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Analytical and descriptive study of the production behavior for pilot multi-stages hydraulic fracturing wells in southeast Iraq

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Abstract

The hydraulic fracturing technique is a widely used technique worldwide, making it interesting to study. This technique was applied for the first time in Iraq on a tight carbonate reservoir in the Halfaya oil field. In this field, the oil production rates, and flowing pressure were low during production periods reflecting a problem for the development plan designed to increase production using a hydraulic fracture technique. Initially, the hydraulic fracture well showed high oil-producing rates, but then, quickly experienced a high decline failing to keep a stable production rate. To address this problem, it is important to describe and analyze the behavior of pilot hydraulic fracturing wells during their production period, study the inflow performance relationship (IPR), and determine the optimum wellhead pressure above the bubble point pressure (Pb) to avoid loss of lifting energy. Furthermore, it identifies the allowable flow rate to keep stable production, investigates the effect of selecting internal tubing size, and reveals a future production procedure for hydraulic fracture wells.

This study reveals that the transient inflow performance relationship observed in the production history of hydraulic fracture well in the tight carbonate reservoir and traditional inflow performance relationship concepts are not applicable. The optimum wellhead pressure for stability in production for Wells w-5 and w-55 is determined to be 750 and 580 psi with optimum rates of 800 and 450 Bbl/D, respectively. The results also showed that producing at a high flow rate may cause a depletion in the fracture potential storage without giving an opportunity for a reservoir to compensate for the produced fluid into fracturing potential storage. The internal tubing size has a passive effect on the hydraulic fracture well, as an increase in size causes an unstable flow zone. Lastly, future production procedures emphasize keeping wellhead pressures stable or increasing them if they drop. This can be accomplished by re-adjusting the choke size according to any changes observed.

Keywords: Hydraulic fracture optimization; nodal analysis; tight reservoir.

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1- Introduction

The first hydraulic fracture technique applied two pilot wells (W-5 and W-6) to develop the reservoir production on one of the Halfaya formations of the Sadi formation, which is considered a giant limestone reservoir, it is located in Missan province in southeast Iraq, about 35 km away from Amara City, the capital of Missan Province. The initial oil in place of the Sadi reservoir is about 25% of the total Halfaya oilfield [1], second only to the main Mishrif reservoir, Halfaya oil field is generally an NW-SE long axis anticline, about 35 km long and 8 ~ 9 km wide. The Sadi formation is divided into three layers: B1, B2, and B3, the anticline structure is complete, and the dip angle of the two wings of the central part is 2~3 °.

However, the severe tightness of the Sadi reservoir with its low porosity and low permeability leads to low production from the Sadi formation. The Halfaya oil field met the peak output objective; the contractor company in the field is required to sustain peak production according to the contract. On this basis, significant challenges must also be dealt with for their successful development, especially the Sadi formation considered a second reserve of the Halfaya oilfield. The first pilot hydraulic fracture research was conducted on a first pilot hydraulic vertical well in southern Iraq in December 2016, followed by the first pilot horizontal hydraulic fracture well in Iraq with a multi-stage (eight stages) fracture in December 2019, all with the goal of improving well productivity and investigating the overall production mode of the Sadi reservoir. Generally, natural wells in the Sadi formation are produced with a fluctuating low flow rate and shut-in for pressure build-up from time to time due to no flow. Also, production rates drop quickly in hydraulically fractured wells, which is the main problem that needs to be solved.

There were several studies on unconventional reservoirs after they suffered from rapid pressure drops, and its relevant issues after trying to develop tight oil reservoirs utilizing the hydraulic fracture urgently, the behavior of tight oil reservoirs throughout the transient linear flow period [2], as reservoir pressure drops below the bubble point could a two-phase flow develops due to oil production combined with high-pressure drawdowns. The main consideration study in the flow of fluids in an

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unconventional formation is that the extremely low permeability of the formation results in a transient pressure response [3], it takes a long time before the pseudo-steady state, or entering the fracture interference period, begins. In addition, the findings of the studies conducted on the Cardium formation (tight reservoir) [4] have revealed a sharp drop in pressure alongside primary depletion in fully developed fields. An intensive analysis of the effects of drainage areas [5] on production performance, concluded that a multifracture horizontal well has flow rates many times higher than a vertical fracture well, making it the only decision in exact tight formation. permeability has the biggest impact on the depth of investigation (compared to viscosity and

Porosity. Some of proposed model of hydraulic fracturing wells [6-11] can predict and analyse the production performance of reservoirs hydrocarbons, the optimizing of hydraulic fracture reveal that the transient production-index [12] as a tool for assessing producing data and discussed its application to hydro-fractured horizontal wells in shale reservoirs result that the transient productivity index can be utilized to study production reduction for hydraulically cracked horizontal wells in rigid formations with worldwide or local natural crack networks, transient inflow performance relationship correlation [13] for multistage fracturing horizontal wells in a tight oil reservoir, obtained a real average reservoir pressure changing with the production history, in the southeast of Iraq [14] used simulator software through tight reservoirs properties discovered the best increase in oil production is achieved that eight and ten fracture phases are optimal, after which the output surge starts to diminish. An analytical solution [15] was obtained for the trilinear flow model developed [16]. Fracture, inner reservoir matrix, and outer reservoir matrix are the three important components of the trilinear flow model, which describes how fluid enters the wellbore from the reservoir. A case study [17] was conducted to analyze the efficiency of hydraulic fracturing in exploratory wells in Hanoi, Vietnam. The study focused on examining the reservoir and production output after the most recent fracture treatment, with special attention to the treatment's effects.

Rapid production decreases are a potential issue in tight reservoirs; thus, considering this is crucial when planning for the future of this resource, based on a semi-analytical simulation of productivity index (PI) fluctuations [18] in producing wells from unconventional formations developed. one of developed a technique [19] to maximize net present value for produced oil depending on well flow rates over the reservoir's lifetime using a fully implicit and three dimensions black-oil simulator to get the advancing solution, maximizing plateau production (plateau length) may not always result in the optimum economics over the lifetime of a field. A good model-field productivity indices match makes production estimates considering reservoir heterogeneities like hydraulic or natural cracks possible. explained that the fracture properties could change [20] during the reservoir operation owing to fluid pressure changes, thermal cooling, and precipitation of minerals and decreased pressure during fluid extraction from the reservoir can cause fractures to close. Wentao et al., proposed a new nodal-analysis method that involved using an IPR model generated from a semi-analytical reservoir simulator. A straightforward method [22] to develop IPR curves for solution gas-drive reservoirs for two or three-phase flow at any level of depletion or at any time from the output of a Black-Oil reservoir simulator.

The results obtained :

a. A straightforward automated process to produce IPR curves from the output of reservoir simulators.
b. An optimization process that considers the current values of each production parameter and it is possible to visualize dynamic IPR curves that change with depletion.

Most of the well's productive life is linear [15] under these conditions and the well's productivity rises as fracture spacing reduces, but incremental gains for each additional fracture decline. described two fundamental factors that must be considered during optimization [23]. First, it explains how parameter uncertainty is quantified when optimizing the production model to fit data with little information content. Furthermore, it suggested how production models that are simple to solve and fit production data can be selected using system identification. evaluated statistically the pressure calculation method [24] statistically based on well-test data for every component of the production system.

Through a well model, the inflow performance relationship (IPR) was established by correlating production data from previous wells using [25] Vogel imperial solution for multi-fractured horizontal and vertical fracture wells. Elias et al., discovered a novel model for predicting the IPR curve that was developed using a correlation that adequately describes oil mobility's behavior as a function of average reservoir pressure

It is difficult to stabilize the reading of wellhead pressure by adjusting a specific choke because of the rapid depletion of flowing pressure; thus, it is important to produce by identifying the optimum wellhead pressure above bubble point pressure. Also, finding suitable flow rates to avoid high depletion rates and advising for next development wells. A different investigative approach to studying how to reduce pressure loss in the production system will be discussed next.

2- Study methods

In this study, both descriptive and analytical methodologies were put into play in the process of this investigation on both wells (W-5 and W-6) to get more details of the production behavior, do proper production rates, and apply in future development wells (more than sex hydraulic fracturing wells was implemented till 2022). Obtaining the validity of the IPR behavior in the Sadi formation after drilling the pilot hydraulic fracture wells when production history was available by using a well-defined productivity index (PI) [27] entry with a straightline inflow model used above the bubble point based on the equation shown:

$$PI = \frac{Q}{Pi - Pwf} \quad (1)$$

Where the PI is a productivity index (bbl per day\psi), Q is a flow rate (bbl per day), Pi is initial reservoir pressure (Psi), and Pwf is wellbore flowing pressure (Psi). Whereas the Vogel empirical solution [28] used below the bubble point pressure:

$$\frac{Q}{Qmax} = 1 - 0.2\frac{Pwf}{Pr} - 0.8\left(\frac{Pwf}{Pr}\right)^2 \quad (2)$$

Where Q_{max} is the maximum flow rate (bbl per day), Q is a flow rate (bbl per day), Pr is reservoir pressure (Psi), and Pwf is wellbore flowing (Psi). Both equations are used to determine the IPR using the well model. Furthermore, it concentrated on determining the pressure above the bubble point pressure [29] to avoid gas evolution within the reservoir and recognizing the allowable rate of hydraulic fracture from periods with slight depletion. Also, comparing the calculated Pwf history from production history with the flowing gradient survey and determining whether there are any matches between calculated and measured knowing that a well's production could be improved using a selected internal diameter completion.

Describe the production of the pilot hydraulic fracture wells and analysis of the IPR behavior and internal tubing sized effects suggestion was utilized as the following scenarios through well production life to:

Scenario 1: understand the events and status of wells by showing the well production history.

Scenario 2: Calculate bottom-hole pressure history via well model and compare it with the measured flowing gradient survey also conducted bubble point pressure with the red line.

Scenario 3: Calculated inflow performance relationship for each measured flowing gradient survey and conducted the optimum wellhead pressure that verified production rate above the bubble point pressure.

Scenario 4: Study tubing size selection scenarios of the hydraulic fracture well to check their effects on production behavior via using the Internal Single tubes 2.441, 2.992, 3.340, and 3.92 inches.

3- Data acquisition

The type of data collected is strictly secondary[30]; the data was measured and provided via the owner company [30] of the field, as mentioned in Table 1. It was collected from the Sadi formation in October 2012.

Table 1. The PVT Data of Sadi Formation[31]

Reservoir Temperature, °C	87
Initial Reservoir pressure, psia	4846
Pb, psia	3125
GOR, SCF/ STB	868
Bo @ Res. Pressure, Bbl/STB	1.418
Bo @ Pb, Bbl/ STB	1.438
Tank Gravity API°	27
Viscosity @ Res. Pressure, CP	0.818
Viscosity @ Pb, CP	0.73
H_2S, ppm	0
N_2, mole%	0.82
CO_2, mole%	1.91
Gas gravity (Air=1)	0.843

4- Production optimization results

The stabilizing flow rate corresponding to bottom-hole pressure is determined [32] by the intersection of the inflow performance relationship and the vertical lift relationship. When there is a continuous flow between the reservoir and the tubing string, a stabilized flow rate is reached; however, in a tight reservoir, the stabilized flow occurs for a short period, which is due to continuous depletion around the wellbore. This study's empirical method was to find IPR using the productivity index entry as mentioned in equations 1 and 2, and the reason behind it was the changing productivity index during the elapsed time.

- Scenario 1 of W-55

The production period of the W-55 showed an average production averaged 150 BOPD before implementing the hydraulic fracture in December 2016, as illustrated in Fig. 1. On the other hand, the flow rate improved after doing a hydraulic fracture starting producing as in Fig. 2, with 818 BOPD with choke size 27/64" in 25-December-2016, but when the choke changed to 20/64" on 4-January-2017, flow rate dropped to 300 BOPD inner in the unstable flow, then choke up to 30/64" gradually giving 883 BOPD with a faster drop in tubing head pressure (THP) from 1140 Psi to 730 Psi then for optimizing pressure drop, the choke decrease till 24/64" with THP about 650 Psi, Although the choke decreases to stabilize the THP, the pressure still drops due to the fracture potential depletion, which means the Sadi formation cannot help with the fluid gain at a high rate.

As a result of proppant exit during production, which leads to a strict flow path through the choke, THP starts increasing with an average rate of 440 BOPD at the end of the first quarter of 2018, so that an internal choke inspection is done before increasing the choke to 32/64" to optimize the well .

On the contrary, THP dropped from 800 psi to 400 psi with a rate starting at 616 BOPD and continuing with an average rate of 450 BOPD until the end of 2021.

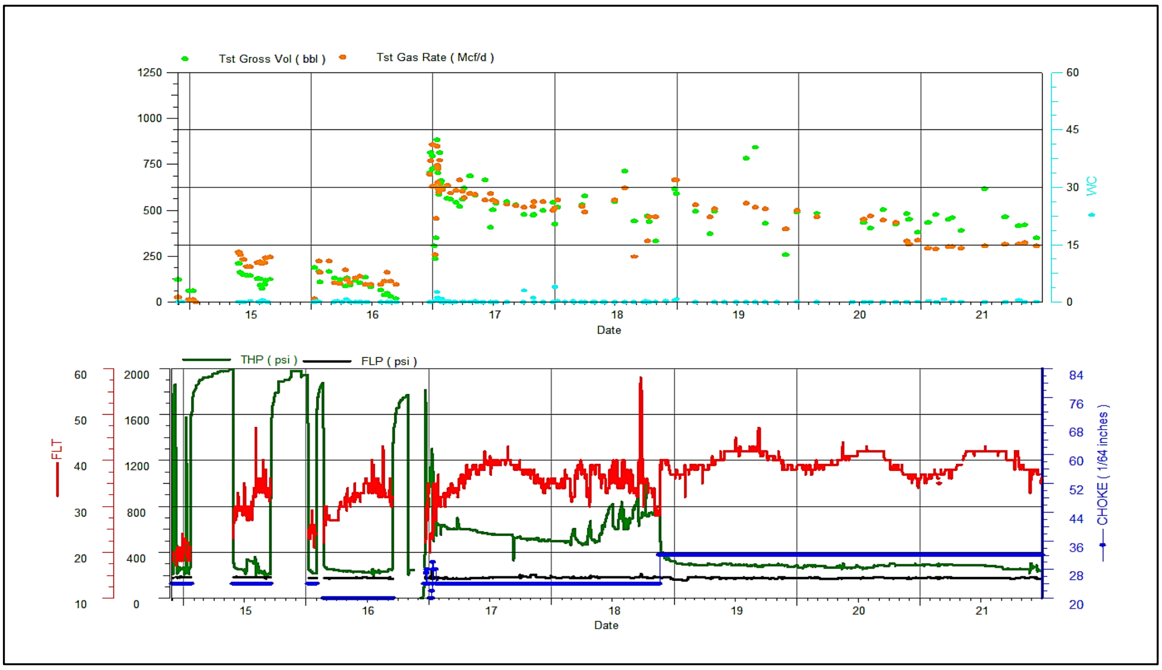

Fig. 1. Daily Well Performance of Well-55

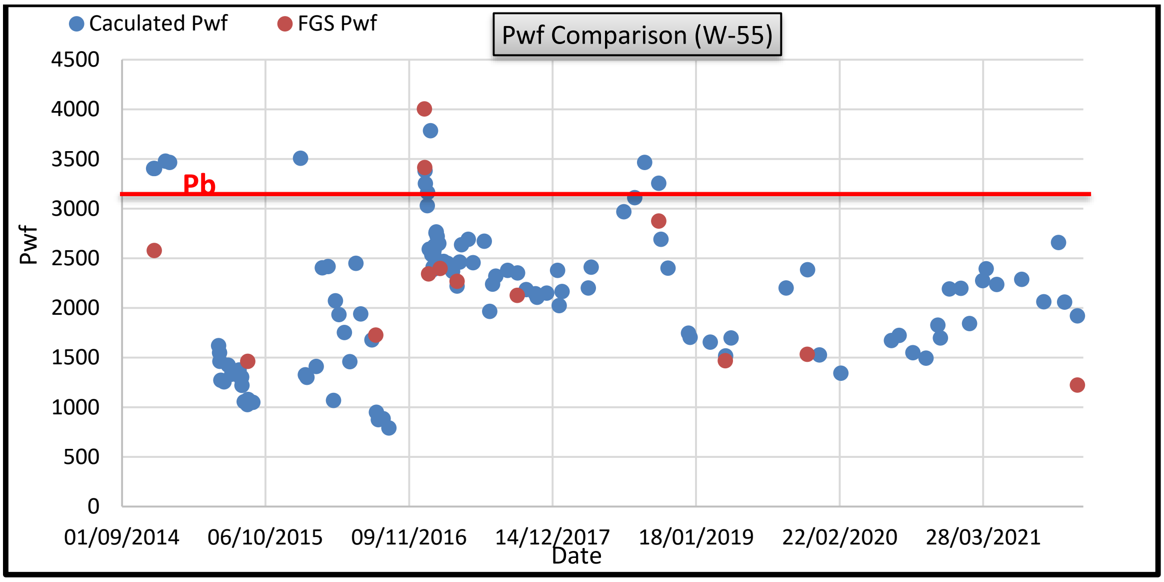

Fig. 2. The FGS Measurement and Calculated Pwf

- Scenario 2 of W-55

The historical Pwf of a well (W-55) before and after hydraulic fracture in December 2016 shows that FGS and calculated Pwf are in good agreement. Even after hydraulic fracture, the majority of PWF is below Pb.

- Scenario 3 of W-55

More specifically, IPR before hydraulic fracture is 0.0454 BOPD/Psi, considered too low. In contrast, IPR after a hydraulic fracture was 1.47 BOPD/Psi in December 2016; it did not last long, therefore, decreasing to reach 0.28 BOPD/Psi in February 2017, then reaching 0.228 BOPD/Psi in March 2017, and finally, IPR is 0.136 BOPD/Psi in April-2019. The observed inflow-performance relationship behavior is similar to the transient behavior of a vertical hydraulic fracture.

The optimum pressure above Pb across IPR in 4-Feberory-2017 can approved with a wellhead pressure of 580 psi, oil rate less 460BOPD, and less than 350BOPD in 23-March-2017 as shown in Fig. 3.

These rates are measured in a separator test on the surface and re-adjust the choke size is to hit these target rates because it is definitely too difficult in hydraulic fracture to sustain it with stable status.

More pressure that is flowing below bubble point pressure, and must be used with caution. Setting the choke size on one set is insufficient to stabilize the well; therefore, it must be re-adjusted frequently to keep the wellhead pressure in a stable or increasing mode while considering the economic producing rates.

- Scenario 4 of W-55

The suggested internal tubing sizes in well W-55 are implemented with THP equal to 640 Psi from the measured depth of 2673 m across all IPR as illustrated in Fig. 4. Overall, increasing internal tubing size in vertical hydraulic fracture, which causes an increase in liquid loading in the tubing string, so the best selection of 2.92-inch size selected by the owner company of the oilfield.

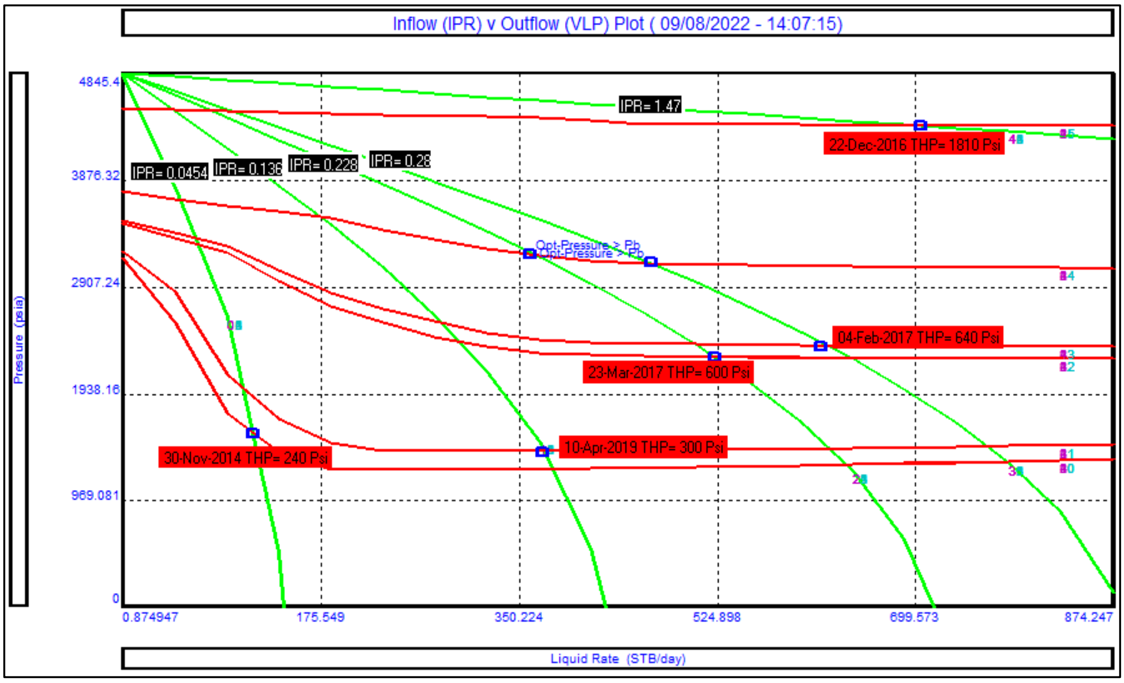

Fig. 3. IPR During Flowing Gradient Survey

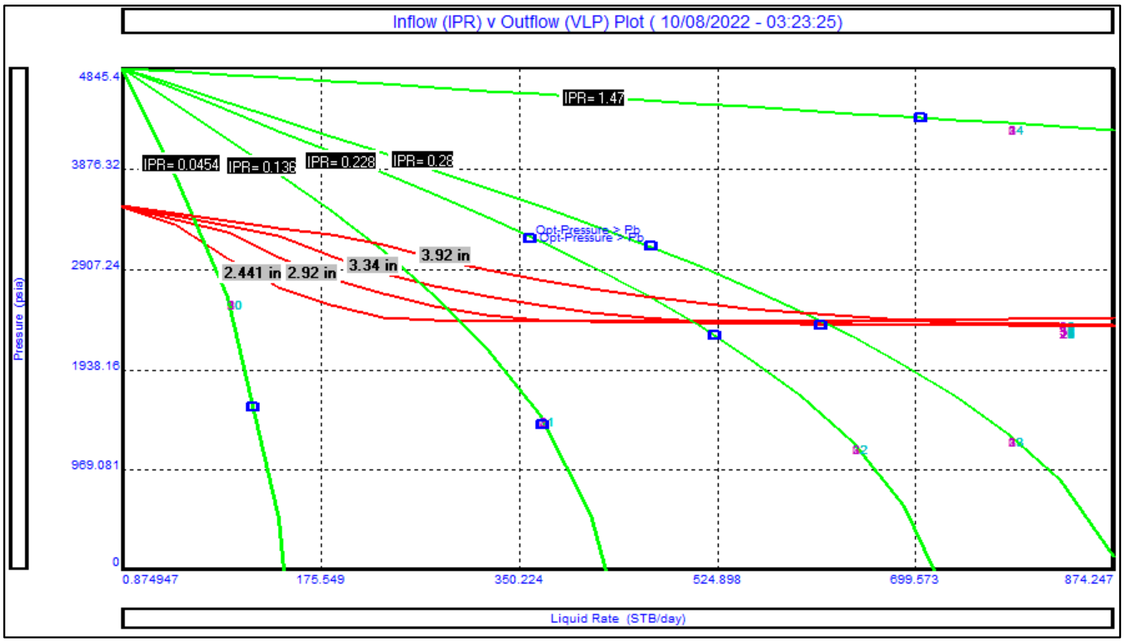

Fig. 4. Internal Tubing Size Suggestion

- Scenario 1 of W-5

The first successful pilot hydraulic fracturing well with eight stages in Iraq is W-5, which is considered the most important well perforated in the Sadi formation. The operator company of the oil field set a target plateau rate of 1500 BOPD to begin production. Fig. 5, depicts a multi-choke change to keep the plateau rate as constant as possible. When production reaches a plateau, it cannot sustain this rate due to continuously flowing pressure depletion and the reservoir support cannot provide this rate, but the fluid initially provided from fractured capacity did not compensate at the same rate as gaining, so production and pressure fall rapidly.

The following finding of W-5:

- The plateau rate of 1500 BOPD is above the provided rate from the reservoir.
- The wellhead pressure begins to rise as the choke decreases from 30/64" to 24/64" on 27 January 2020, but the rate of 315 BOPD inner is unstable; thus, the choke increases to 28/64" on 31- January 2020, giving a flow rate of 1045 BOPD. The pressure stabilized at 935 psi, after seventeen days the oil rate is 732 BOPD, and accordingly, the choke increases to 32/64" to meet the plateau rate. The rate becomes about 1650 BOPD, but the pressure decreases so fast, which leads to understanding why the plateau rate is not preferable.
- The capacity of the fracture increased during the shut-in period from 8 February 2021 to 29 March 2021, about 49 days of shut-in for a static gradient survey. The shut-in wellhead pressure started to increase up to 1010 psi. Unless it reopens on 30 March 2021, wellhead progress is increasing.

- Scenario 2 of W-5

The calculated bottom-hole pressure through the well model and the FGS pressure were nearly identical, as shown in Fig. 6. The Pwf started to decrease fast when the production started, and the reason was a decrease in the pressure support from the tight oil reservoir, so the Pwf of W-5 begins below Pb in some periods at the first FGS reading, which means free gas also started producing inside the reservoir. It is clear after the shut-in from period 8-February-2021 to 29-March-2021 that the Pwf had supported and was trying to recover the lake in fracture potential after depleted.

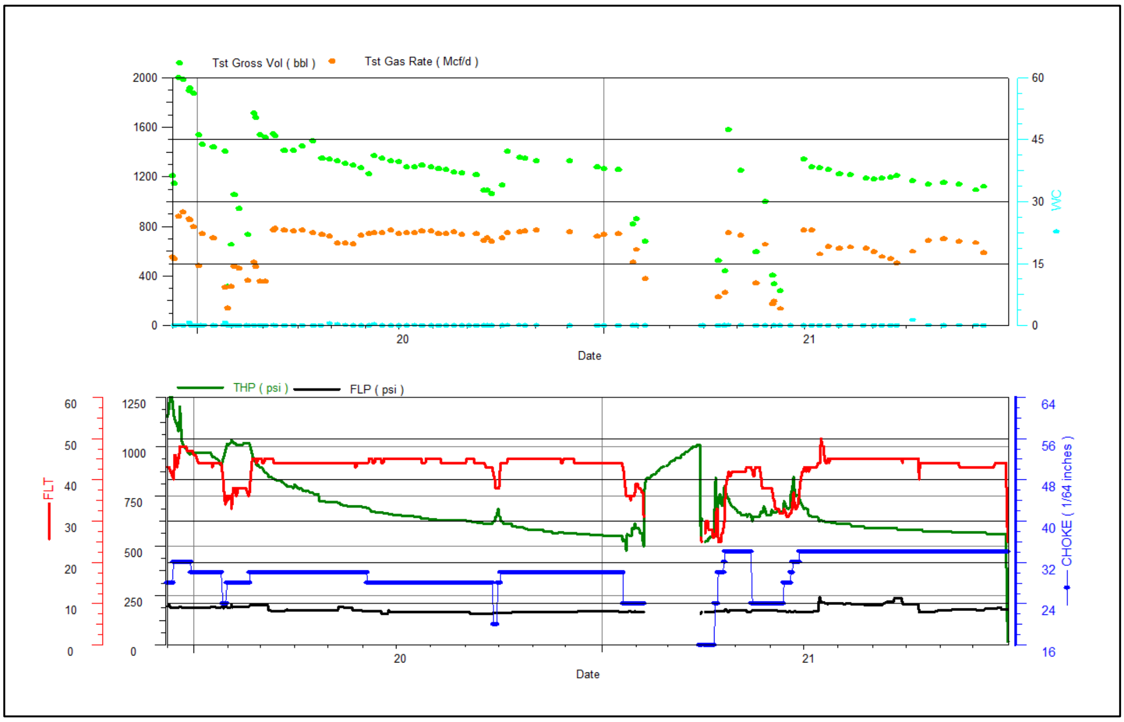

Fig. 5. Daily Well Performance of Well-5

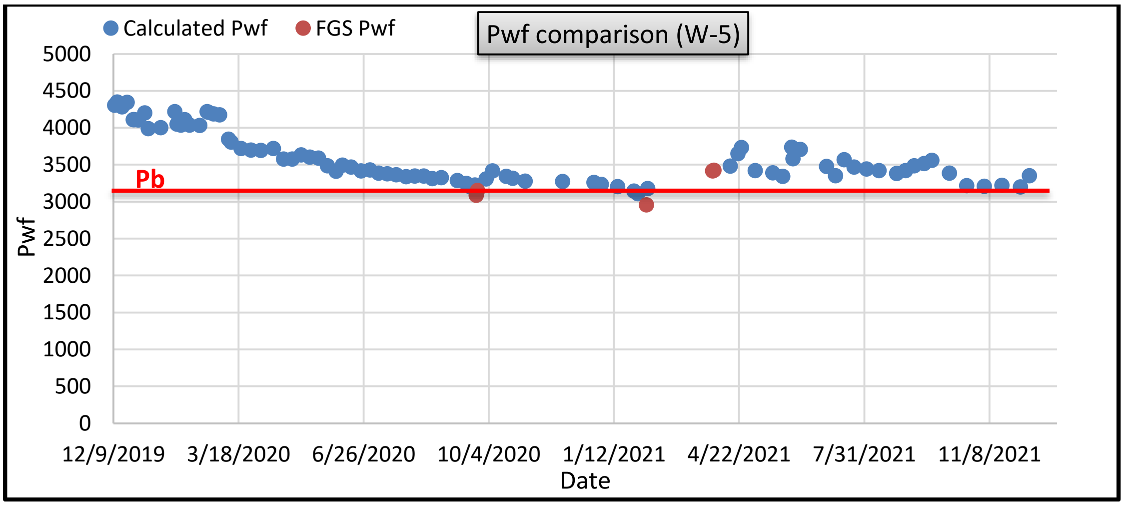

Fig. 6. The FGS Measurement and Calculated Pwf

- Scenario 3 of W-5

The first FGS implemented on 24-Septamber-2020 gave an IPR of 0.549 BOPD/psi with the tubing correlation conducted by Biggs and Brill, this is not the maximum IPR since it is considered a late FGS implemented after 290 days from the start of the commission.

Then the second FGS on 7-February-2021 gave an IPR equal to 0.322 BOPD/psi, resulting in a transient IPR drop with elapsed time as shown in Fig. 7. The FGS on 1-April-2021 set in an unstable flow zone where the choke size was 16/64" which means the choke size on 16/64" is not preferable.

The optimum wellhead pressure that achieves Pwf above Pb is 750 psi to cross the IPR of 0.549 BOPD/psi with an oil rate equal to 925 BOPD and an oil rate of 550 BOPD to cross the IPR of 0.322 BOPD/psi. Producing with pressure above this reading is allowable, or the THP can reach the optimum value with close monitoring to avoid the optimum wellhead pressure decreasing over it by adjusting the choke size every time due to the continuous depletion of pressure around the wellbore. Sufficient shut-in time to achieve recharging and reproducing at optimum wellhead pressure.

- Scenario 4 of W-5

Conducting the best internal tubing size test for horizontal hydraulic fracture wells is very important. W-5 consists of two tubes, first extended from the surface to 2560 m-MD with 2.992 inches, then joined with 3.92 inches till 3724 m-MD. Therefore, after implementing different internal tubing sizes from a measured depth of 3592 m, negative effects (creeping into an unstable zone) occurred when increasing the internal tubing size for horizontal hydraulic fracture, so it is better to use their field contractor company as mentioned in Fig. 8.

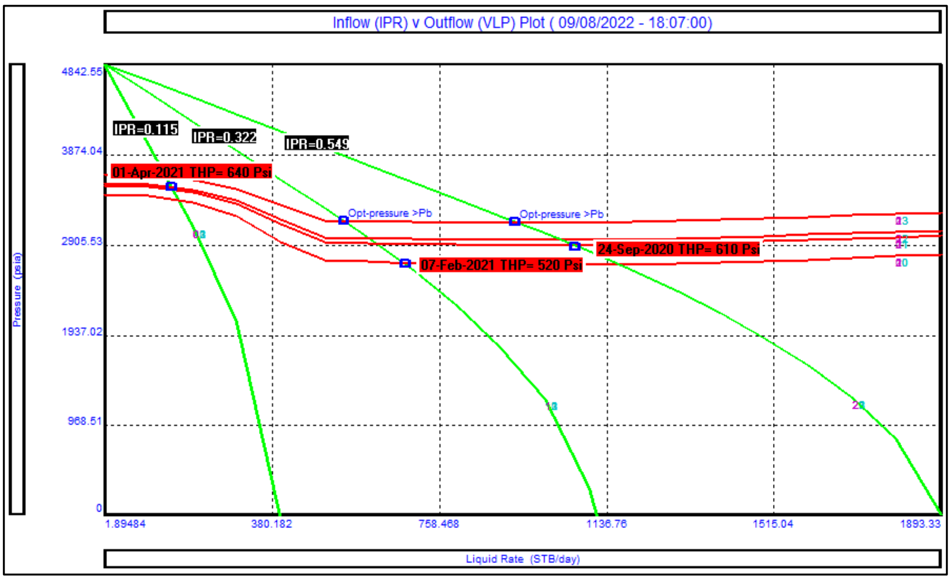

Fig. 7. IPR During Flowing Gradient Survey

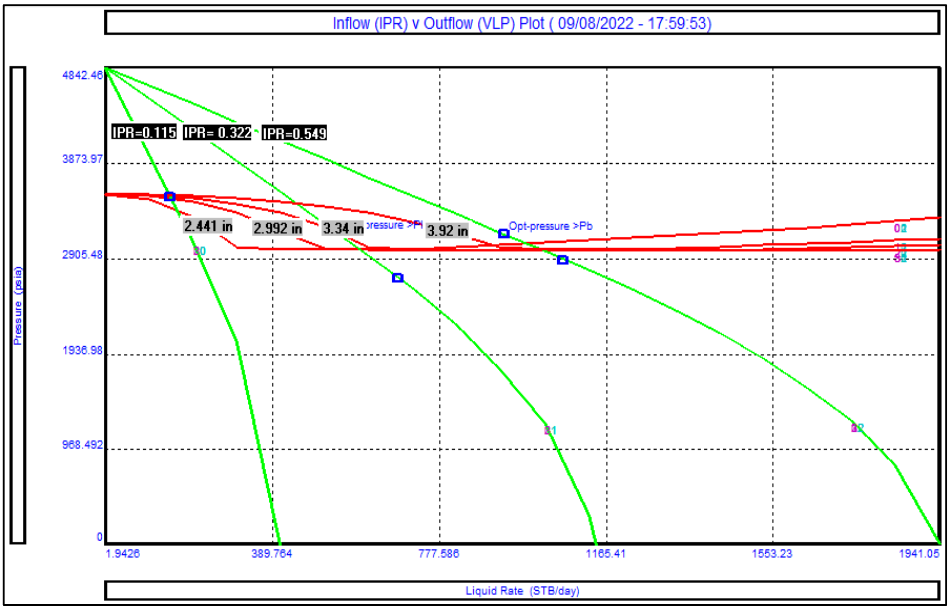

Fig. 8. Internal Tubing Size Suggestion

5- Conclusions

Studying the behavior of hydraulic fractured wells for unconventional reservoirs, which were first implemented in Iraq is critical for extending production as long as possible due to their rapid production and pressure decline. Sadi wells' similarity shows that increasing internal tubing size negatively affects stability by increasing the unstable flow. The hydraulic fracture behaviors are as follows:

Vertical hydraulic fracturing well (W-55): the good production before doing hydraulic fractural was exposed to shut-in status periodically for pressure build-up due to no flow, whereas after doing the first vertical hydraulic fracture in the Sadi formation started producing with 818 BOPD then rapidly declined to average 450 BOPD without holding the production on high rates, in additional most production periods below Pb which led to losing the lifting energy of the reservoir drive mechanism,

Horizontal hydraulic fracturing well (W-5): start producing with a high oil rate of about 2000 BOPD above the bubble point, then start to decrease with elapsed time, it seems that producing a high liquid rate above the capability of the reservoir to compensate for the same outlet producing rate instantly from fracture storage.

The inflow performance relationship in the vertical well indicated a significant difference between the IPR before and after doing hydraulic fracturing, the IPR after doing vertical hydraulic fracturing decreased continuously with elapsed time. Also, horizontal hydraulic fracturing wells show transient inflow performance relationship state decrease with elapsed time.

Prolong the production by avoiding producing below the bubble point as long as possible can done through the key control "wellhead pressure", setting an inappropriate fixed choke size causes a continuous decrease in flowing pressure and production rates. This key control can be achieved through a well model by producing from 800 BOPD of W-5 (eight stages), also by keeping the THP of W-5 above 750 psi, while the optimum producing pressure above Pb is 580 Psi for W-55.

Finally, if depletion starts in hydraulic fracture wells, there are three keys to be considered

The production procedure in the Halfaya oil field was not perfect because of the high production rates in there concerning without forward the fracture and reservoir-producing capability, so future procedures for prolonging the production possible of the hydraulic fracture wells in such a tight carbonate reservoir can be achieved by:

a. keeping the wellhead pressure stable through monitoring it at surface reading and if it decreases then the re-adjust the choke size is essentially to hold the wellhead stabilize or make it in increasing mode while taking care of the economic production rate and avoiding producing below the bubble point.
b. Shut in the hydraulic fracture wells for enough time until the first THP shut-in can restore the original condition, and then re-open the well with the following steps (a).

Nomenclature

IPR = Inflow Performance Relationship, BOPD/ psi
VLP =Vertical Lift Performance.
PI =Productivity Index, BOPD/ psi
PVT =Pressure-Volume-Temperature
GOR = Gas-oil Ratio, bbl/scf
Pb =Bubble point, Psi
Bo =Oil formation volume factor, Bbl/ STB
BOPD =Barrel Oil per Day, Bbl/ STB
THP =Tubing Head Pressure, Psi
FLP =Flow Line Pressure, Psi
FLT =Flow Line Temperature, °C
W.C =Water Cut% ,
bbl. = barrel of oil

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دراسة تحليلية وصفية للسلوك الإنتاجي لآبار التكسير الهيدروليكي التجريبية متعددة المراحل في جنوب شرق العراق

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الخلاصة

تقنية التكسير الهيدروليكي هي من التقنيات المستخدمة على نطاق واسع في جميع أنحاء العالم، مما يجعلها تثير الانتباه للدراسة. تم تطبيق هذه التقنية لأول مرة في العراق على مكمن كربونات محكم في حقل حلفايا النفطي، كانت معدلات إنتاج النفط وضغط التدفق منخفضة خلال فترات الإنتاج مما يعكس مشكلة لخطة التطوير المصممة لزيادة الانتاج باستخدام تقنية التكسير الهيدروليكي. في البداية، أظهرت بئر التكسير الهيدروليكي معدلات إنتاج نفط عالية، ولكن بعد ذلك، شهدت بسرعة انخفاضًا كبيرًا وفشلت في الحفاظ على معدل إنتاج مستقر. لمعالجة هذه المشكلة، من المهم وصف وتحليل سلوك آبار التكسير الهيدروليكي التجريبية خلال فترة إنتاجها، ودراسة علاقة أداء التدفق (IPR)، وتحديد ضغط رأس البئر الأمثل فوق ضغط نقطة الفقاعة (Pb) لتجنب فقدان طاقة الرفع. علاوة على ذلك، تحديد معدل التدفق المسموح به للحفاظ على إنتاج مستقر، والتحقيق في تأثير اختيار حجم الأنابيب الداخلية، والكشف عن إجراء إنتاج مستقبلي لآبار التكسير الهيدروليكي.

تكشف هذه الدراسة أن علاقة أداء التدفق العابر التي لوحظت في تاريخ إنتاج بئر الكسر الهيدروليكي في خزان الكربونات الضيق ومفاهيم علاقة أداء التدفق التقليدي غير قابلة للتطبيق. تم تحديد ضغط رأس البئر الأمثل للاستقرار في الإنتاج للآبار w-5 وw-55 ليكون ٧٥٠ و ٥٨٠ رطل / بوصة مربعة بمعدلات مثالية تبلغ ٨٠٠ و ٤٥٠ برميل / يوم على التوالي. أظهرت النتائج أيضًا أن الإنتاج بمعدل تدفق مرتفع قد يتسبب في استنزاف في تخزين إمكانات الكسر دون إعطاء فرصة للخزان لتعويض السائل المنتج في تخزين إمكانات الكسر. حجم الأنابيب الداخلية له تأثير سلبي على بئر الكسر الهيدروليكي، حيث يؤدي زيادة الحجم إلى منطقة تدفق غير مستقرة. أخيرًا، تؤكد إجراءات الإنتاج المستقبلية على الحفاظ على ضغوط رأس البئر المستقرة أو زيادتها إذا انخفضت. يمكن تحقيق ذلك عن طريق إعادة ضبط حجم الاختناق وفقًا لأي تغييرات ملحوظة.

الكلمات الدالة: أمثلية الشق الهيدروليكي، التحليل العقدي، المكمن الضيق.