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The Effect of Fracturing Fluids Types on Reservoir Fracture Geometry, Production, and Net Present Value

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ABSTRACT

Unconventional reservoirs are distributed over a broad area and only generate commercial quantities of hydrocarbon using specialized technology. Tight reservoirs are reservoirs with permeability less than 0.1md. One of the leading oil fields in Iraq is Halfaya field. The tight reservoir is Saadi. It is a carbonate reservoir with poor petrophysical characteristics, moderate pores, and limited pore throats, so production from these reservoirs require hydraulic fracturing. The hydraulic fracturing can be carried out using fracturing fluid. The selection of fracturing fluids should be selected as the first step in fracturing design. The objective of this research is to find out the effect of fracturing fluids on the shape of the fracture formed. Three designs were constructed based on the fracturing fluids used to build fracturing models, where three kinds of fracturing fluids were used slickwater, guar, and hybrid (combination of slickwater and guar) with a pump rate 31.5 bpm. In the first design, the fracture's height extends up and down the Saadi formation due to the presence of fragile layers around Saadi formation, so fluids are produced from these three formations. In the second design, the fracture's height is limited within the Saadi formation from the top but extends to the Tanuma from below, and therefore the production will be from the Saadi and Tanuma reservoirs. Three hybrid treatments were analysed: 30% guar & 70% slickwater, 50% guar & 50% slickwater, and 70% guar & 30% slickwater. The results show that the third design (50% guar & 50% slickwater) give the best oil production and NPV.

Keywords: Fracturing fluids, Hydraulic fracturing, Saadi formation, Halfaya oil field

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تأثير أنواع سوائل التكسير على شكل الكسر المكمني والانتاج وصافي القيمة الحالية

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الخلاصة

المكامن غير التقليدية هي تلك المكامن الموزعه على مساحه واسعه لا تعطي الا كميات تجارية من الهيدروكربون باستخدام تكنولوجيا متخصصة او اجراءات تحفيز مكثفة. المكامن قليلة النفاذية هي تلك المكامن ذات النفاذية التي تقل عن 0.1 ملي دارسي, وحقل الحلفايا النفطي هو احد الحقول الرائدة في محافظة ميسان جنوب شرق مدينة العمارةويحتوي على مكمن ذو صخور صلدة او متراصة رئيسي هو مكمن السعدي يقع تكوين السعدي تحت تكوين هارثة وفوق تكوين تنومة. وهو مكمن نفط كربوني ذو خصائص بتروفيزيائية سيئة, ومسام معتدلة.يمكن اجراء عملية التكسير الهيدروليكي باستخدام سوائل تكسير وينبغي اختياره كخطوة اساسية في تصميم ووضع المعالجة. لذا الانتاج من هكذا مكامن يحتاج الى اجراء عملية التكسير الهيدروليكي. الهدف من هذا البحث هو معرفة تأثير سوائل التكسير على شكل الكسر المتكون من حيث الطول والعرض والارتفاع. ففي التصميم الاول وجد بأن ارتفاع الكسر المتكون يمتد الى اعلى واسفل تكوين السعدي وذلك بسبب وجود طبقات عالية الهشاشة حوله. وهكذا يتم انتاج الهيدروكربونات من هذه التكوينات الثلاثة. بينما في التصميم الثاني, يكون ارتفاع الكسر محدودا ضمن السعدي من الاعلى ولكنه يمتد الى مكمن التنومة من الاسفل, لذا يكون الانتاج من السعدي والتنومة فقط. اما التصميم الثالث تم تحليل ثلاث معالجات هايبرد (30% guar و 70%ماء, 50%ماءguar , و 70%guar و30%ماء) ويستخدم للتحقق من تأثير تقليل كمية guar في معالجة التصميم. حيث استخدام اقل guar يمكن ان يقلل من تكلفه تحفيز الابار. وتبين النتائج بين تصميم الهجين (50% guar و 50% ماء) يعطي افضل انتاج للنفط واعلى قيمه صافية

الكلمات المفتاحية: سوائل التكسير, تكسير الهيدروليكي, مكمن السعدي , حقل الحلفاية النفطي.

1. INTRODUCTION

Halfaya oil field is one of the leading oil fields in the Maysan province, in the southeast of Iraq. It is situated 35 kilometers from downtown Amara City. Saadi is a carbonate petroleum reservoir with poor petrophysical characteristics, moderate pores, and limited pore throats **(Tali and Farman, 2021; Jasim et al, 2020)**. The Saadi Formation's thickness ranges from 120 to 130 meters on average. Each layer's thickness values are around 51 m for Saadi-A, 28 m for Sadi-B1, 30 m for Sadi-B2, and 20 m for Sadi-B3. The petrophysical examination of the Saadi reservoir reveals that it has poor petrophysics properties. Saadi is characterized by moderate to high porosity (15-20%) and low permeability of (0.05-1.3 md), therefore causing an insufficient liquid supply **(Al-Sudani, 2022; Cui et al., 2018).**

Tight reservoirs are defined as those reservoirs with extra low permeability and are present in the world and Iraq. They contain large oil reserves but can be only extracted after the application of necessary stimulation techniques, such as hydraulic fracturing. It is applied in oil reservoirs to produce oil **(Liang et al., 2015).** (**Hubbert and Willis, 1957)** found that in situ stresses control hydraulic fracture initiation and propagation: the minimum stress depends primarily on where the fracture is initiated, and the maximum stress dominates which direction the fracture propagates **(Hubbert and Willis, 1957).** The width of the fracture is related to the viscosity and pumping rate of the fracture used **(Perkins and Kern, 1961).** The hydraulic fracturing process includes two fluid pumping steps: pad and slurry. Through the pad step, the formation is broken by injecting just liquid into the zone of interest, at this stage there is usually propagation of fractures has occurred. Some chemicals are used with frac fluids to boost viscosity. Afterwards, the slurry stage, in which the liquid is combined with the proppant and injected into the fracture to prevent closure. This combination widens the fracture, thus facilitating the transfer of proppant to the formed fracture**(Kreipl and Kreipl, 2017)**. The purpose of fracturing fluids is (1) to suspend and transport proppant into the formed fracture by using liquids with sufficient viscosity. (2) Fracture cleaning after the fracturing treatment is finished, it is chemically decomposing to low viscosity, allowing a large portion of the fluid to flow to the surface **(Jennings, 1996)**. The fracturing fluids viscosity is an important factor in fracture creation, as many complex fractures form with narrow openings when fluid's viscosity is low**(Warpinski et al., 2005; Cipolla et al., 2008)**. Rickman et al.,2008 observed that the length of the fracture increases when the volume of the fracturing fluid increases**(Rickman et al., 2008)**. **(Economides et al., 2010)** evaluated the productivity of created fractures in vertical and horizontal wells for formation with permeability (0.001 md - 500 md). They reached to the conclusion that in oil reservoirs with permeability lower than 10 md, a vertical fractured well may be the most economical choice. **(Lebas et al., 2013)** demonstrated that for transporting proppant through the fractures, cross-linked gels outperform slick water, due to high viscosity. **(Inui et al., 2014)** studied the fracture geometry by using fracturing fluids of high and low viscosity such as slick water and cross-linked gel. They found that slick water generates complex fractures with multiple branches, and the width is narrower than gel **(Taleghani and Olson,2013)**. Saadi reservoir is a tight petroleum reservoir with poor petrophysical characteristics, moderate pores, limited pore throats, and ultra-low permeability **(Jasim et al., 2020; Al-rubaye and Hamd-allah, 2020)**. Hydraulic fracturing is the capability of hydrocarbons to flow more easily from the reservoir to the wellbore. Hydraulic fracturing treatments are carried out to improve well performance and to achieve economic growth from improved production rates and the ultimate reserve recovery. To create hydraulic fractures, hydraulic fracturing fluid must be injected into the well. As the fracturing fluid is considered one of the most important requirements in this process to ensure its success. The purpose of it is to create fractures of sufficient length and width to place and transport the proppant from the surface to the formed fracture. This treatment is performed with high pressure and rate **(Gaurina-Međimurec et al., 2021).** Halfaya oil field is an important field in Iraq, located in Missan governorate, 35km south of Amara city **(Farouk and Al-Haleem, 2022)**.

The tight reservoirs have a focus in oil industry because they contain huge reserves of oil, and they impact on oil production. These reserves have only extracted by using an important technique namely hydraulic fracturing, that can create fractures and increase production. For this a combination of fracturing fluids are used to evaluate their effect on fracture geometry dimensions and production **(Hasan and Hamd-Allah,2023).**

The key point of this work is to set the height of the fracture within the Saadi reservoir. Three types of fluids such as slickwater, guar, and hybrid were used and compared economically by NPV, and the accumulated oil is estimated.

2. SPECIFICATION OF FRACTURE'S GEOMETRIES

3D model used to calculate hydraulic fracture geometries, it is concerned with:

- Hydraulic Fracture Height: The height of a hydraulic fracture can be estimated using the following equation known as the Perkins-Kern-Nordgren (PKN) model **(Perkins and Kern, 1965)**:

$$h_f = 0.00623 * Q/(k * w * sqrt(p)) \tag{1}$$

where
h_f is the fracture height (ft),
Q is the total injected fluid volume (Ib/gal),
K is the rock permeability (md),
w is the proppant concentration (Ib/ft^2),
p is the net pressure (psi).

-Hydraulic Fracture Length: The length of a hydraulic fracture can be estimated using the following equation known as the Geertsma-de Klerk (GDK) model **(Geertsma and De Klerk, 1969)**:

$$L = 0.00615 * sqrt(Q) * sqrt(\frac{k}{E*w*p}) \tag{2}$$

where:
L is the fracture length (ft),
E is the young's modulus of rock (psi).

-Hydraulic Fracture Width: The width of a hydraulic fracture can be estimated using the following equation known as the Carter-Tracy model **(Carter and Tracy, 1983):**

$$w = 0.364 * (\frac{Q}{K*L})^{1/3} \tag{3}$$

3. METHODOLOGY

Petrophysical and geomechanical properties were calculated for well HF55 by using GOHFER software. Set of logs such as sonic, neutron, density porosity logs, resistivity was used to calculate water saturation and porosity **(Qader and Salih, 2023)**. Sonic logs used to calculate Poisson ratio and Young modulus. The petrophysical examination of the Saadi reservoir reveals that it has poor petrophysics properties. Saadi Reservoir is characterized by moderate to high porosity (15-20%) and low permeability of (0.05-1.3 md), therefore causing in insufficient liquid supply (**Al-Sudani and Husain, 2017)**. The mechanical results show that Saadi B reservoir is brittle, with ductile rock layers above and below. Still, the formations above and below are more brittle than the Saadi B reservoir **(Hashim and Farman, 2023; Alameedy and Al-Behadili, 2023)**. A minifrac was constructed by applying a set of techniques such as before closure analysis, closure, after closure analysis.
Afterward, particular fracturing fluid and proppant types were used for fracturing model. Guar, slickwater, and hybrid systems; 30% guar and 70% slickwater, 50% guar and slickwater, 30% slickwater and 70% guar; were used as fracturing fluids **(Barati and Liang, 2014; Li et al., 2016).** High density Sintered Bauxite 30/50 (F), and low density Bauxite Lite 30/50 (B) were used as proppant types. These types of proppant were selected because they give the highest conductivity even for a stress is higher 6000 psi for Saadi reservoir. No experimental work has been performed, the information is in the software**.** Accordingly, low

viscosity fracturing fluids like slickwater which contains chemicals and guar should be used **(Zicen and Yanling, 2018)**. The viscosity of the slickwater is suitable for the reservoir requirements from the beginning of the hydraulic fracturing process as shown in **Fig. 1**. μ_o is the value at which the viscosity plateau occurs. The viscosity of slick water at zero- shear rate μ_o equal 0.8. This figure shows that the viscosity of slickwater remains constant and independent on the amount of shear rate and behave as Newtonian fluid.

3.1 Fracturing Fluid Viscosity

Viscosity describes the internal friction of a moving fluid. The physical features of the fracturing fluids are crucial for the efficient implementation of hydraulic fracturing HF treatment. One of the key factors affecting fracture designing is fluid viscosity. High viscosity widens the crack, promoting proppant transfer, and lowers loss of fluid throughout formation. Nevertheless, low fluid viscosity produces a narrower fracture width. The majority of complicated fracturing fluids behave in a non-Newtonian manner. When it comes to fluids that are shear-thin, the viscosity drops as the shear rate increases. Since neither infinite (for low shear rates) nor zero viscosity (for high shear rates) can be attained in practice, this pattern only applies to a certain range of shear rates for real fluids. Consequently, Newtonian plateaus are obtained for both low and high shear rates. The viscosity of the base solvent is correlated with the high shear rate plateau **(Wrobel et al., 2021; Jennings,1996).**

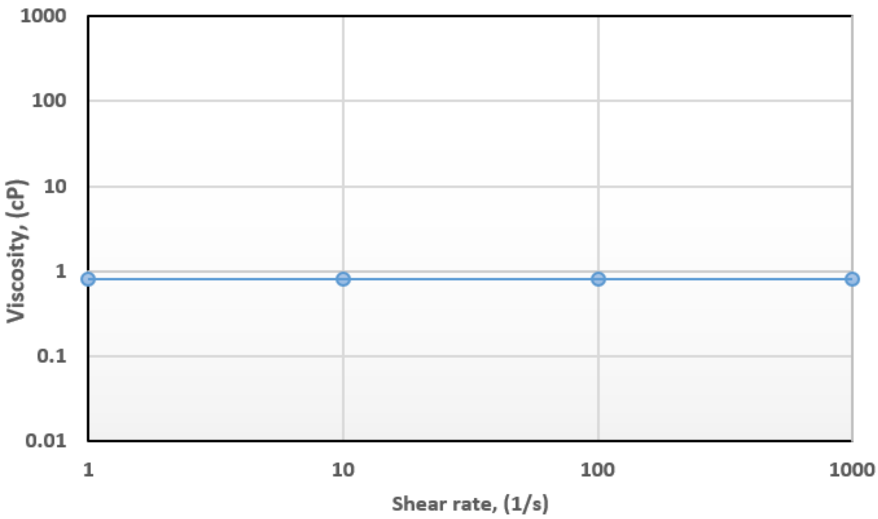

Figure 1. Variation of viscosity of slickwater with different shear rate

Fig. 2 shows that the guar viscosity is high at the start of treatment and may cause treatment failure owing to gel loading, but it starts to drop gradually. This fluid is considered non-Newtonian, which means the viscosity depends on shear rate, so its viscosity decreases non-linearly with respect to increasing shear rate and this behavior is called shear thinning. The viscosity of guar at zero shear rate μ_0 is 1302.57 cP.

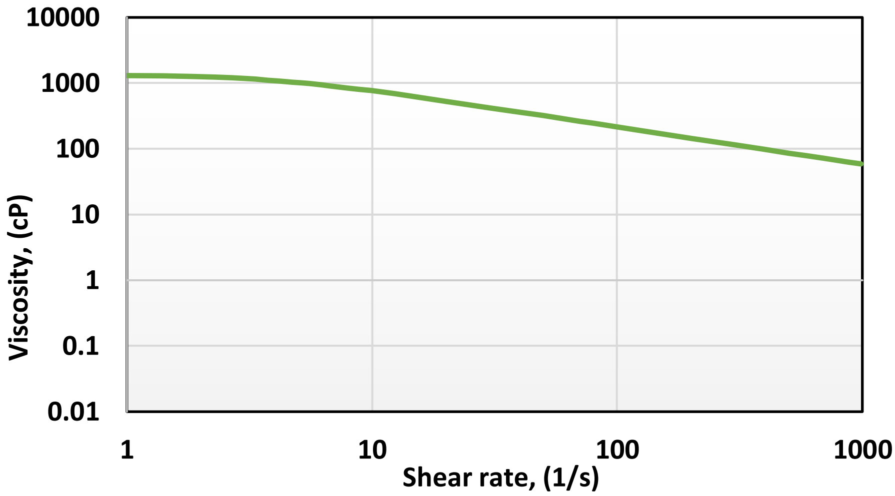

Figure 2. Viscosity of guar at different shear rate

3.2 Economics

Net Cash Flow (*NCF*) is an approach used to determine profit of hydraulic fracturing process (adopted for increasing oil production). The Net Present Value (*NPV*) is the difference between the present value of cash inflows and the present value of cash outflows over some time. The net present value of fractured wells for number of years is estimated as:

$$NPV = \sum_{i=1}^{N} \left[\frac{NCF}{1-Discount\ rate)i}\right] i \tag{4}$$

Net Cash Flow (NCF) is a function of cumulative hydrocarbon production over the entire project period, *OPEX* and *CAPEX,* for fractured wells. Operating expense cost (OPEX) is the ongoing cost for running a project, while (*CAPEX*) Capital expenditures cost are the money invested upfront to create future benefits. Both costs used to calculate total cost

$$CAPEX = Drilling\ cost + Fracturing\ cost \tag{5}$$

$$OPEX = Monthly\ well\ cost * Number\ of\ months \tag{6}$$

$$Total\ cost = OPEX + CAPEX \tag{7}$$

$$Fracturing\ cost = Fracturing\ fluid\ cost + Proppant\ cost + fixed\ job\ cost \tag{8}$$

$$Fracturing\ fluid\ cost = \text{Required fracturing fluid volum} * \text{price per fracturing fluid unit} \tag{9}$$

$$Proppant\ cost = Required\ proppant\ mass * Price\ per\ proppant\ mass\ unit \tag{10}$$

All of these costs used to calculate Net Cash Flow (NCF)

$$NCF = Gross\ Revenue - Total\ Cost \tag{11}$$

Gross Revenue=Cumulative Production* Price (12)

4. RESULTS AND DISCUSSION

Hydraulic fracturing models were constructed by selecting three types of fracturing fluids, which include slickwater, guar, and hybrid (combination of slickwater and guar) with a pumping rate of 31.5 bpm. These fluids were selected depending on high NPV and best fracture height which gave the highest NPV and best fracture height confinement within Saadi Formation**.**

4.1 Design 1 (Guar100%)

In this design, 53476 gallons of cumulative pad volume, 55871 gallons of cumulative slurry volume, and 72013 lbs of cumulative proppant are injected into the perforation. The propagation of the fracture is in the Saadi formation with lateral direction. It's clear that the fracture height is not confined within the Saadi Formation, but extends higher toward the Hartha formation and lower downward Tanuma Formation. Due to the presence of highly brittle rocks above and below the Saadi formation, hydrocarbons may be produced from these three formations as shown in **Fig. 3.** Also the fracture grows and spreads within the Saadi formation, and it has a degree of symmetry on the other side of the well**.** The value of the maximum fracture's width is 0.127in.

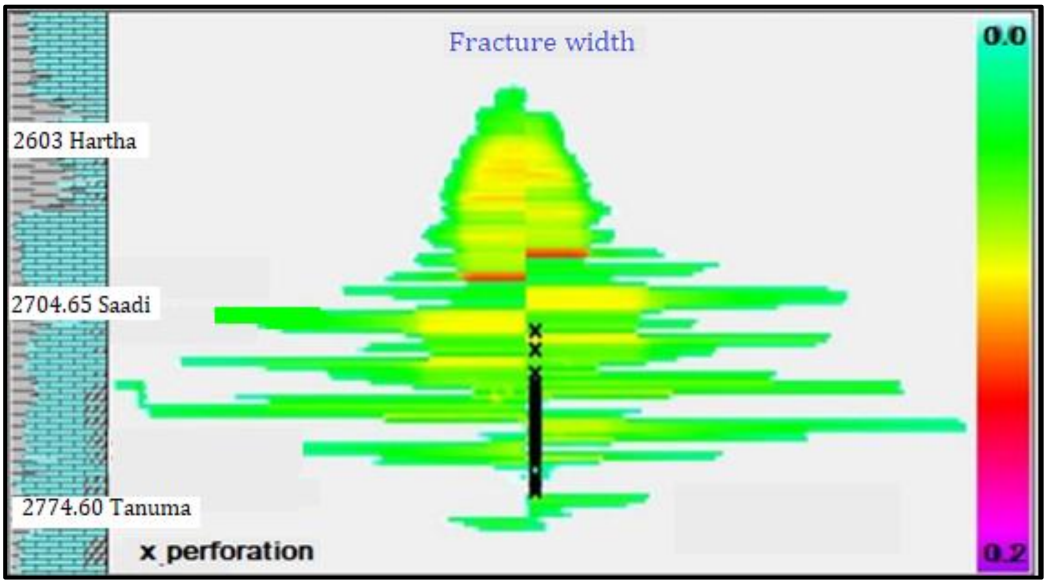

Figure 3. Width's fracture using 100% guar, (0-0.2) represents the range of fracture width in inch

4.2 Design 2 (slickwater 100%)

In this design, 53354.4 gallons of cumulative pad volume, 56404.5 gallons of cumulative slurry volume, and 72013 lbs of cumulative proppant are injected into the perforation. Each fracturing fluid was optimized, and these quantities were selected because they gave the best results (best fracture height within Saadi formation and highest NPV). It is clear that there is no significant barrier in the pay zones between the Saadi and Tanuma formations, so the fracture will extend into Tanuma and cannot be controlled as shown in **Fig. 4**. However, for the top part, the fracture remains only within the Saadi formation, that means not extending to the Hartha formation and the production is going to be from these two formations (Saadi and Tanuma). The fracture is asymmetric on both sides of the well. The dimensions of the created fracture are; length 257m, height 96 m, and maximum width 0.114in.

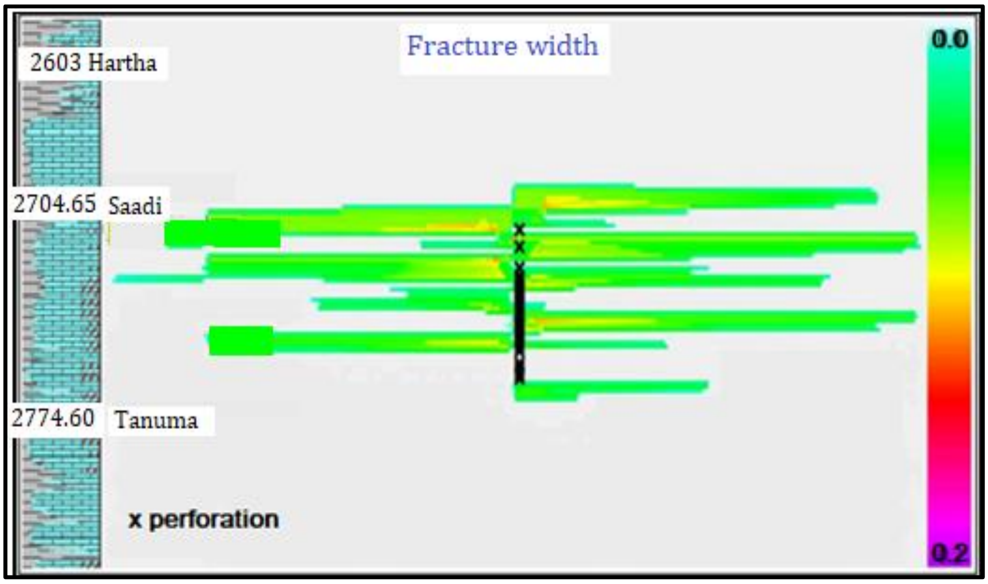

Figure 4. Width's fracture using 100% slickwater, (0-0.2) represents the range of fracture width in inch

4.3 Design 3 (hybrid)

Three hybrid treatments were analysed within the formations: 30% guar with 70% slickwater, 50% guar with 50% slickwater, and 70% guar with 30% slickwater. Hybrid-frac design was used to investigate the impact of reducing the amount of guar in the treatment design. Using less guar in the treatment can lower the cost of well stimulation

4.3.1 Design 3a (30% guar with 70% slickwater)

In this design, 52727.2 gallons of cumulative pad volume, 55739.5 gallons of cumulative slurry volume, and 72013 lbs of cumulative proppant are injected into the perforation. The created fracture has a maximum width equal to 0.154in. **Fig. 5** shows that the fracture's width is higher than design 3b and 3c because of the fracture's propagation in the lateral direction.

4.3.2 Design 3b (50% guar and 50% slickwater)

In this design, 52989.6 gallons of cumulative pad volume, 56057.3 gallons of cumulative slurry volume, and 72013 lbs of cumulative proppant are injected into the perforation. The length of the fracture is 274m, the height is 186m, and the maximum width is 0.148. **Fig. 6** demonstrates that the fracture extends greatly to the top of Hartha and the bottom of Tanuma. Since the guar can create long fracture height by overcoming the stress between layers.

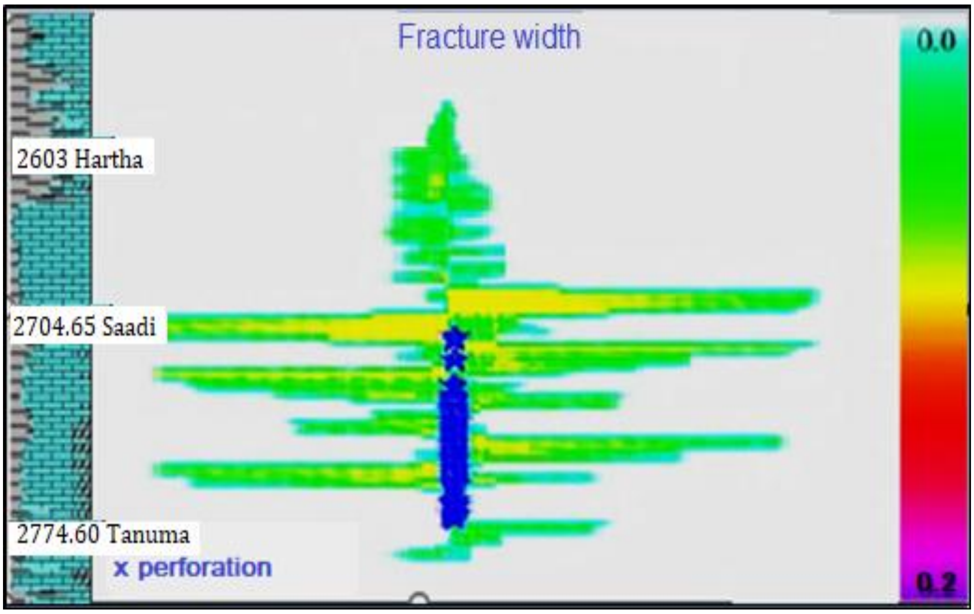

Figure 5. Width's fracture using (30% guar and 70% slickwater), (0-0.2) represents the range of fracture width in inch

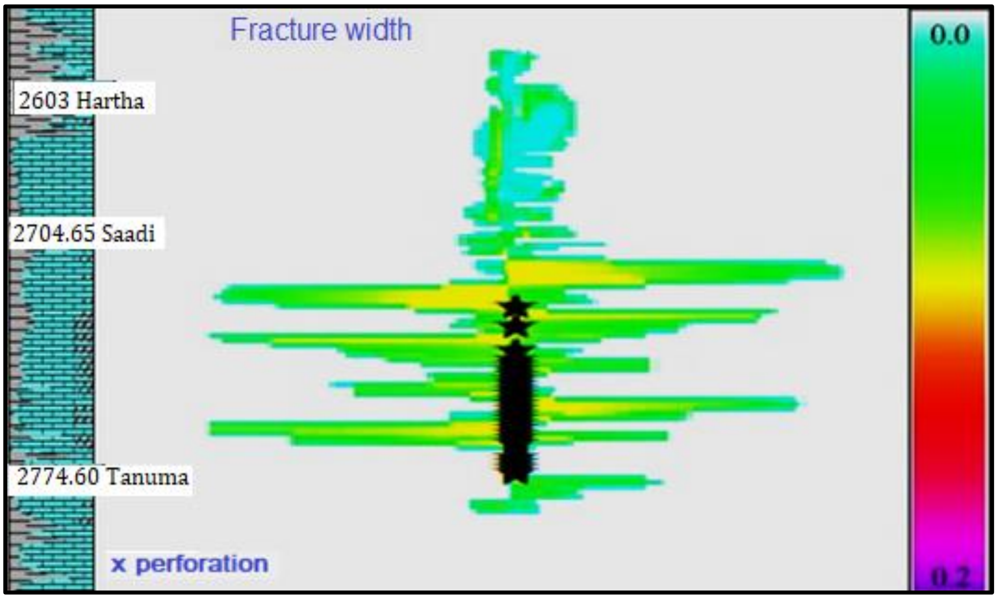

Figure 6. Width's fracture using (50% guar and 50% slickwater), (0-0.2) represents the range of fracture width in inch

4.3.3 Design 3c (70% guar and 30% slickwater)

In this design 53454.3 gallons of cumulative pad volume, 56505gallons of cumulative slurry volume, and 72013 lbs of cumulative proppant are injected into the perforation. The length of the fracture is 269m, height is 172m, and the maximum width is 0.107in. **Fig. 7** shows the fracture's height propagate laterally and extend to Hartha and Tanuma, and the production from three formations.

4.4 Production Forecast and NPV using Fracturing Fluids (Guar, Slickwater, Hybrid)

Fracturing fluids and proppant units cost assumed at 1$/gallons, and 0.4 $/Ib, respectively. Monthly well cost is assumed at 1500 $/month. Also, the oil price is assumed at 60$. The fracturing treatment cost is assumed to be 400000$. The net present value for each design is calculated by assuming the discount rate at 15 %. So, the NPV increased as cumulative production increase. **Fig. 8** shows the results of the production and economic evaluations for two design. Design 1 (guar100%) provides an average oil rate of 718 barrels per day with plateau duration 4044 days (11 years), cumulative oil production 7860 Mbbl with NPV 172 MM$ from the software. The design 2 (slickwater 100%) consistently produces 198 bbl/day of oil on average over the course of production with plateau duration 593 days (1.6 year), the cumulative oil production 2170Mbbl and NPV 81 MM$ as shown in **Fig. 9**.

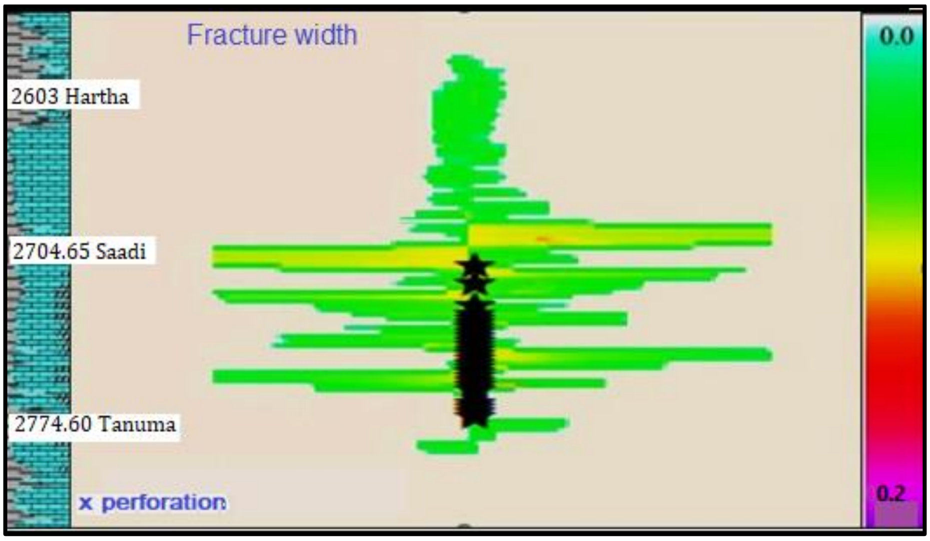

Figure 7. Width's fracture using (70% guar and 30% slickwater), (0-0.2) represents the rang of fracture width in inch

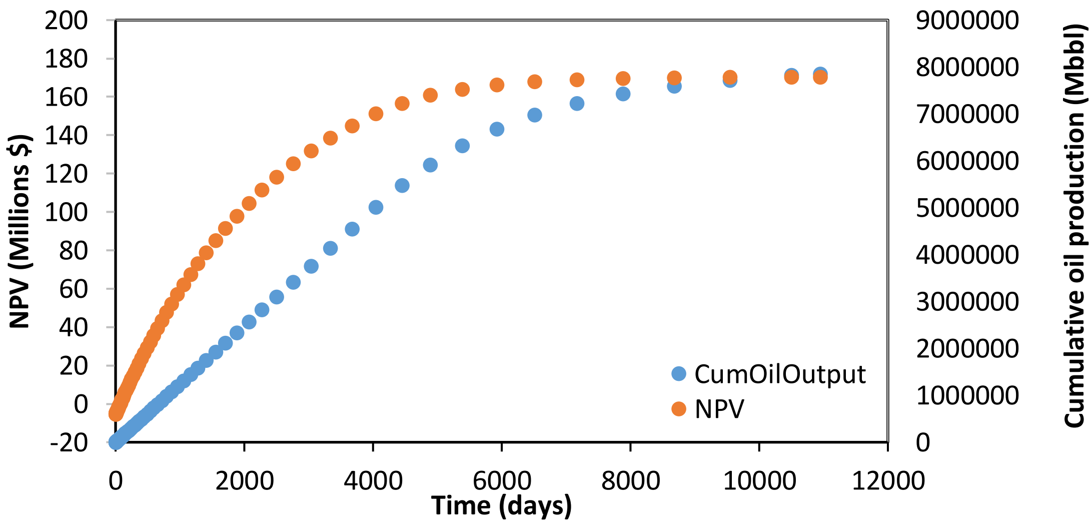

Figure 8. NPV and cumulative oil production of design 1

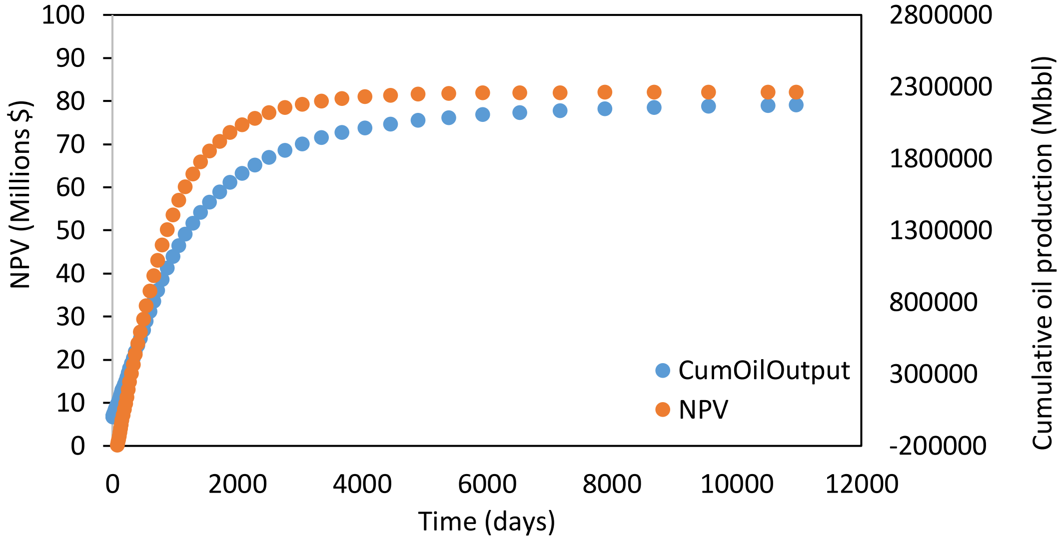

Figure 9. NPV and cumulative oil production of design 2

Fig. 10 shows the economically comparison between 3 sections of design 3 (30% guar and 70% slickwater), (50% guar &50% slickwater) and (70%guar &30% slickwater) through NPV. 163.655 MM$, 731.659 MM$, and168MM$, respectively. Design of (50% guar & 50% slickwater) is considered the best design, since it gives the highest NPV with an average oil rate of 731.659 bbl/day. That means this design is superior to other ones economically.

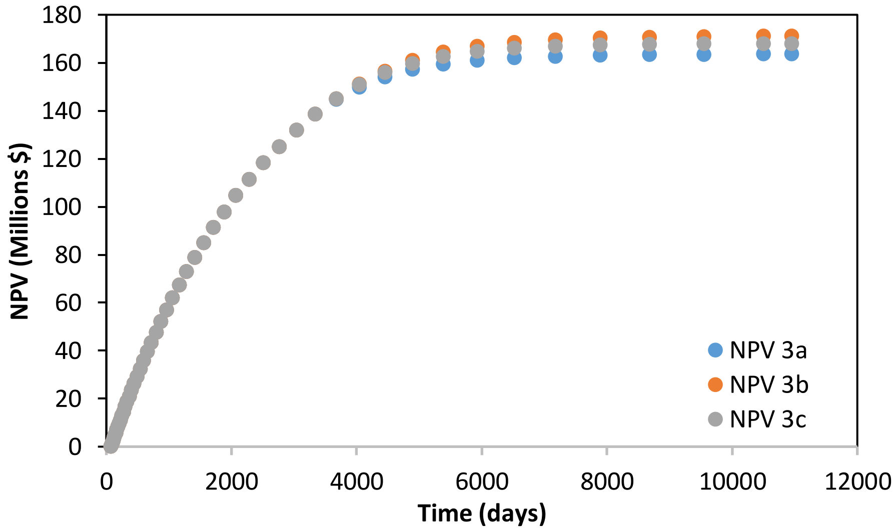

Figure 10. NPV for well HF55 of designs3 (hybrid)

Fig. 11 shows the results of production for 3 hybrid deigns (30% guar and 70% slickwater), (50% guar &50% slickwater) and (70% guar &30% slickwater). Since design one of hybrid produces 629 bbl/day of oil on average over the course of production with plateau duration of 3340 days (9 years), the cumulative oil production 6888.8 Mbbl. Design of 50% guar &50% slickwater gives 731.259 bbl/day of average oil rate throughout the production, and cumulative oil production 8011.67 Mbbl with a plateau of 4044 days (11 years). Design of

70% guar &30% slickwater gives average rate of 686 bbl/day, and production of 7512.3 Mbbl with a plateau of 3675 (10 years) as shown in **Fig. 12**.

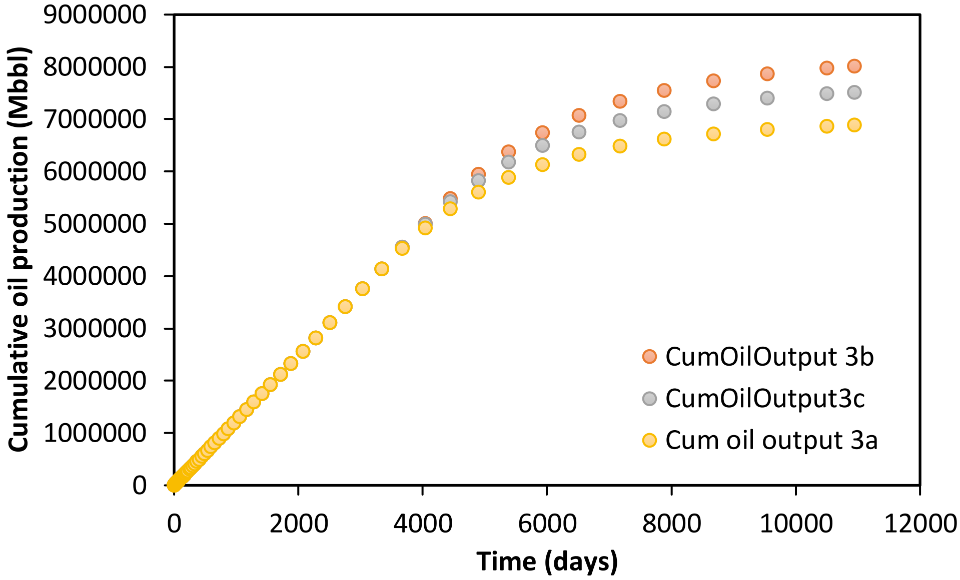

Figure 11. Cumulative Oil production of Design 3 (hybrid)

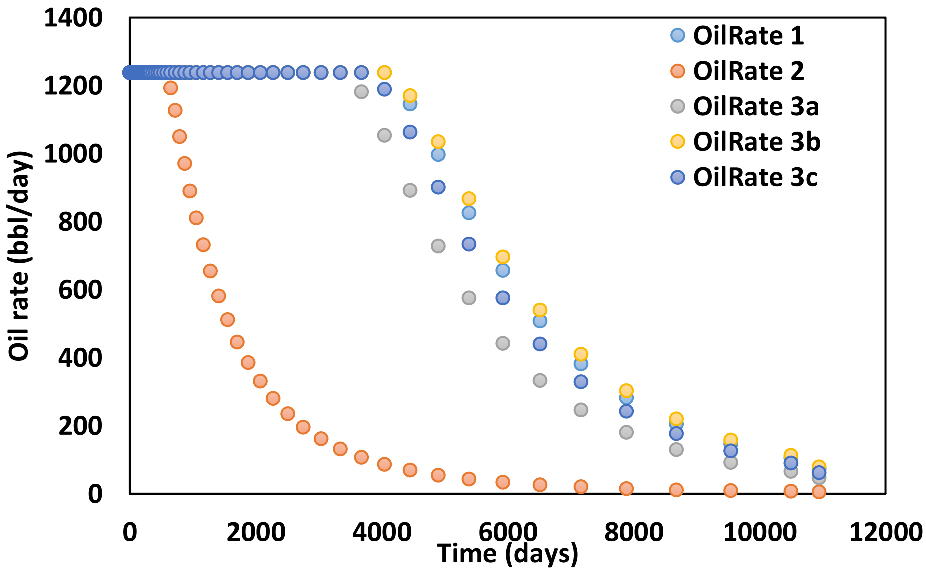

Figure 12. Oil rate for design one (100% guar), design two (slick water 100%), and hybrid (3a, 3b, and 3c)

5. CONCLUSIONS

Design one that uses Guar generates wider, longer, and higher fractures than design two of Slickwater because of its low viscosity. The fracture formed when using guar is able to penetrate the layers above and below the Saadi formation through overcoming the stress between Saadi and the formations above and below it. Also, according to the high viscosity of the guar, Guar is able to transport the proppant (combination of fluid and sand) into the wellbore to prevent the fracture from closing, because the proppant resists the stress on both sides of the fracture, allowing a large amount of fluids to pass into the well and thus increasing the reservoir conductivity. The fracture will be within almost the Saadi formation, when using slickwater. The created fractures will be narrower, containing less proppant, because the proppant settle away down in the fractures and thus less conductive. The design that uses hybrid containing little guar like (30% guar and 70%slickwater), causes less production. Finally, based on treatment economics and oil production, the design that uses hybrid fluids system containing 50% guar and slickwater seems to be the greatest effective hydraulic fracturing fluid intended for the examined location, since it gives cumulative oil production 8011.67 Mbbl and NPV is 171.22. As the increase in production may be due to high fracture height, thus increasing NPV.

NOMENCLATURE

Symbol	Description	Symbol	Description
CAPEX	Capital expenditures cost $	OPEX	Operating expense cost $
h_f	height fracture, m	W_f	width fracture, in
μ_0	viscosity at zero- shear rate, cP	X_f	half-length fracture, m
NCF	Net cash flow		

REFERENCES

AbdulMajeed, R.K., and Alhaleem, A.A., 2020. An accurate estimation of shear wave velocity using well logging data for Khasib carbonate reservoir - Amara oil field. *Journal of Engineering, 26(6),* pp. 107–120. Doi:10.31026/j.eng.2020.06.09.

Alameedy, U. and Al-Behadili, A. 2023. An Overview of How the Petrophysical Properties of Rock Influenced After Being Exposed to Cryogenic Fluid. *Journal of Engineering*, 29(11), pp. 1–16. Doi: 10.31026/j.eng.2023.11.01.

Al-rubaye, W., and Hamd-allah, S., 2020. A high resolution 3D geomodel for giant carbonate reservoir- A field case study from an Iraqi oil field. *Journal of Engineering,* 26(1), pp.160-173. Doi: 10.31026/j.eng.2020.01.12.

Al-Sudani,H. 2022. Evaluation of Petrophysical Properties of Sadi Formation, South of Iraq. Report by Petroleum Technology Department, University of Technology, Ministry of Higher Education and Scientific Research, p. 1-11. Doi: 10.13140/RG.2.2.14398.84801.

Al-Sudani, A. J., Husain, M.K., 2017. Evaluation of Acid and Hydraulic Fracturing Treatment in Halfaya Oil Field-Sadi Formation. *Iraqi Journal of Chemical and Petroleum Engineering*, 18(4), pp. 25 - 33.

Al-Zubaidy, W. and Al-Jawad, M. 2023. Prediction Unconfined Compressive Strength for Different Lithology Using Various Wireline Type and Core Data for Southern Iraqi Field", *Journal of Engineering*, 29(11), pp. 109–128. Doi: 10.31026/j.eng.2023.11.07.

Barati, R. and Liang, J.T., 2014. A review of fracturing fluid systems used for hydraulic fracturing of oil and gas wells. Journal of Applied Polymer Science, 131(16). Doi: 10.1002/app.40735.

Cipolla, C.L., Warpinski, N.R., Mayerhofer, M.J., Lolon, E.P., and Vincent, M.C., 2008. The relationship between fracture complexity, reservoir properties, and fracture treatment design. *Proceedings - SPE Annual Technical Conference and Exhibition*, 4(November), pp. 2215–2239. Doi:10.2118/115769.

Cui, M., Ding, Y., Zhu, D., Chen Y., Cai, W., Liang, C., Hu, Z., Yan, J., Wang, D., and Zhang, T., 2018. A case study: The first hydraulically fractured well in carbonate reservoirs in Iraq. *Society of Petroleum Engineers - SPE Asia Pacific Oil and Gas Conference and Exhibition 2018, APOGCE 2018*, pp. 1–15. Doi:10.2118/191908.

Farouk, A.K., and Al-Haleem, A.A., 2022. Integrating petrophysical and geomechanical rock properties for determination of fracability of the Iraqi tight oil reservoir. *Iraqi Geological Journal*, 55(1F), pp. 81–94. Doi:10.46717/igj.55.1F.7Ms-2022-06-22.

Gaurina-Međimurec, N., Brkić , B., Topolovec, M., and Mijic,P., 2021. Fracturing fluids and their application in the Republic of Croatia. *Applied Sciences*, 11(6), p. 2807. Doi:10.3390/app11062807

Geertsma, J. and De Klerk, F., 1969. A rapid method of predicting width and extent of hydraulically induced fractures. *Journal of petroleum technology*, 21(12), pp. 1571–1581.

Jasim, N., Hamd-Allah, S.M., Abass, H., 2020. Specifying quality of a tight oil reservoir through 3-d reservoir modeling. *Iraqi Journal of Science*, 61(12), 3252–3265.

Jeffrey et al., R. G. 2009. Measuring hydraulic fracture growth in naturally fractured rock. SPE annual technical conference and exhibition.

Hasan, A.H., Hamd-Allah, S., 2023**.** Estimation of the Fracturing Parameters and Reservoir Permeability Using Diagnostic Fracturing Injection Test. *Iraqi Geological Journal.* Vol. 56, No.2A. Doi:10.46717/igj.56.2A.19ms.

Hashim, A. R., Farman, M.G., 2023. Evaluating Petrophysical Properties of Sa'di Reservoir in Halfaya Oil Field. *Iraqi Geological Journal,* 56 (2D). Doi:10.46717/igj.56.2D.9ms.

Hashim, H.A., Al-Jawad, S.M., Klati, A.K., 2023. Utilizing Reservoir Model to Optimize Future Oil Production for Hydraulic Fracture Wells in Tight Reservoir. *Iraqi Geological Journal.* 56 (2B). Doi:10.46717/igj.56.2B.2ms.

Hubbert, M.K., and Willis, D.G. 1957. Mechanics of hydraulic fracturing. *Transactions of the AIME*, 210(01), pp. 153–168.

Inui, S., Ishida, T., Nagaya, Y., Nara, Y., Chen, Y., and Chen, Q., 2014. AE monitoring of hydraulic fracturing experiments in granite blocks using supercritical CO2, water and viscous oil. in *48th US Rock Mechanics/Geomechanics Symposium*, Minneapolis, Minnesota, June 2014. p. ARMA-2014-7163

Jasim, N., Hamd-allah, S., and Abass, H., 2020. Specifying quality of a tight oil reservoir through 3-d reservoir modeling. *Iraqi Journal of Science*, 61(12), pp. 3252–3265. Doi:10.24996/ijs.2020.61.12.14.

Kreipl, M.P. and Kreipl, A.T., 2017. Hydraulic fracturing fluids and their environmental impact: then, today, and tomorrow. *Environmental Earth Sciences*, *76*, pp.1-16.

Lebas, R., Lord, P., Luna, D. and Shahan, T., 2013, February. Development and use of high-TDS recycled produced water for crosslinked-gel-based hydraulic fracturing. In *SPE Hydraulic Fracturing Technology Conference*. OnePetro.

Liang, X.u., Kai, H. E., Jayant., P. R., 2015. Spontaneously Imbibed Fluids for Increasing Contact Area between Hydraulic Fracturing, Hydraulic Fracturing Fluids and Formation Matrix in Liquids- Rich Shale Plays. Society of Petroleum Engineers (SPE), pp. 2-3. Doi:10.2118/175536.

Li, L.; Al-Muntasheri, G.A.; Liang, F.A.,2016. Review of Crosslinked Fracturing Fluids Prepared With Produced Water. Petroleum 2016, 2,pp. 313–323.

Montgomery, C., 2013, May. Fracturing fluids. In *ISRM International Conference for Effective and Sustainable Hydraulic Fracturing*. Doi:10.2118/169552.

Noori, A.K., Lazim, S.A., and Ramadhan, A.A., 2019. Geological Model of the Tight Reservoir (Sadi Reservoir-Southern of Iraq). *Journal of Engineering*, 25(6), pp. 30–43. Doi:10.31026/j.eng.2019.06.03.

Perkins, T.K., and Kern, L.R. 1961. Widths of Hydraulic Fractures. *Journal of Petroleum Technology*, 13(09), pp. 937–949. Doi:10.2118/89-PA.

Qader**,** M. F., Salih A.D.2023. Fractures and Porosity Analysis of Cretaceous Kometan Carbonate Reservoirs in Selected Oilfields Adjoining the Boundary between High Folded Zone and Low Folded Zone, Kurdistan Region, NE Iraq**.** *Iraqi Geological Journal,* 56(2B). Doi:10.46717/igj.56.2B.4ms.

Rickman, R., Mullen, M., Prtrre, E., Grieser, B., and Kundert, D., 2008. A practical use of shale petrophysics for stimulation design optimization: All shale plays are not clones of the Barnett Shale.*Proceedings - SPE Annual Technical Conference and Exhibition*, 2(Wang), pp. 840–850. Doi:10.2118/115258.

Taleghani, A.; Olson, J.E.,2013. How Natural Fractures Could Affect Hydraulic-fracture Geometry. SPE J. 2013, 19, pp. 161–171.

Tali, A.H., Farman, G.M., 2021. Use Conventional and Statistical Methods for Porosity Estimating in Carbonate Reservoir in Southern Iraq, Case Study. *Iraqi Geological Journal*, 54(2D), pp. 30–38.

Jennings Jr, A.R., 1996. Fracturing fluids-then and now. *Journal of petroleum technology*, *48*(07), pp.604-610.

Warpinski, N.R., Kramm, R.C., Heinze, J.R. and Waltman, C.K., 2005. Comparison of single-and dual-array microseismic mapping techniques in the Barnett shale. In *SPE Annual Technical Conference and Exhibition*, October pp. SPE-95568. Doi:10.1190/1.2147914

Wrobel, M., Mishuris, G., and Papanastasiou, P., 2021. On the influence of fluid rheology on hydraulic fracture. Internatio*nal Journal of Engineering Science*, 158(1), pp. 1–21. Doi:10.1016/j.ijengsci.2020.103426.

Zichen, Y., Yanling, w. 2018. Reduced thr Adsorption of Guar Based Hydraulic Fracturing Fluids in the Formation. Society of Petroleum Engineers (SPE). Doi:10.2118/192386.