RESEARCH ARTICLE

Implementation of Hydraulic Fracturing Operation for a Reservoir in KRG

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ABSTRACT

This study focuses on procedures to enhance permeability and flow rate for a low permeability formation by creating a conductive path using the hydraulic fracturing model. Well data are collected from the Qamchuqa KRG oil field formation. A Fracpro simulator is used for modelling the hydraulic fracturing process in an effective way. The study focuses on an effective hydraulic fracturing design procedure and the parameters affecting the fracture design. Optimum design of fracturing is achieved by selecting the proper fracturing fluid with a suitable proppant carried in a slurry, determining the formation fracturing pressure, selection of a fracture propagation fluid, and also a good proppant injection schedule, using a high pump rate and good viscosity. Permeability and conductivity are calculated before and after applying the hydraulic fracturing. Fracture height, length, and width are calculated from the Fracpro software, among other parameters, and the production rate changes. From the results, it is observed that by using hydraulic fracturing technology, production will increase and permeability will be much higher. The original formation permeability is 2.55 md, and after treatment, the average fracture conductivity has significantly increased to 1742.3 md-ft. The results showed that average fracture width is 0.187 inch. The proppant used in this treatment has a permeability of 122581 md. The suitable fluid choice is hyper with an apparent viscosity of 227.95 cp, and the proper proppant type is Brady sand with a conductivity of 2173.41 md-ft. Fracture orientation from the Khurmala oil field in Kurdistan is vertical fractures produced at a depth of 1868 m. Fracture half-length, total fracture height, and average fracture width are 220 ft, 42 ft, and 0.47 inch, respectively. After fracturing, the maximum and average area of fracture are 33.748 and 17.248 ft^2, respectively. The recommended pump hydraulic horse power is 3200 HHP, and the total required fluid is 1076.3 bbl. In this study, hydraulic fracture is designed, and then, it has been analyzed after that production is optimized.

Keywords: Hydraulic fracturing, Proppants, Fracpro, Fracture width, Fracture length

1. INTRODUCTION

The economical production of hydrocarbons from trapped oil and gas reservoirs requires intelligent skills and advanced and cost-effective technologies. Hydraulic fracturing is a technology that is being used in the oil and gas industry for many decades to create highly conductive channels in formations having low permeability values. Multistage hydraulic fracturing along with horizontal drilling has proven to be a great achievement in oil and gas industry to enhance the production from unconventional reservoirs. Hydraulic fracturing is a well stimulation

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technique in which rock is fractured by pressurized liquid that is put under high pressure. The fracture is formed when the formation breaks down. At that moment, the injected fluids go through the fractures. Fluids free from solid particles are injected first till the fracture becomes sufficiently wide to receive a propping agent (which is usually well-sorted quartz sand grains, ceramic spheres, or aluminum oxide pellets). The fracturing fluids must not only break down the formation but also have to transfer the propping agent into the fracture (Bajestani and Osouli, 2015).

When oil in the formation cannot be produced as it is unable to flow into the wellbore owing to its low permeability, at that stage hydraulic fracturing should be used (Economides, 1992). Fracking can be used for more than one formation such as sandstone, shale, and carbonate. There are two types of fracturing: hydraulic fracturing and acid fracturing. The suitable design of hydraulic fracturing will improve its efficiency to increase production. A fracking site can be anywhere with natural gas from a remote desert to several hundred feet. It starts out with a long vertical hole known as a wellbore, drilled down through layers of sediment, when the well reaches 2500-3000 m, it is at its kickoff point. Where deviation can begin the process of horizontal drilling, it turns 90 degrees and extends horizontally for about 1.5 kilometers through a compressed black layer called the shale rock formation. Then a specialized perforating gun is lowered and fired, creating a series of small inch long holes. The well is ready for fracking. To begin fracking, fluid is pumped into the well at a high pressure. As a result, it cracks the shale rock, creating fractures through which the trapped gas and oil can escape (Economides, 1992). Hydraulic fracturing treatment is affected by several parameters, and some of them cannot be controlled while some others are controlled. The uncontrolled parameters are rock mechanics, reservoir and rock properties, reservoir temperature, formation depth, permeability, in-situ stress, rock modulus, and porosity. On the contrary, the controlled factors are pump size, pump rates, density, fracture fluid viscosity, fluid loss, and propping agent concentration. The crucial considerations about the fracturing design are fracture propagation, orientation, conductivity, and permeability. Fracture propagation and geometry is controlled by three main in-situ stresses; they are vertical stress, minimum stress, and maximum horizontal stress. After drilling, the maximum expenditure is well stimulation (Cleary, 1980).

Fracking is a well stimulation technology that has a long history. In the beginning, explosives were used to produce fractures that break down the formation and produce conductive channels. This method was applicable from 1890 to 1960. In 1930, acid was used to perform the process of stimulation. The concept of hydraulic fracturing of oil and gas formations for accelerating oil production was imagined after a long study on cement squeezing into formations by pressurizing. The first attempt of hydraulic fracking was in the United States in 1947 in the Chase formation at 2400 ft. Hydraulic fracturing was applied for a gas well for the purpose of increasing productivity as it was a low productivity well. This was in the Hugoton field in western Kansas, Well No.1. In this attempt, napalm – thickened gasoline – was injected without using any proppant. After that, it was found that using a proppant is very crucial to hydrocarbon recovery (Jones and Britt, 1997). This was the first well stimulation treatment that was directly compared with acidizing. Through this study, mechanical rock characteristics such as fracture propagation, shape, and orientation are explained (Cleary, 1980).

This technique was first introduced in the industry in 1948 by J. B. Clark and licensed in 1949. At first, fracture design consisted of a minor amount of fluid and proppant volumes. This was to bypass near wellbore damage. From 1970 to 1980, fracking developed to enhance production performance and produce unconventional reserves from tight gas formation. In 1980, TSO (tip screen-out) fracking was demonstrated and used for the purpose of enhancing fracture conductivity and well performance (Geertsma and Haafkens, 1979).

Frac packing, which is a combination of gravel packing and TSO fracking, was conducted in 1990. This development was used to control high permeable unconsolidated formations. Proper and cleaner fluid systems (crosslinkers, breakers, and gellants) were demonstrated. For deep-well applications, higher-strength synthetic proppants were presented. With the progress of microseismic monitoring, fracture dimensions can now be calculated by using microseismic mapping. This was a significant development as, at first, the process of fracking was very complicated because the events were not directly shown. This problem was solved by indirect analyses based on flow rate and pressure of wellbore (Wieland, 1971).

The first fracking treatment to use one-half million pounds of proppant was completed in Stephen country in October 1968 by the Pan American Petroleum Corporation. In 1991, a French gas and oil institute survey debated that 71% of all wells are completed by the use of fracture stimulation. Today, the hydraulic fracturing technique is designed by using different types of software. The main types are fracture design programs and fracture simulator. Trends in hydraulic fracturing have shown an increase in the development of fracturing jobs in the recent years. Development of sophisticated technology in both pumps and fracturing fluids has led to an increase in productivity and flow rate from tight reservoirs; however, mechanical limits have not been developed correctly to overcome problems such as a high pump rate and high viscosity fracturing fluid (Wieland, 1971).

There are three main reasons for performing the hydraulic fracturing stimulation: First, to bypass neighboring wellbore damage; second, to produce long conductive channels for maximizing permeability; and third, to manage the reservoir (Cleary, 1980). Oil and gas cannot be produced at their optimum level as radial flow into the wellbore is not the best flow regime. The reason for that is the fluid which goes through smaller areas will minimize production. Accurate design of the hydraulic fracturing approach will change radial flow to nearly linear to increase productivity. Cementing, completion, and drilling operations reduce permeability near the wellbore which in turn reduces production. The hydraulic fracking technique overcomes this problem (Economides, 1992). Carbonate is a dominant reservoir in the Kurdistan region. Carbonate has a complex porosity and permeability. Carbonate formation with high natural fracture results in a sharp decrease in production after a short period of time. A suitable and accurate hydraulic fracturing design for this complex formation would be a very important solution to minimize this reduction in permeability.

2. FRACTURE MODELING

The modeling process starts from proppant selection and ends in optimization of the hydraulic fracturing job. Before starting, all the equipment must be tested to make sure that they are working in a proper way. Any leak must be determined and should be eliminated. Fracpro is one of the important programs used to model and design hydraulic fracturing. This software will enable the user to design the length, width, and all other required parameters. Later, the selection of the most appropriate parameters and results will be performed according to the planned scenario as shown in Table 1.

Table 1: Steps of achieving hydraulic fracturing

1 - Fracture Design	
Reservoir Parameters	Fluid & Proppant selectioin

2 - Fracture analysis
Treatment schedule

3 - Production analysis
Well production

4 - Economic optimization
Optimizatioin of economic data

3. FIELD DATA

Tables 2-5 show the collected data from the Upper Qamchuqa formation in the KRG oil field. The data are divided into several parts such as formation gradient, formation evaluation, downhole data, and reservoir data.

Table 2: Formation gradient data

Number	Holes	Formation fracture gradient (psi/ft)
1	1st Hole / 17 1/2" (surface-750 m)	0.65
2	2nd Hole / 12 1/4" (750-1280 m)	0.55
3	3rd Hole / 8 1/2" (1280-2138 m)	0.50

Table 3: Formation evaluation data

Zones	Top (m)	Bottom (m)	Dominant lithology	Total porosity (%)	Formation tops
1	1770	1810	Dolomite	15-20	Upper Qamchuqa
2	1810	1825	Dolomite	15-20	
3	1825	1868	Dolomite and Limestone	8-15	

Table 4: Downhole data

Well no.	Tubing dimensions		Casing dimensions		Total depth
	ID inches	Depth (m)	ID inches	Depth (m)	
VR. 1	3 ½	1765	6 5/8	1800	1800

Table 5: Reservoar data

Parameters	Quantity
Gas gravity	0.73
Water salinity	150000 PPM
Gas FVF	0.03909 RB/Mscf
Porosity	0.2
Permeability	2.55 MD
Reservoir pressure	2730.5 Psig
Reservoir temperature	159 °F
Perforation interval	1774-1815 m

4. ANALYSIS AND DISCUSSION OF RESULTS

In the Khurmala Kurdistan Upper Qamchuqa oil formation, before using the hydraulic fracturing process, the zone was very tight, it was about 2.55 md and the production was limited. However, after using hydraulic fracturing on VR.1 well, conductivity has increased in the fracture zone to 1742.3 md-ft, as shown in Table 6 (Sarbast, 2019).

Table 6: Summary of fracture conductivity information

Property	Value	Property	Value
Avg. conductivity* (md-ft)	1742.3	Avg. frac. width (closed on prop) (in)	0.187
Dimensionless conductivity**	3.14	Ref. formation permeability (md)	2.55
Proppant damage factor	0.52	Undamaged prop perm at stress (md)	255374
Apparent damage factor***	0.00	Prop perm with prop damage (md)	122580
Total damage factor	0.52	Prop perm with total damage (md)	122580
Effective propped length (ft)	217	Proppant embedment (in)	0.009

* All values reported are for the entire fracture system. Actual conductivity could be lower if equivalent multiple fractures have been modeled
** Total damage factor and proppant embedment have been applied
*** Apparent damage owing to non-Darcy and multi-phase flow
After hydraulic fracturing, average conductivity is 1742.3 md-ft. before it was 2.55 * 41 = 104.55 md-ft.

4.1. Fracture Geometry

Table 7 shows detailed information about the resulting fracture geometry induced by the Fracpro simulator.

Maximum Area of the fracture = length of fracture * Max. width of fracture

$= 2\ (220) * 0.0767 \quad = 33.748\ ft^2$

Average area of the fracture = length of fracture * Avg. Width of fracture

$= 2\ (220) * 0.0392 \quad = 17.248\ ft^2$

Table 7: Fracture geometry summary

Property	Value	Property	Value
Fracture half-length (ft)*	220	Propped half-length (ft)	217
Total fracture height (ft)	42	Total propped height (ft)	305
Depth to fracture top (ft)	5761	Depth to propped fracture top (ft)	5762
Depth to fracture bottom (ft)	6070	Depth to propped fracture bottom (ft)	6067
Equivalent number of multiple fracs	1.0	Max. fracture width (in)	0.82
Fracture slurry efficiency**	0.59	Avg. fracture width (in)	0.47
Avg. proppant concentration (lb/ft²)	1.63		

* All values reported are for the entire fracture system at a model time of 46.70 min (end of Stage 10 Main frac flush)
** The value is reported for the end of the last pumping stage (Stage 10, Main frac flush)

4.2. Fracture Pressure

Table 8 indicates that closure stress gradient is equal to 0. 723. This value has been obtained from Fracpro software, which is less than the formation overburden pressure. This leads to vertical shape fracture in the fracture zone. It means that the proppants have entered all the pores of the fracture, and oil can be produced from the fractures without losing the proppants which helps keep the fracture open.

Table 8: Fracture pressure summary

Property	Value	Property	Value
Model net pressure (psi)*	334	BH fracture closure stress (psi)	4234
Observed net pressure (psi)**	0	Closure stress gradient (psi/ft)	0.723
Hydrostatic head (psi)***	2569	Avg. surface pressure (psi)	2204
Reservoir pressure (psi)	2730	Max. surface pressure (psi)	4176

* Averages and maxima reported for Main Frac stages.
** Values reported for the end of the last pumping stage (Stage 10, Main frac flush)
*** Value reported for clean fluid

5. OPERATION SUMMARY

Table 9 shows the required design for fracturing pump and proppant properties. The recommended pump hydraulic horse power after adding the safety factor is 3200 HHP. The total volume of the fluid required is 1076.3 bbl

Table 9: Hydraulic Fracturing operation summary

Property	Value	Property	Value
Total clean fluid pumped (bbls)*	1076.3	Total proppant pumped (klbs)	172.3
Total slurry pumped (bbls)	1261.8	Total proppant in fracture (klbs)	172.1
Pad volume (bbls)	309.5	Avg. hydraulic horsepower (HHP)	1619
Pad fraction (% of slurry vol)**	27.5	Max. hydraulic horsepower (HHP)	3067
Pad fraction (% of clean vol)**	31.7	Avg. btm. slurry rate (bpm)	29.9

* Averages and maxima reported for Main Frac stages. Total reported for all injections combined.
** Based on following volume ratio of stage types: Main frac pad / (Main frac pad + Main frac slurry), and excluding flush.

Table 10 shows the distance from the well and fracture system width.

Table 10: Distance from the well versus fracture system width

Distance from Well,ft. (ft)	Fracture System Width, in. (in)
21.7	0.812
43.5	0.800
65.2	0.780
87.0	0.750
108.7	0.710
130.5	0.658
152.2	0.590
174.0	0.501
195.7	0.376
217.5	0.135

Figure 1 shows that the fracture width is decreasing with an increasing distance from the well. From the graph, it can be concluded that the width of the fracture is sufficient for the current fracturing job.

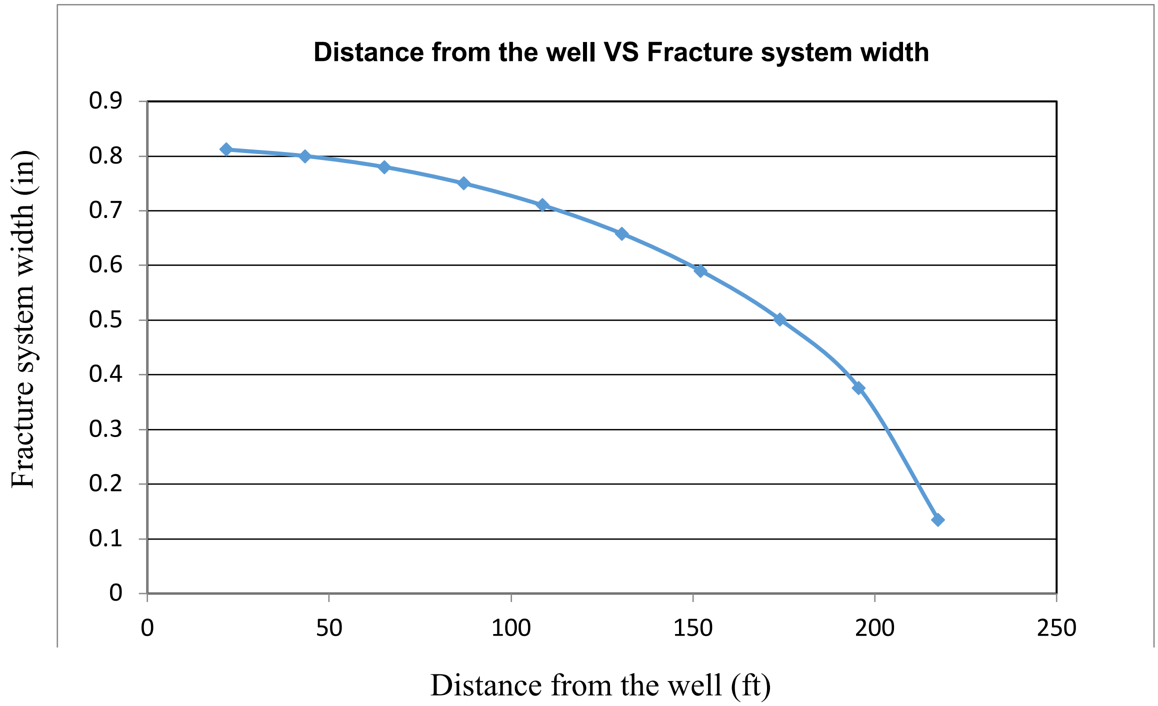

Figure 1. Distance from the well versus fracture system width

Table 11 gives the relationship between distances from the well by feet against conductivity per frac. in md-ft.

Table 11: Distance from the well VS conductivity per frac

Distance from the well (ft)	Conductivity per frac (md-ft)
21.7	2713.6
43.5	2669.9
65.2	2590.7
87	2377.6
108.7	2229.7
130.5	2008.1
152.2	1749.9
174	1420.4
195.7	1009.4
217.5	0

Figure 2 shows that as the distance from the well increases, the conductivity of the fracture decreases. This means that the fracture conductivity is maximum at the well center.

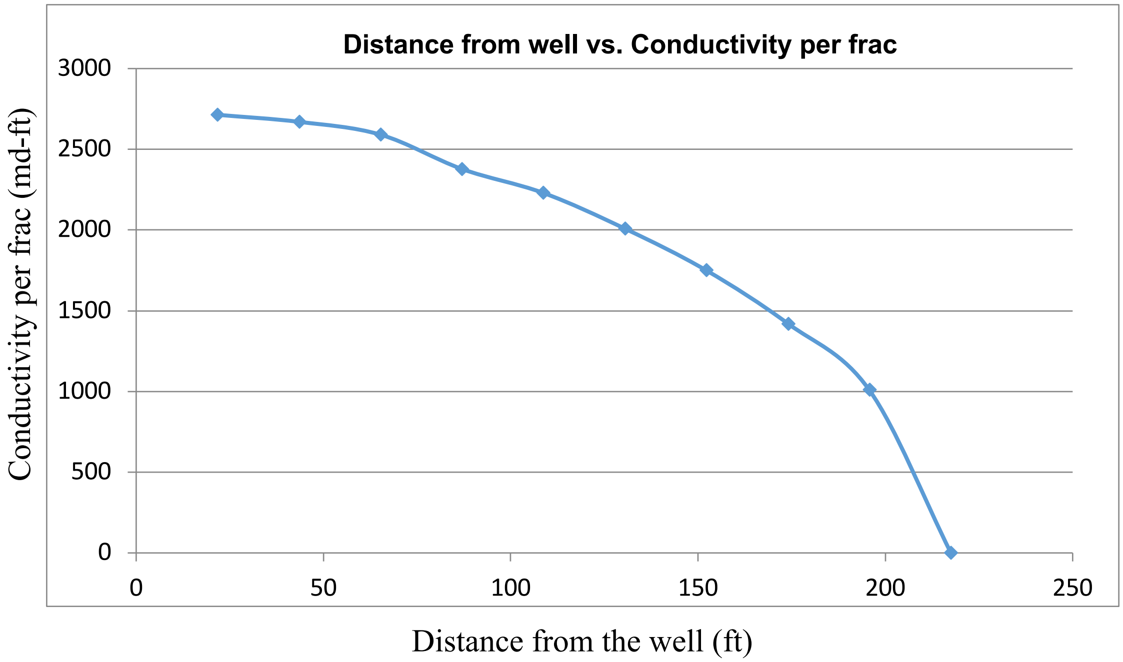

Figure 2. Distance from the well versus conductivity per frac

Table 12 shows the relationship between distances from the well against proppant concentration per frac.

Table 12: Distance from the well versus proppant concentration per frac

Distance from the well (ft)	Proppant conc. per frac (Ib/ft^2)
21.7	2.45
43.5	2.41
65.2	2.35
87	2.17
108.7	2.04
130.5	1.86
152.2	1.64
174	1.37
195.7	1.02
217.5	0

As shown in Figure 3, the proppant concentration per frac is inversely proportional to distance from the well. This trend shows that the fracturing fluid is well sorted around the well, and thus the fracturing job is successful.

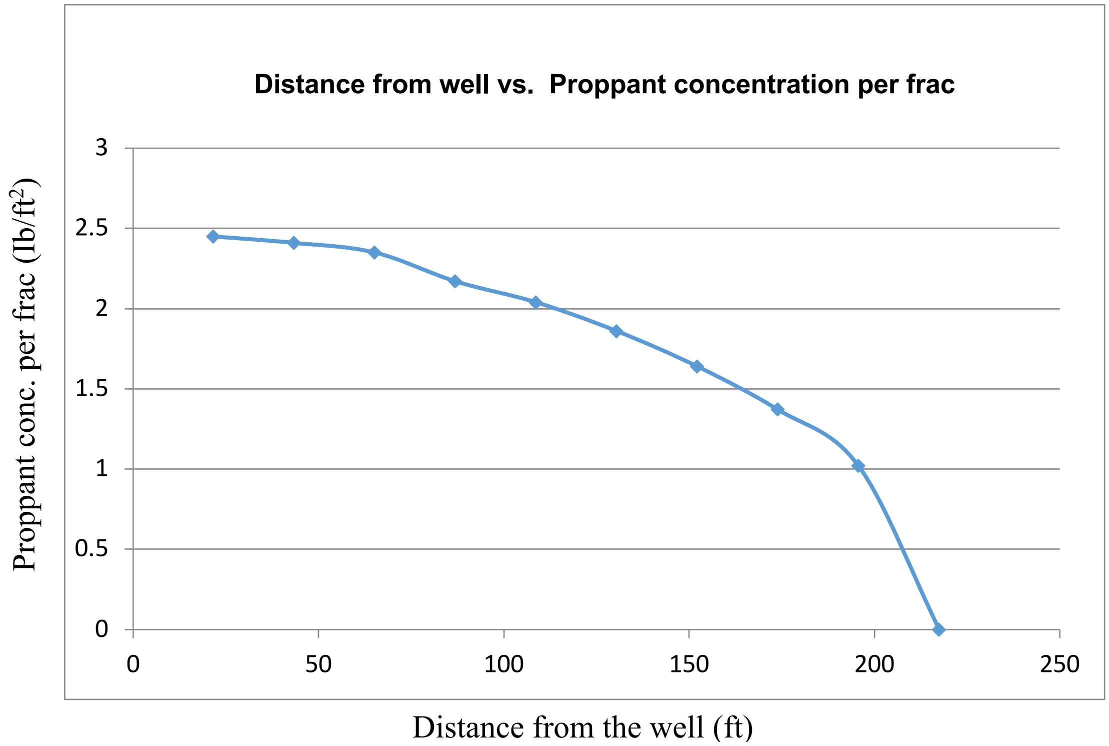

Figure 3. Distance from the well versus proppant concentration per frac

6. VERIFICATION OF THE SUCCESS OF THE TWO DESIGNS

In this section, two graphs are compared. The first graph is given from a case study built in Fracpro software. The second graph is the result of a fracturing job production plot of the Kurdistan Khurmala oil field after using Fracpro software. From the two graphs, it is observed that the Fracpro software result for the Kurdistan Khurmala oil field is acceptable. The second graph gives the same trend as the first in terms of hydrocarbon rate and cumulative hydrocarbon production. This gives us an idea that the fracturing job in the simulator has a good match with another scholars' graph.

Figure 4 represents a successful design of the hydraulic fracturing operation adopted by the current software.

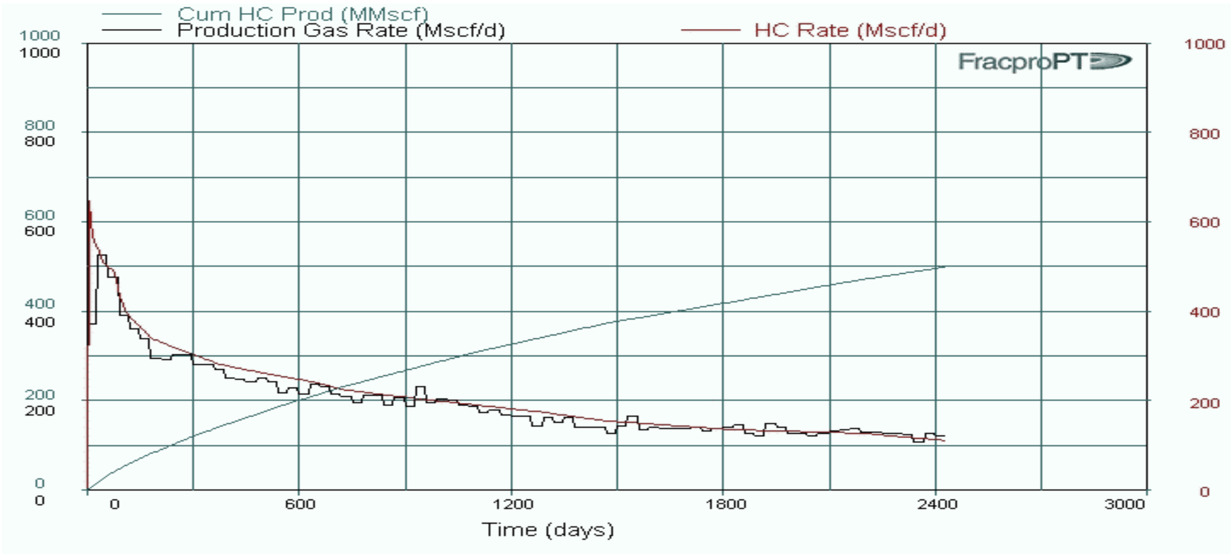

Figure 4. Verification of the success design inside Fracpro software

Figure 5 represents the result of the present research. It is found that both cases are matched which indicates the success of the proposed design for all parameters included in the developed scenarios of this research. It also shows that the accumulative hydrocarbon production is increasing steadily, and the white line shows the hydrocarbon rate from the start until the end. From the two lines, it can be concluded that the job was successful in increasing the permeability of a tight formation and creating high fracture conductivity from a tight zone.

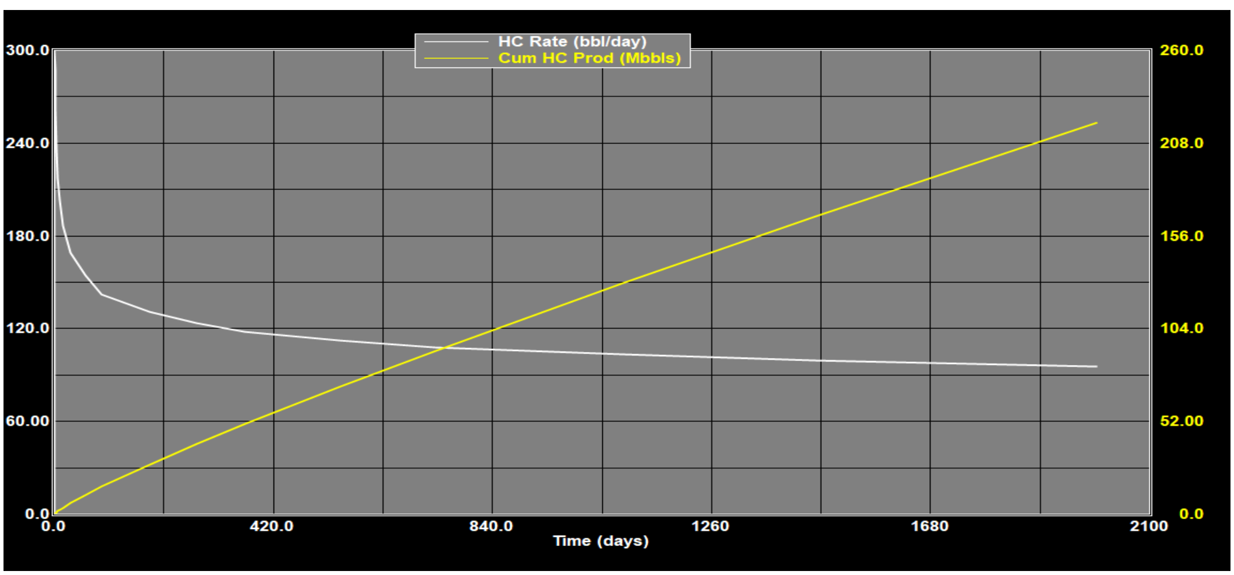

Figure 5. Production analysis curve

7. CONCLUSION

The following conclusions can be drawn from this research:

- The suitable fluid choice is hyper with an apparent viscosity of 227.95 cp.
- The successful proppant type is Brady sand with a conductivity of 2173.41 md-ft and **a** concentration of 1.63 Ib/ft^2. The recommended pump hydraulic horse power is 3200, and the total required fluid is 1076.3 bbl.
- Fracture orientation for the Kurdistan Khurmala oil field is vertical fractures produced in a depth of 1868 m. Fracture half-length, total fracture height, and average fracture width are 220 ft, 42 ft, and 0.47 inch, respectively.
- In the Khurmala Kurdistan Upper Qamchuqa formation, permeability before using the hydraulic fracturing process was very tight at about 2.55 md. After using hydraulic fracturing, the permeability increased to 29.04 md. The conductivity of the formation has changed from 104.55 md-ft to 1742.3 md-ft.

8. RECOMMENDATIONS

Based on this study, the following are recommended:

- To use a different hydraulic fracturing software and compare using different types of proppants and fluids.
- To conduct both theoretical and experimental work and compare the results.

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