enhancing production and flow distribution.
- The option for hydraulic fractures is not available in a vertical well. This is due to the fact that vertical wells generally depend on establishing singular, vertical conduits to the productive strata. As the fracture predominantly occurs along the longitudinal axis of the vertical well, the introduction of multiple fractures in this well type is unadvantageous.

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التقييم المقارن لأداء التكسير الهيدروليكي في الآبار الرأسية والأفقية باستخدام برنامج Pipesim

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الخلاصة

تستخدم هذه الورقة البحثية برنامج Pipesim لإعادة إنتاج وتقييم أداء الآبار، بمقارنة الآبار الرأسية والأفقية المستخدمة عمليات التكسير الهيدروليكي. تدرس هذه الدراسة تأثير المعايير الرئيسية، مثل طول الكسر وعرضه ونفاذية وعدد الكسور، على تحسين الإنتاج. في المكامن منخفضة النفاذية، تشير دراسات المحاكاة إلى أن الآبار الأفقية غالبًا ما تحقق معدلات إنتاج أعلى مقارنةً بالآبار الرأسية، ويعود ذلك في الغالب إلى تحسين اتصال المكمن وتحسين اتصال الكسور.حيث ازدادت الانتاجية في البئر العمودي الى300 (stb/d) بينما في البئر الافقي الى اكثر من 9000 (stb/d) بعد استخدام الكسور الهايدروليكية. تشير النتائج إلى أن عرض الكسر يؤثر بشكل أقل على أداء الآبار الرأسية مقارنةً بالآبار الأفقية، على الرغم من أن طول الكسر وعدد الكسور يؤثران بشكل كبير على إنتاجية الآبار الأفقية. يؤكد هذا التفاوت على ضرورة تصميم الكسور واختيار الآبار استراتيجيًا لتحسين إنتاج النفط في ظل ظروف المكمن المتغيرة. تؤكد الورقة البحثية على ضرورة استخدام أدوات نمذجة متطورة مثل Pipesim للتنبؤ الدقيق بأداء الآبار وتوجيه عملية صنع القرار في عمليات التكسير الهيدروليكي. يمكن لتقنيات التكسير المصممة خصيصًا والمستندة إلى خصائص المكمن أن تعزز بشكل كبير كفاءة الإنتاج المستمر وإطالة عمر الآبار.

الكلمات الدالة: حقل حلفايا النفطي، التكسير الهيدروليكي، الآبار الأفقية، الآبار العمودية.