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Numerical Simulation of Hydraulic Fracturing in Unconventional Reservoirs

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Abstract

Hydraulic fracturing is a well-stimulation technique that uses a large amount of water mixed with proppants at high pressure to enhance and boost oil and gas production. Proppants, in conjunction with water, facilitate the cracking process, acting as a catalyst for the oil and gas to pass through the formation and into the producing well. The primary goal of this research is to look into the parameters that influence hydraulic fracturing quality. Moreover, such parameters that improve the productivity of oil in unconventional reservoirs are evaluated. The field properties of the Eagle Ford Shale were used to create a geological model on the tNavigator software for this purpose. This software is used to simulate three different horizontal and vertical wells to observe the production of oil and gas. Then, hydraulic fracturing is performed on the same wells with different scenarios using three parameters, namely the length of fracture, the width of fracture, and the height of fracture. These parameters are selected because the usage of proppants can be dependent on them. The findings are quite convincing and demonstrate the importance of hydraulic fracturing in an unconventional reservoir. Besides, it is observed that the greater the width, length, or height of the fracture, the greater the productivity of oil and gas in an unconventional reservoir due to the increment of the seepage area of the hydrocarbons. Thus, hydraulic fracturing can make any potential unconventional reservoir economically viable.

Keywords: Hydraulic Fracturing; Numerical Simulation; Oil Production; Unconventional Reservoir.

1. Introduction

Hydraulic fracturing is a technique used to extract oil from unconventional reservoir deposits. It is extremely important in the industry. Fracking allows for a significant increase in domestic oil and gas production. The primary goal is to thoroughly investigate the fracturing process and determine the parameters that influence the productivity of oil and gas in an unconventional reservoir. Hydraulic fracturing is a new technique that is mostly used in countries that have a lot of potential unconventional reservoirs. Oil and gas are scarce in unconventional reservoirs. This is due solely to low permeability, porosity, and a poor manufacturing mechanism. These difficulties make it uneconomic for a country to rely on unconventional reserves. Countries such as America, particularly along the coast of Texas, have a large number of unconventional reservoirs with the potential to produce billions of barrels of oil and gas. Hydraulic fracturing techniques are used to turn this unfavorable situation into a favorable situation. Such a technique only allows a country to produce massive amounts of oil and gas while remaining cost-effective. There are numerous factors that influence oil and gas productivity. Fracture length [1], fracture width [2], fracture height, proppant used, size and shape of proppants, pressure [3] at which those proppants are injected, and fracture conductivity will all be considered in this study, but only the width, length, and height of fractures will be considered. The ultimate goal is to identify a suitable parameter and set of conditions to improve and increase the productivity and ultimate output of the wells.

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2. Methodology and Experimental Setup

A numerical simulator-based software called tNavigator was used to create a geological model, which was then used to perform hydraulic fracturing simulations on. The properties of the Eagle Ford Shale, an American oil and gas producing site, were used to prepare the geological model of an unconventional reservoir (citation). A geological model with dimensions of 300 feet, 300 feet, and 46 feet in the X, Y, and Z directions, respectively, was created. The model was built with 27, 20, and 15 grid blocks in the X, Y, and Z directions, respectively. The geological model's reservoir and fluid properties are as follows:

Table 1 Reservoir and Fluid Properties used to prepare geological model [4]

Property	**Value**	**Unit**
Depth	9000	Ft
Porosity	0.08-0.18	Unit-less
Permeability in X direction	0.002466 - 0.030339	mDarcy
Permeability in Y direction	0.002466 - 0.030339	mDarcy
Permeability in Z direction	0.00014796 - 0.0018203	mDarcy
Net to Gross Ratio	0.7	Unit-less
Initial Water Saturation	20%	Unit-less
Initial Reservoir Pressure	3400	Psi
Reservoir Temperature	270	Degree Fahrenheit
Bubble Point Pressure	3306.1 Psia	Psia
Formation Volume Factor	1.26	Rb/Stb
Oil Density	53.002	lb/ft^3
Oil API	35	Unit-less
Gas Density	0.044672	lb/ft^3
Water Oil Contact	8700	Ft
Gas Oil Contact	7800	Ft
Water Salinity	10,000	Ppm
Bottom Hole Pressure	1000	Psia
Proppant Size	0-3000	mDarcy
Flow Function	Exponential	Unit-less

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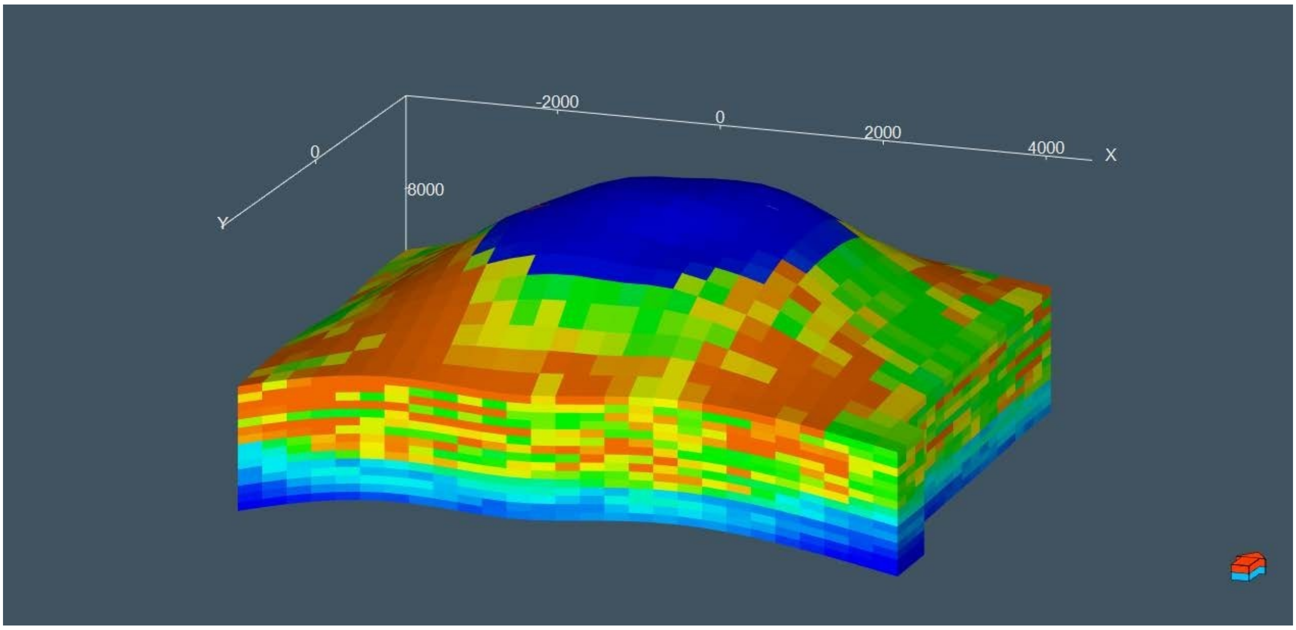

Fig. 1 3D view of a geological model via tNavigator regarding the relevant properties.

Table 1 clearly shows that the porosity and permeability selected while developing this model are very low, making it an unconventional reservoir. This geological model has the potential to produce 240.41 million barrels of oil and 129.16 million Mscf of gas. As a result, this geological field is a potential field that is economically inconvenient. Hydraulic fracturing will be used to increase oil and gas production in order to make this field more economically viable.
In addition, while performing hydraulic fracturing, the three selected parameters will be tested to determine the impact of those factors on the rate of oil and gas production.

3. Results and Analysis

In order to evaluate the productivity improvement for unconventional reservoir, hydraulic fracturing was performed on the three of following parameters:

1) Fracture Half – Length (Length of Fracture)
2) Width of Fracture
3) Height of Fracture

These three parameters were used to accomplish two goals at the same time. First, observe the increase in oil and gas productivity in unconventional reservoirs after hydraulic fracturing is used. The second goal is demonstrating the aforementioned parameters have an effect on the productivity of unconventional reservoirs. These simulations lasted 30 years.

3.1 Hydraulic Fracturing in Vertical Wells

In order to get a better insight on the impact of hydraulic fracturing, three wells were selected. All those wells were tested with different, height and width of the fractures. All these three wells were drilled in the same place for all three scenarios at a constant control bottom hole pressure of 1000 psia in order to get more accurate results.

3.1.1 Length of Fracture

Three producing wells were created in order to test the dependency of fracture length on the production of oil and gas. Fracturing was performed at three different lengths which were 200 meters, 300 meter and 400 meters, while keeping fracture height = 30 meters and fracture width = 0.5 Meters

Table 2 Results of Well-1, before and after hydraulic fracturing is performed.

Well 1	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Length (Meters)	Before Hydraulic Fracturing	After Hydraulic Fracturing	Before Hydraulic Fracturing	After Hydraulic Fracturing
200	171.129	597.57	66.5513	216.58
300	171.129	754.098	66.5513	263.414
400	171.29	827.895	66.5513	281.649

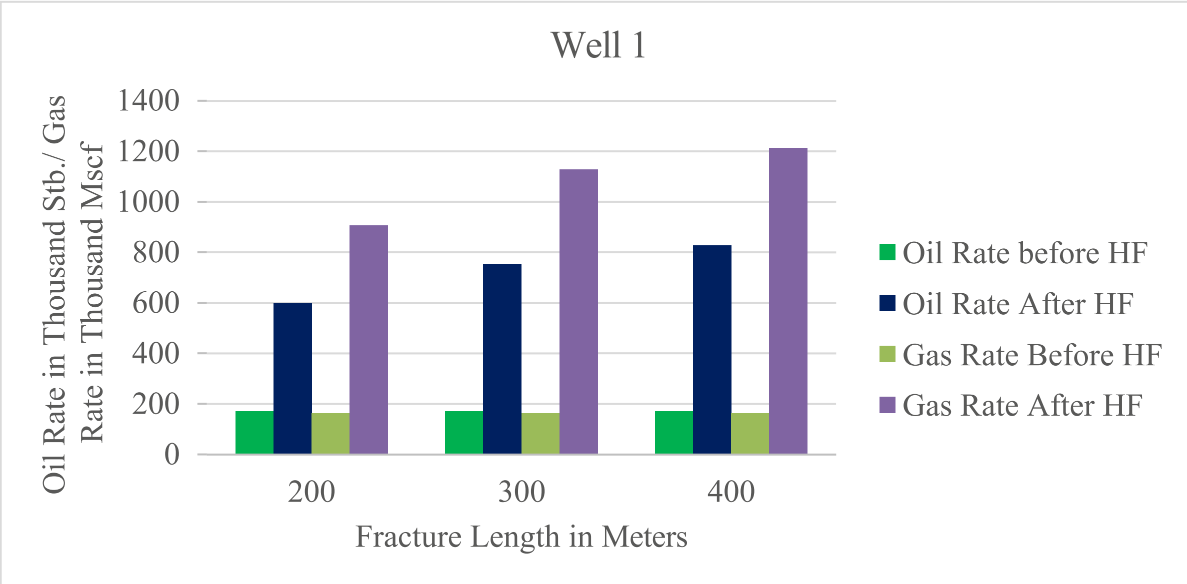

Fig. 2 Results of Well-1, before and after hydraulic fracturing.

It can be seen by just applying hydraulic fracturing, the oil rate and gas rate for the well 1 changed drastically. It can also be seen, that the half fracture length has also a great impact on the productivity of the oil wells.

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Table 3 Results of Well-2, before and after hydraulic fracturing

Well 2	Oil Rate (Thousand Stb.)		Gas Rate (Thousand Mscf)	
Fracture Length (Meters)	Before Hydraulic Fracturing	After Hydraulic Fracturing	Before Hydraulic Fracturing	After Hydraulic Fracturing
200	120.879	490.563	162.539	907.217
300	120.879	623.993	162.539	1127.9
400	120.879	704.944	162.539	1214.09

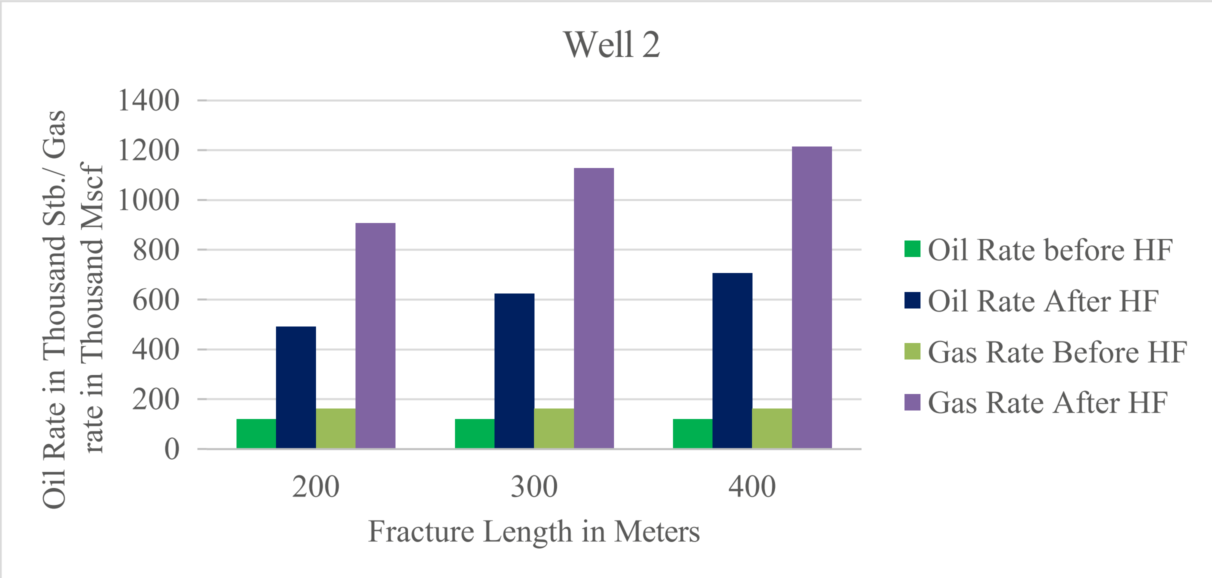

Fig. 3 Results of Well-2, before and after hydraulic fracturing.

Similarly, the same simulation was run on different grids of the reservoir in order to verify the impact of hydraulic fracturing on unconventional reservoirs. In well 2, the exponential rise in the rate of oil and gas production can also be observed.

Table 4 Results of Well-3, before and after hydraulic fracturing

Well 3	Oil Rate (Thousand Stb.)		Gas Rate (Thousand Mscf)	
Fracture Length (Meters)	Before Hydraulic Fracturing	After Hydraulic Fracturing	Before Hydraulic Fracturing	After Hydraulic Fracturing
200	181.455	624.24	188.76	773.581
300	181.455	810.882	188.76	1011.3
400	181.455	892.621	188.76	1123.48

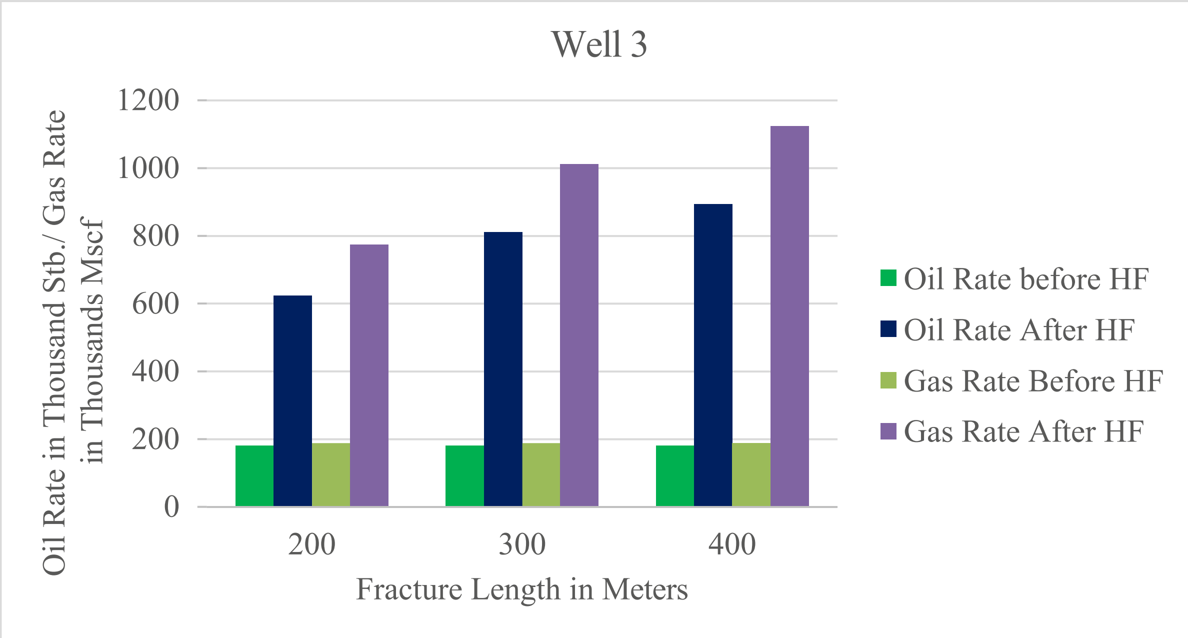

Fig. 4 Results of Well-3, before and after hydraulic fracturing

Similarly, it can be seen clearly that the fracture length has a great impact on the production rate of oil and gas. Three different wells drilled at different locations, with increase in the productivity of oil and gas shows the importance of the length of the fracture.

3.1.2 Width of Fracture

Second parameter which we are we going to consider while performing the hydraulic fracturing is the width of fracture. Three producing wells were created on the same wells 1, 2 and 3 as mentioned above in order to test the dependency of fracture width on the production of oil and gas.

Fracturing was performed at three different widths which were 0.4 meters, 0.5 meters and 0.6 meters, while keeping fracture height = 30 meters and fracture length = 300 meters.

Table 5 Results of Well-1, before and after hydraulic fracturing

Well 1	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Width (Meters)	Before Hydraulic Fracturing	After Hydraulic Fracturing	Before Hydraulic Fracturing	After Hydraulic Fracturing
0.4	171.129	704.201	66.5513	240.875
0.5	171.129	754.098	66.5513	263.414
0.6	171.129	792.611	66.5513	281.677

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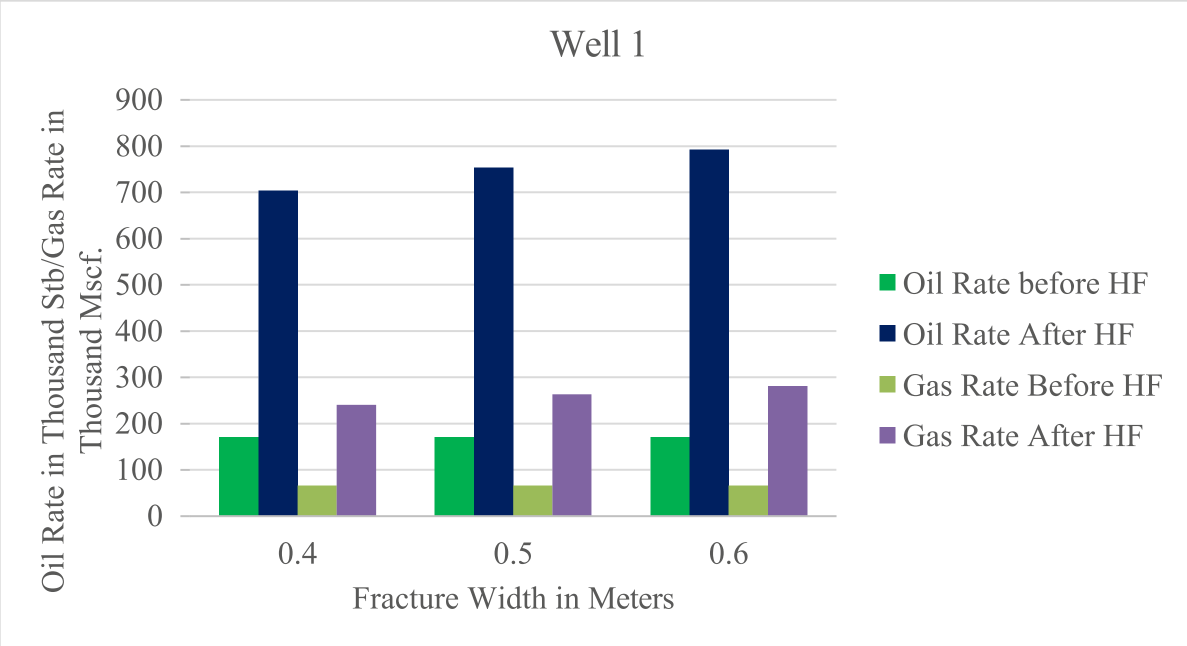

Fig. 5 Results of Well-1, before and after hydraulic

Table 6 Results of Well-2, before and after hydraulic fracturing

Well 2	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Width (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
0.4	120.879	589.271	162.539	1056.12
0.5	120.879	623.993	162.539	1127.9
0.6	120.879	667.824	162.539	1184.92

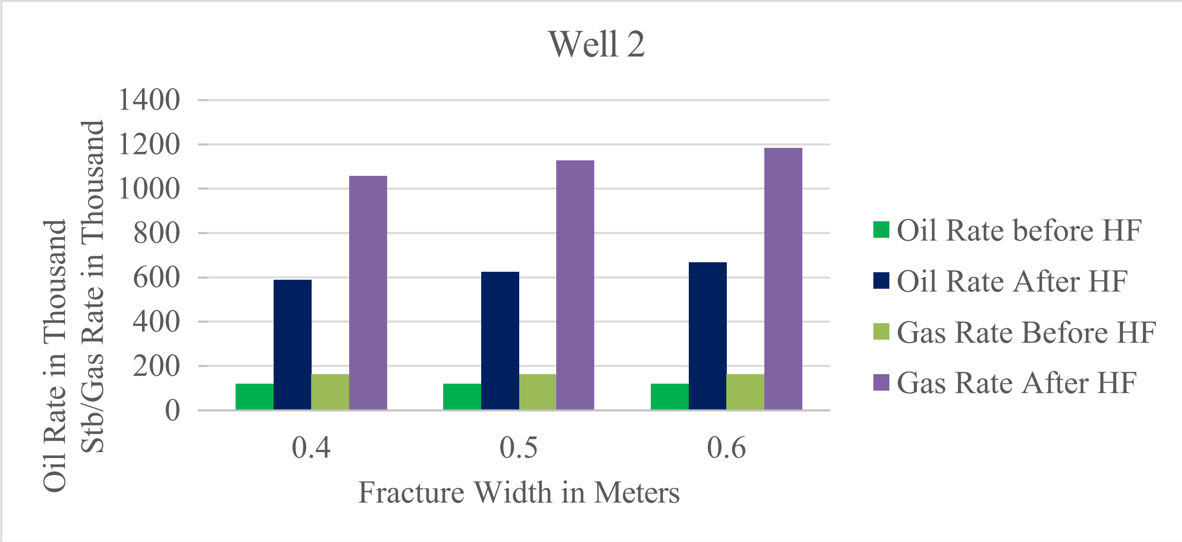

Fig. 6 Results of Well-2, before and after hydraulic fracturing

Table 7 Results of Well-3, before and after hydraulic fracturing

Well 3	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Width (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
0.4	181.455	759.119	188.76	930.583
0.5	181.455	810.882	188.76	1011.3
0.6	181.455	852.237	188.76	1079.43

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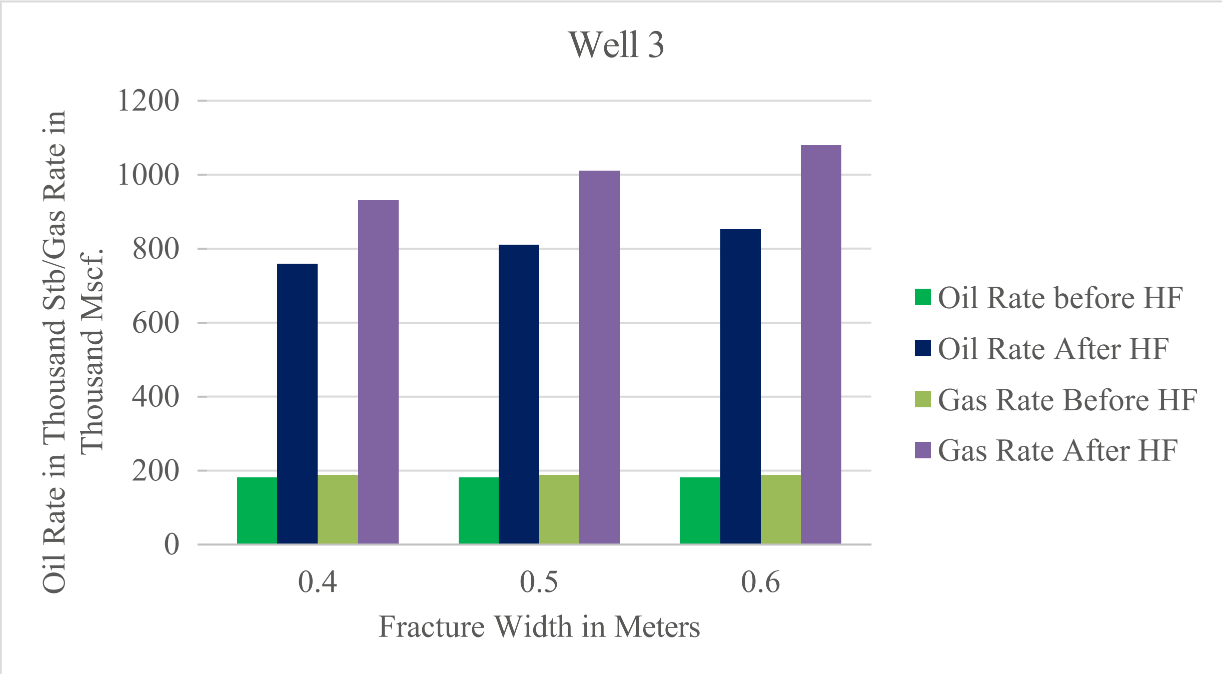

Fig 7 Results of Well-3, before and after hydraulic fracturing

Once again, it can be seen the importance of the hydraulic fracturing in increasing the productivity of the well. Along with that it can be observed that greater the width of fracture, greater the width of fracture, greater will be the oil production.

3.1.3 Height of Fracture

Third parameter which we consider is the height of the fractures. Similarly, three producing wells named well 1, well 2 and well 3 were created in order to test the dependency of fracture height on the production of oil and gas.

Fracturing was performed at three different height which were 25 meters, 30 meters and 35 meters, while keeping fracture width = 0.5 meters and fracture length = 300 meters.

Table 8 Results of Well-1, before and after hydraulic fracturing

Well 1	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Height (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
25	171.129	751.97	66.5513	262.383
30	171.129	754.098	66.5513	263.414
35	171.129	754.631	66.5513	263.524

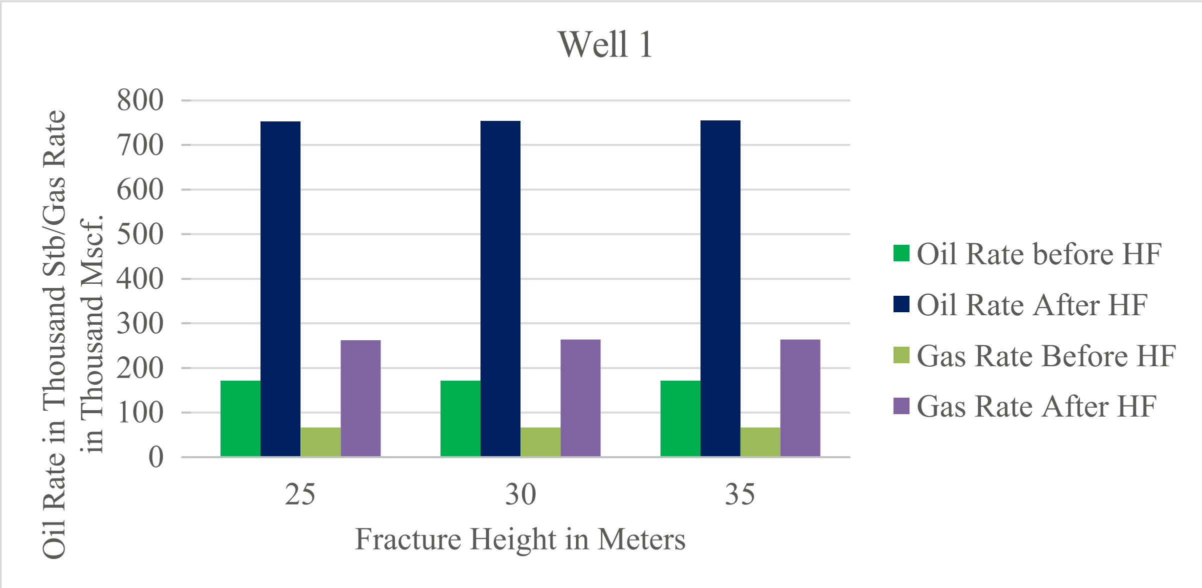

Fig 8 Results of Well-1, before and after hydraulic fracturing

Table 9 Results of Well-2, before and after hydraulic fracturing

Well 2	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Hight (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**AfterHydraulic Fracturing**
25	120.879	632.485	162.539	1125.99
30	120.879	623.993	162.539	1127.9
35	120.879	623.313	162.539	1011.33

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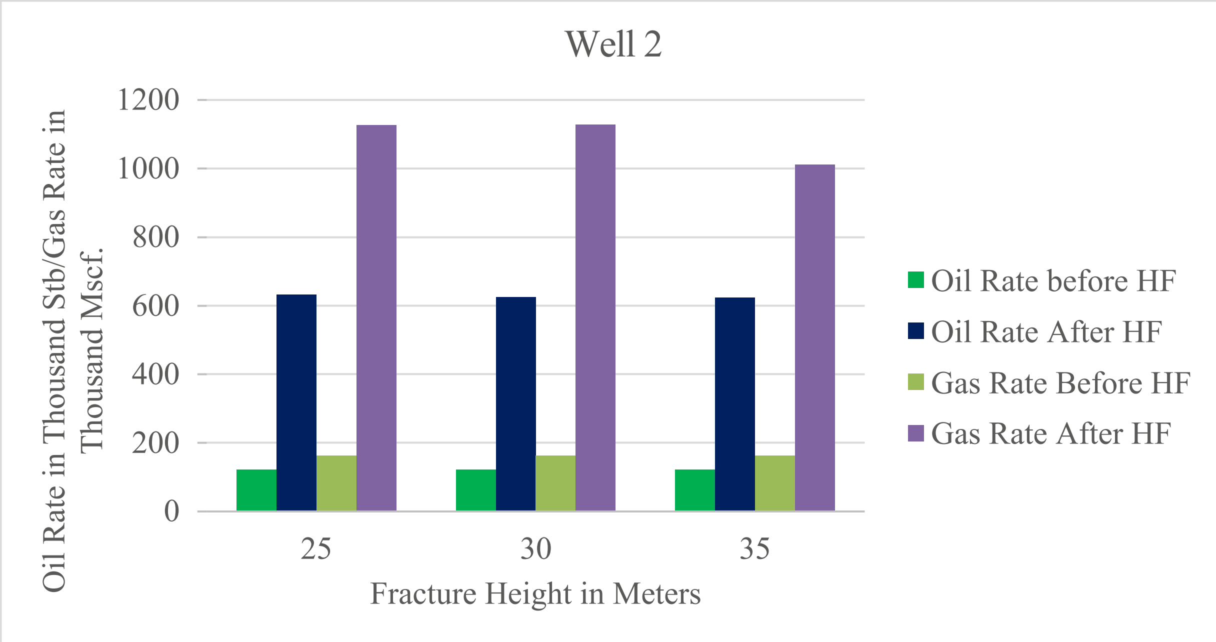

Fig 9 Results of Well-2, before and after hydraulic fracturing

Table 10 Results of Well-3, before and after hydraulic fracturing

Well 3	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Height (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
25	181.455	809.542	188.76	989.441
30	181.455	810.882	188.76	1011.3
35	181.455	812.206	188.76	1030.5

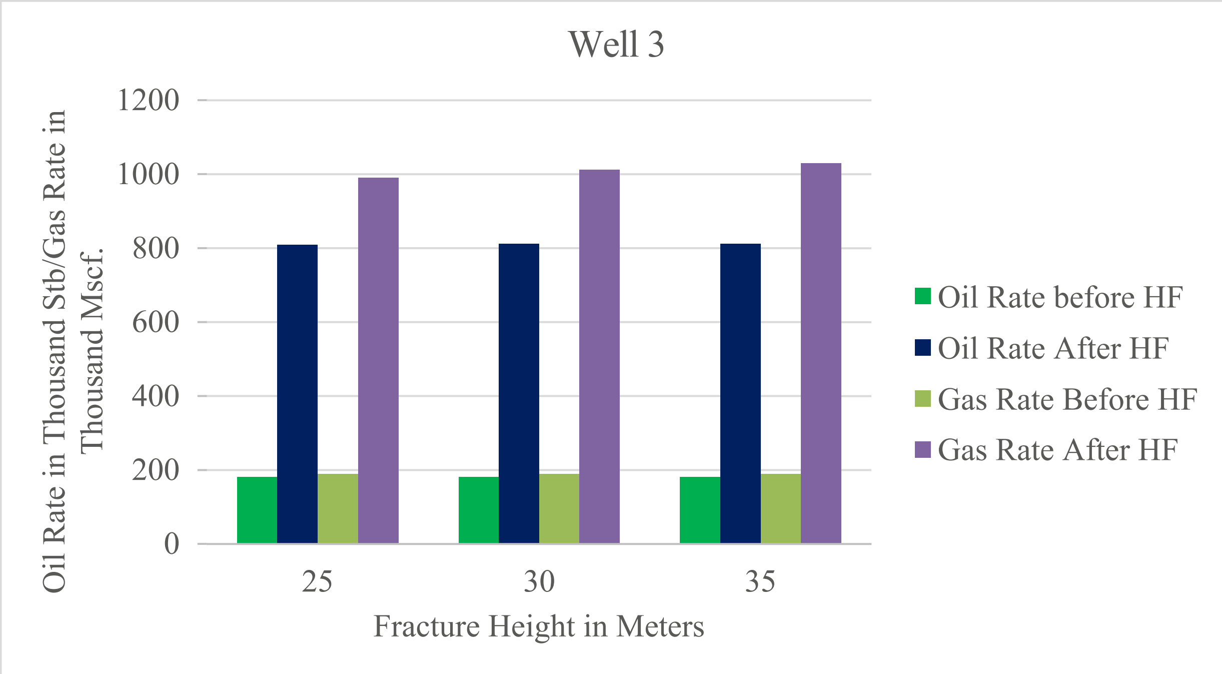

Fig 10 Results of Well-3, before and after hydraulic fracturing

The same kind of exponential increase results were observed. Similarly, it can be seen the importance of the hydraulic fracturing in increasing the productivity of the well. Along with that it can be observed that greater the width of fracture, greater the width of fracture, greater will be the oil production.

3.2 Hydraulic Fracturing in Horizontal Wells

The same parameters were also used to evaluate the productivity of unconventional reservoirs using hydraulic fracturing. Three main parameters affecting hydraulic fracturing used are the

1) Fracture Half – Length (Length of Fracture)
2) Width of Fracture
3) Height of Fracture

3.2.1 Length of Fracture

Three producing wells were created in order to test the dependency of fracture length on the production of oil and gas. Fracturing was performed at three different lengths which were 200 meters, 300 meter and 400 meters, while keeping fracture height = 30 meters and fracture width = 0.5 Meters.

Table 11 Results of Well-1, before and after hydraulic fracturing

Well 1	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Length (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
200	230.983	663.095	823.995	970.739
300	230.983	716.28	823.995	995.112
400	230.983	779.135	823.995	1021.39

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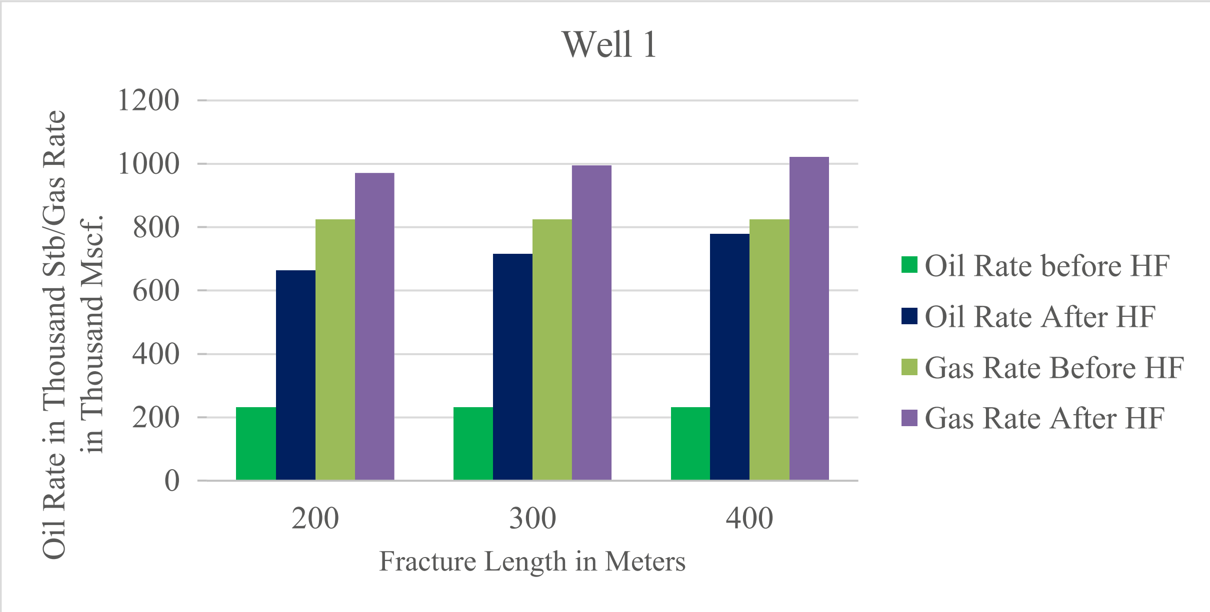

Fig 11: Results of Well-1, before and after hydraulic fracturing

Table 12: Results of Well-2, before and after hydraulic fracturing

Well 2	Oil Rate (Thousand Stb.)		Gas Rate (Thousand Mscf)	
Fracture Length (Meters)	Before Hydraulic Fracturing	After Hydraulic Fracturing	Before Hydraulic Fracturing	After Hydraulic Fracturing
200	196.095	819.618	954.182	1173.15
300	196.095	1014.37	954.182	1234.8
400	196.095	1117.26	954.182	1482.25

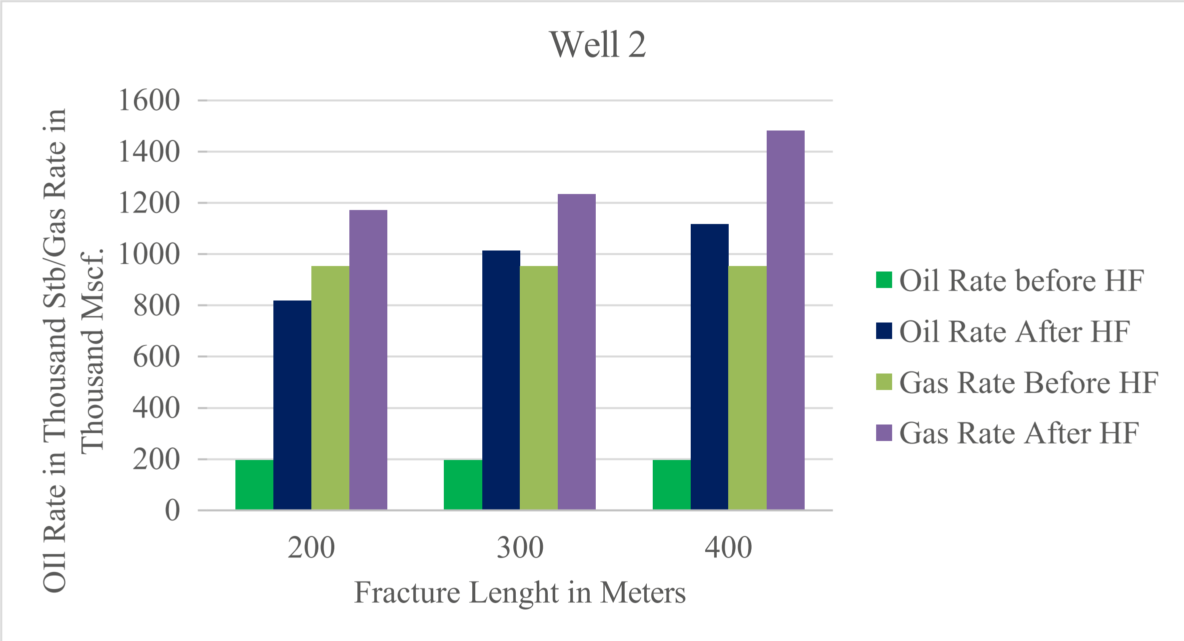

Fig 12: Results of Well-2, before and after hydraulic fracturing

Table 13: Results of Well-3, before and after hydraulic fracturing

Well 3	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Length (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
200	173.516	580.238	1325.73	1459.79
300	173.516	630.733	1325.73	1482.25
400	173.516	688.127	1325.73	1506.9

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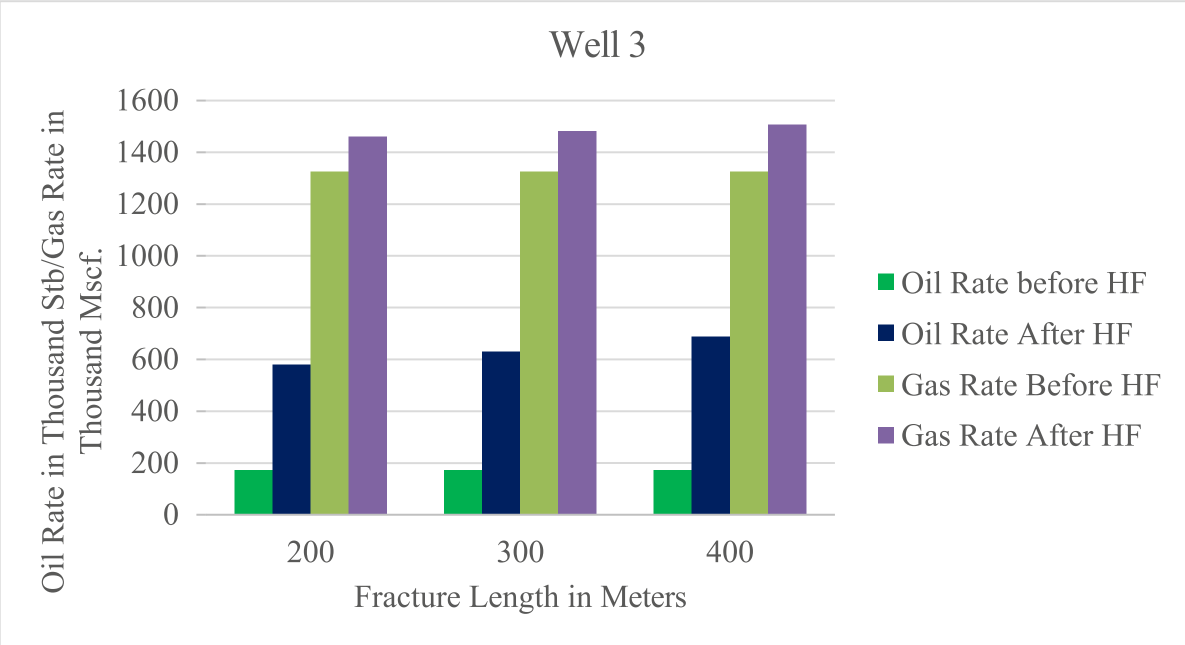

Fig 13: Results of Well-3, before and after hydraulic fracturing

3.2.2 Width of Fracture

Three producing wells were created in order to test the dependency of fracture width on the production of oil and gas. Fracturing was performed at three different widths which were 0.4 meters, 0.5 meters and 0.6 meters, while keeping fracture height = 30 meters and fracture length = 300 meters.

Table 14 Results of Well-1, before and after hydraulic fracturing

Well 1	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Width (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
0.4	230.983	681.877	823.995	974.308
0.5	230.983	716.28	823.995	995.112
0.6	230.983	743.761	823.995	1013.53

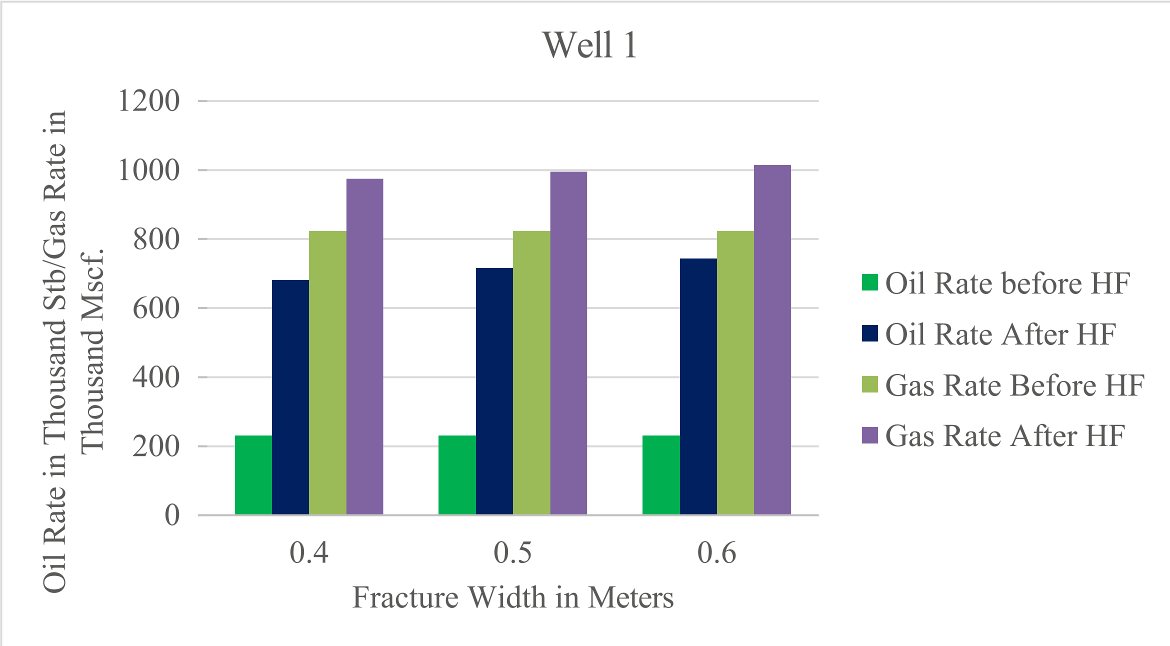

Fig 14 Results of Well-1, before and after hydraulic fracturing

Table 15 Results of Well-2, before and after hydraulic fracturing

Well 2	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Width (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
0.4	196.095	956.485	954.182	1206.35
0.5	196.095	1014.37	954.182	1234.8
0.6	196.095	1059.95	954.182	1258.42

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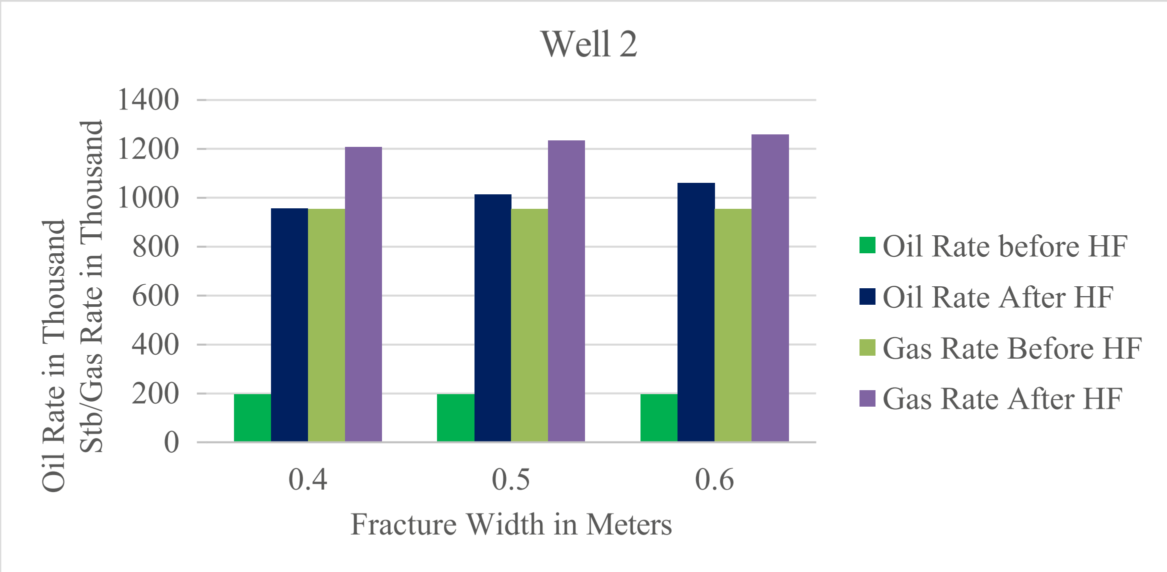

Fig 15 Results of Well-2, before and after hydraulic fracturing

Table 16 Results of Well-3, before and after hydraulic fracturing

Well 3	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Width (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
0.4	173.516	597.959	1325.73	1463.78
0.5	173.516	630.733	1325.73	1482.25
0.6	173.516	656.696	1325.73	1499.02

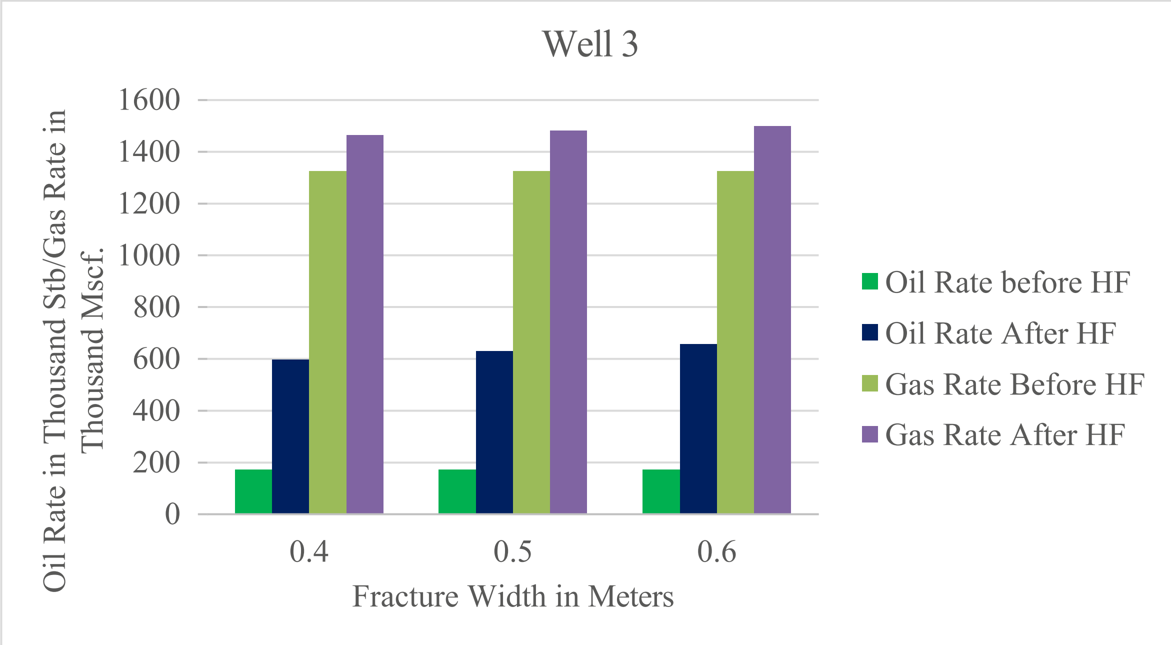

Fig 16 Results of Well-3, before and after hydraulic fracturing

3.2.3 Height of Fracture

Three producing wells were created in order to test the dependency of fracture height on the production of oil and gas. Fracturing was performed at three different height which were 25 meters, 30 meters and 35 meters, while keeping fracture width = 0.5 meters and fracture length = 300 meters.

Table 17 Results of Well-1, before and after hydraulic fracturing

Well 1	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf.)**	
Fracture Height (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
25	230.983	690.758	823.995	982.705
30	230.983	716.28	823.995	995.112
35	230.983	740.402	823.995	1006.69

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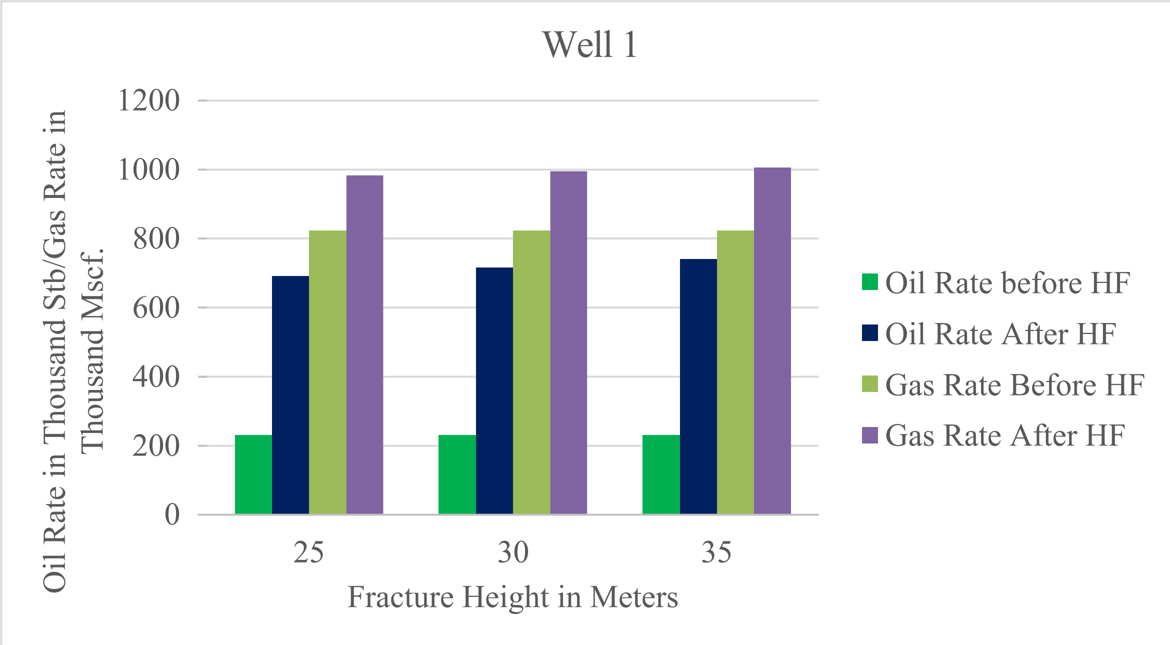

Fig 17 Results of Well-1, before and after hydraulic fracturing

Table 18 Results of Well-2, before and after hydraulic fracturing

Well 2	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Height (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
25	196.095	980.164	954.182	1218.32
30	196.095	1014.37	954.182	1234.8
35	196.095	1044.26	954.182	1249.99

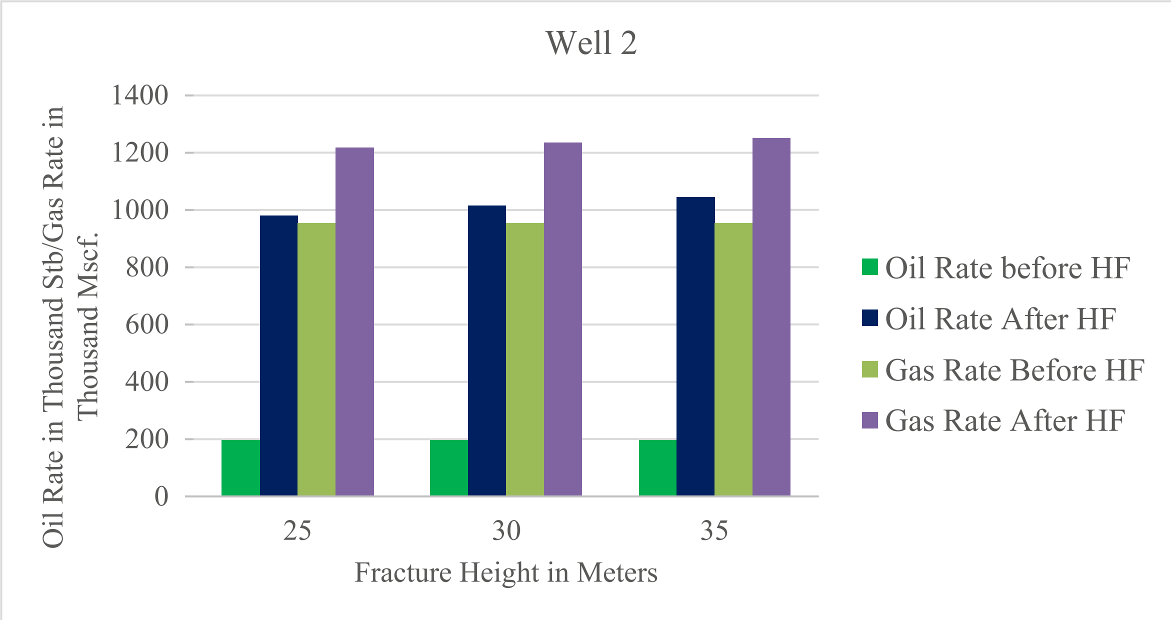

Fig 18 Results of Well-2, before and after hydraulic fracturing

Table 19 Results of Well-3, before and after hydraulic fracturing

Well 3	**Oil Rate (Thousand Stb.)**		**Gas Rate (Thousand Mscf)**	
Fracture Height (Meters)	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**	**Before Hydraulic Fracturing**	**After Hydraulic Fracturing**
25	173.516	606.89	1325.73	1471.13
30	173.516	630.733	1325.73	1482.25
35	173.516	653.101	1325.73	1492.59

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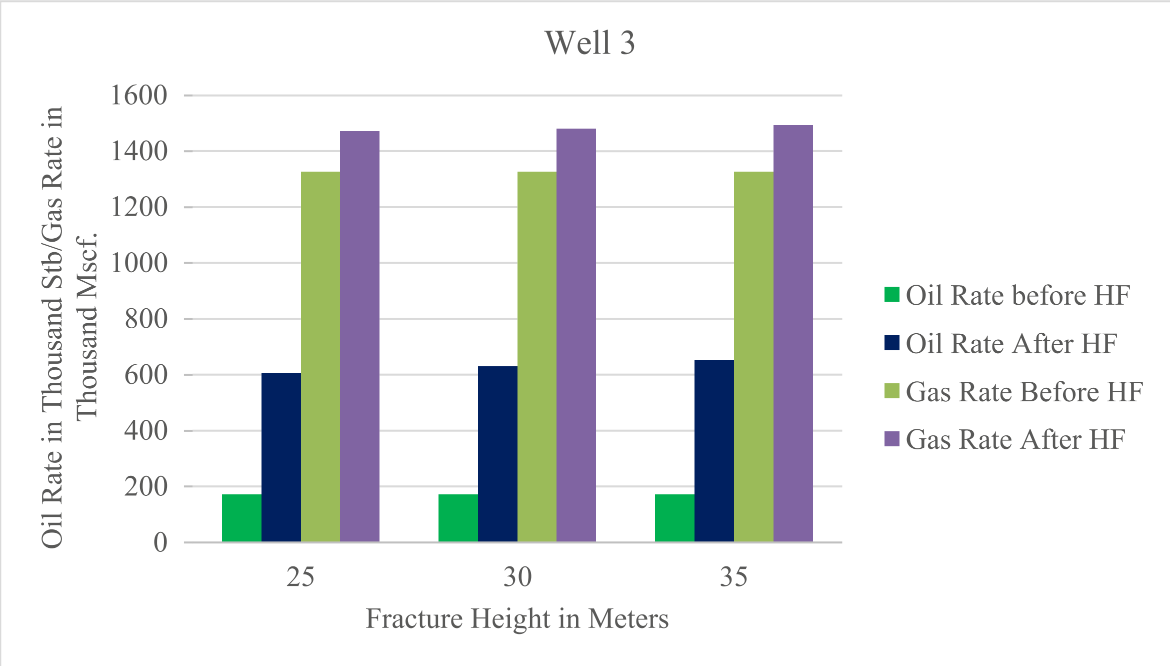

Fig 19*:* Results of Well-3, before and after hydraulic fracturing

4. Discussion

The importance of performing hydraulic fracturing can easily be observed from all of the obtained results. Because the production rate of oil and gas in unconventional reservoirs is very low, hydraulic fracturing is used. Countries such as the United States have billions of barrels of oil and gas on their land that are not considered economically viable due to their location in unconventional reservoirs. Hydraulic fracturing is used to access those potential oil and gas producing sites.
There are numerous hydraulic fracturing parameters that influence oil and gas production. The parameters we chose, namely the length, width, and height of the fracture, produced very convincing results. The reason for using these parameters is that the size of these above-mentioned parameters affects the use of proppants during hydraulic fracturing. Based on the analysis of the three vertical and horizontal wells used, it was observed that the greater the width, length, and height of the fracture, the greater the production rate. From the section 3, it is safe to conclude that all of these parameters are in fact interconnected. If the length of the fracture is long but the width and height are small, the well's productivity will be affected. Furthermore, the greater these parameters, the slower the decrease in reservoir pressure is achieved; the slower decrease in reservoir pressure is advantageous because it increases the time of production [5], [6] and [7].
The use of proppants is also critical when performing hydraulic fracturing. The rate at which they are introduced into the fracture, as well as their size and compressibility, are all affected by the results of hydraulic fracturing. The proppant used in hydraulic fracturing is 90% sand and water, with the remaining 1% consisting of guar and various surfactants. Proppants are used to keep fractures from collapsing back into the formation.

Along with that, proppants provide a route for trapped oil and gas to travel to the well. Further research opportunities were limited due to computational constraints. This software did not support the selection of proppant density, type, or shape. The research opportunities will lead to more detailed results on the parameters affecting the productivity of oil and gas in an unconventional reservoir as reservoir simulators continue to be developed.

The difference in production rates of Well 1, Well 2, and Well 3 in both horizontal and vertical wells is due to the fact that they are drilled in three different grid blocks, and each grid block in the simulator has its own oil and gas saturation rate.

5. Conclusion

This paper strives to evaluate and provides a new framework for unconventional gas recovery method and production system, allowing it to increase the productivity of the well and enhance the ultimate production of the well. The following points can be outlined as the main conclusion:

(1) A geological model having low porosity and permeability was prepared in order to have an unconventional reservoir. Since the productivity of unconventional reservoirs is very low, the hydraulic fracturing technique was applied in order to increase productivity. In order to perform the simulations on the geological model, three producing vertical and horizontal wells were prepared and run on the simulator.

(2) Out of many parameters, three parameters are observed to enhance oil and gas production using hydraulic fracturing. Those parameters were the fracture length, the fracture width, and the fracture height.

(3) After the successful running of simulations, it was observed that these parameters greatly influence the production of oil and gas. The results obtained were exponentially increased with the increase in the value of the width, length, and height of the fracture.

(4) It was also observed that the horizontal wells were higher compared to the vertical wells, thus also proving the fact that horizontal wells are always more suitable for unconventional reservoirs.

(5) In the future, it is highly recommended that the other parameters affecting the quality of hydraulic fractures such as a change in azimuth angle, skin factors, and different types of proppant values should be considered in order to observe the change in the production of oil and gas in the unconventional reservoir.

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Competing Interests

The author(s) declare no competing interests.

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