Case study

The Effect of Fracture Geometry on Proppant Size in Hydraulic Fracturing Design Optimization

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ABSTRACT

Problems with sandstone reservoirs include the small initial permeability which will hinder fluid flow from the reservoir to the bottom of the well. This will cause a small initial productivity due to a small initial permeability so that it will be more difficult for oil to flow from the drain radius which causes a small Productivity Index value. The Hydraulic Fracturing stimulation method is applied to increase the permeability value by designing the fracture geometry, proppant size according to the fracture geometry, so that it is hoped that it can increase the permeability, transmissivity, production rate and productivity index.

Keywords: Low permeability, low Productivity Index, Fracture Geometry, Proppant.

1. INTRODUCTION

Well FM-013, like other wells in this field, has a productivity index of 0.4 bbl/day/psi. The small productivity index value is caused by the small initial permeability, which is only 5 mD. For this reason, it is necessary to develop a stimulation method using Hydraulic Fracturing which is expected to overcome this problem by improving the permeability of the rock or formation around the drill hole at the drain radius [1].

The application of hydraulic fracturing techniques to wells with low productivity often faces challenges in producing sufficient oil and gas production to be economical. Therefore, the hydraulic fracturing technique has become a promising solution to increase the productivity of these wells. This research describes the basic principles of hydraulic fracturing, including the working mechanism and components involved in the process. In addition, this research will discuss factors that influence the success of hydraulic fracturing in wells with low productivity, such as the geological nature of the rock formation, reservoir pressure, and the type of fracturing fluid used [2].

The Perkins-Kern-Nordgren method is one of the approaches used in hydraulic fracturing modelling to estimate fracture geometry in rock formations. This method assumes that hydraulic fractures can be considered as a series of elliptical fractures with the main direction of the fracture following the direction of the maximum shear stress in the rock. This method can help in predicting the pattern and size of fractures that may form during the hydraulic fracturing process [3].

This research scope discusses the selection of proppant sizes used in hydraulic fracturing (fracking) techniques as well as the proppant sizes that best suit the geometry of fractures in rock formations. Hydraulic fracturing is a technique commonly used in the oil and gas industry to enlarge fractures in rock formations, so that oil or gas can flow more easily to the surface. Proppants, such as sand, ceramic, and gravel, are used to keep fractures open and prevent fractures from closing again after applying pressure. This research also covers the various types of proppants used, including natural and artificial proppants. The types of proppants that will be discussed include silica sand, ceramics, coated resin, gravel, and other innovative proppant materials. In addition, this paper will discuss the effectof proppant size on fracture performance. The proppant sizes that will be discussed include mesh size, diameter, size distribution, and their relationship to the hydraulic properties of the fracture [4].

The hydraulic fracturing method is used to increase the flow of hydrocarbons from reservoir rock formations by creating fractures in the rock using high pressure fluid and proppant (porous granules) to keep the fractures open. Various approaches and techniques are used in planning fracture geometry and determining optimal proppant size. Predictions of oil or natural gas production rates can be optimized by considering optimal fracture design and proppant size. Factors such as injection pressure, fluid viscosity, proppant concentration, as well as the geological characteristics of the reservoir rock formation will be discussed in the context of more accurate production rate predictions. [5]. By choosing the right size of proppant and the right shape and quantity, it is hoped that a good fracture geometry will be formed so that the productivity value will be good.

2. METODOLOGI

A deep well producing fluid from the formation will one day experience production problems. The problems that arise are characterized by the small production rate. Well FM-013 experienced a similar thing due to the small permeability around the drill hole which was only 5 mD. So it is necessary to make efforts to increase productivity by carrying out stimulation in the form of Hydraulic Fracturing. Before implementing Hydraulic Fracturing, it is necessary to design the fracture geometry. The method used in this fracture geometry is the Perkins, Kern, and Nordgren (PKN) method. The use of the PKN method is due to the relatively thin perforation interval in Well FM-013.

In planning Hydraulic Fracturing, several scenarios are carried out to determine the proppant size, proppant type, and proppant volume in order to obtain the best results. The expected results in the form of good well productivity include several parameters, namely average formation permeability, Productivity Index, and production rate. In general, the fracture geometry model is as follows: Two-dimensional (2D) model, where this model can be used to predict the direction and shape of fractures in rock formations that have been fracked [6]. Pseudo three-dimensional (P3D) model where in this model the height of the fracture increases, the fluid flow is 1D or 2D. Then the three-dimensional (3D) model is a model with the intersection of three planes which is used to describe fractures formed as a result of hydraulic pressure in rock formations. This model can be used to predict the direction and shape of fractures in rock formations. In this research, the model used is only a 2D fracture geometry model because the mathematical and graphical calculations are easier and more practical than other models [7]. In the 2D fracture model there are 3 types of fracture geometry, as follows: Howard & Fast (PAN American) model, PKN model and KGD model. For more details, the research flow chart can be seen in Figure 1, below.

The methodology in this research can be described in 3 main steps as follows:

1. Evaluation of hydraulic fracturing planning

Important hydraulic fracturing planning parameters include the type of fracturing fluid, injection pressure, fluid flow, proppant (supporting material), number and location of injection points, and selection of fracture zones.[8]

2. Evaluation of the implementation of hydraulic fracturing

The hydraulic fracturing process consists of several stages, namely location selection, well planning, implementation, and monitoring.[9]

3. Evaluation of the results of implementing hydraulic fracturing

Results evaluation is carried out by calculating several aspects such as fracture geometry, proppant selection, fracturing fluid selection, injection pressure calculations and increasing production performance.

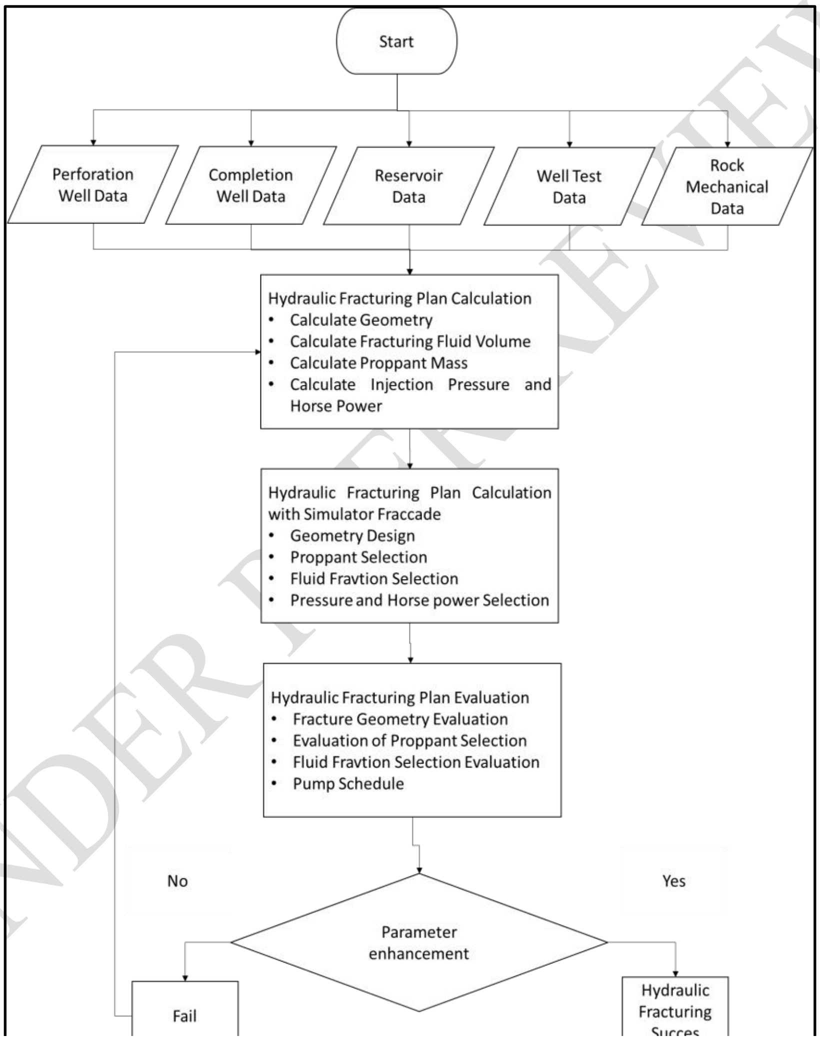

Figure 1. Flow Chart

3. RESULTS AND DISCUSSION

3.1. Field Data

The materials needed to evaluate hydraulic fracturing in sandstone formations are Reservoir data (Table 1), Well Completion Data (Table 2), and Perforation data (Table 3).

Table 1. Reservoir data

Parameter	Mark	Units
Well Type	Oil	
Reservoir thickness	45,9	ft
Reservoir Pressure	2530	psi
Water Saturation	31	%
Pwf	1600	psi
Bottom Hole Temperature	210	^{o}F
Porosity	20	%
Permeability	2.3	mD
SG Gas	1.1	
Gas Components (N2)	4.1	%
Gas Components (CO2)	44.1	%
SG Water	1	
Water Salinity	11961	Ppm
Water Compressibility	1.00E-06	1/psi
Gradient fracture	0.81	psi/ft

Table 2. Well completion data

Parameter	Mark	units
Case O.D	7	inch
Casing ID	6,366	inch
OD Tubing	3.5	inch
Tubing ID	2,992	inch
Hole Size	8.5	inch
Well radius (Rw)	0.125	Ft
Drain fingers (Re)	820	Ft
Packer Depth (MD)	7530	Ft
Top Performance (MD)	7510	Ft
Bottom Performance (MD)	7560	Ft
Well Depth	7700	Ft

Table 3. Perforation data

Parameter	Value	units
Top Performance (MD)	7510	ft
Bottom Performance	7560	ft

(MD)		
Performance intervals	50	Ft
Shoot Density	5	spf
Entrance Dia	0.4	inch

3.2. Analisis and Result

3.2.1. Fracture Geometry

To calculate the length of the fracture, it can be calculated using the equation :

$$Xf = \frac{(w+2Sp)qi}{4\pi hfCl^2}\left[\exp(\beta^2)\, erfc(\beta) + \frac{2\beta}{\sqrt{\pi}} - 1\right] \quad (1)$$

To calculate fracture width, you can use the equation:

PKN method

$$w_{(0)} = 9.15^{\frac{1}{2n^F+2}}\ x\ 3{,}98^{\frac{n^F}{2xn^F+2}} x \left[\frac{1+2{,}14\ x\ n^F}{n^F}\right]^{\frac{n^F}{2n'+2}} x\ K'^{\frac{1}{2n^F+2}} \left[\frac{q_i^{n^F} h_f (1-n^F) x_f}{E'}\right]^{\frac{1}{2n^F+2}} \quad (2)$$

Method KGD

$$w_{(0)} = 11.1^{\frac{1}{2n^F+2}}\ x\ 3{,}24^{\frac{n^F}{2n^F+2}}\left[\frac{1+2n^F}{n'}\right]^{\frac{n^F}{2n^F+2}} x K'^{\frac{1}{2n^F+2}}\left[\frac{qi^{n^F} X f^2}{hf^{n^F} E'}\right]^{\frac{1}{2n^F+2}} \quad (3)$$

Assuming that the shape factor:

$$w = \frac{\pi}{5}\, w(0) \quad (4)$$

Calculating fracture conductivity using the equation :

$$Wkf = kf\ xw \quad (5)$$

Fracture geometry evaluation was carried out using the 2D PKN method. Manual calculations were carried out with the following data:

Table 4. Fraction geometry calculation data

Data Parameters	Mark	Unit
Young's Modulus (E)	3.46E+06	Psi
Poisson Ratio (v)	0.26	
n'	0.65	
K'	0.00296	lb. sec1/2/ft ^{2}
Injection Rate (qi)	20	Mr
h_f	45,9	Ft
X_f	160.2	Ft
Koeff leak off total (CL)	0.00028	ft/min $^{1/2}$
Total treatment time (ti)	16.5	Min
Spur loss (Sp)	0	gal 100ft ^{2}

- Initial length of fracture iteration (Xf(iteration)) = 160.2 ft or 48.82 m. This price is used because it is the result of the mainfrac software Fraccade. maximum fracture width using the equation:

$$W_{(0)} = 9{,}15^{\frac{1}{2n'+2}}\, x\, 3{,}98^{\frac{n'}{2n'+2}}\, x\, \left[\frac{1+2{,}14n'}{n'}\right]^{\frac{n'}{2n'+2}} x K'^{\frac{1}{2n+2}}\, x \left[\frac{qi^{n'}\, x\, hf^{(1-n')} x\, Xf}{E}\right]^{\frac{1}{(2n'+2)}} \quad (6)$$

$$W_{(0)} = 9{,}15^{\frac{1}{2(0{,}65)+2}}\, x\, 3{,}98^{\frac{0{,}65}{2(0{,}65)+2}}\, x\, \left[\frac{1+2{,}14(0{,}65)}{0{,}65}\right]^{\frac{0{,}65}{2(0{,}65)+2}} x 0{,}00296^{\frac{1}{2(0{,}65)+2}}\, x$$

$$\left[\frac{20^{0{,}65} x\, 45{,}9^{(1-0{,}65)} x\, 160{,}2}{3710853{,}71}\right]^{\frac{1}{(2(0{,}65)+2)}}$$

$$W_{(0)} = 0{,}073196\, ft$$

•Find the average fracture width (W_{avg}) with the equation:

$$W_{avg} = \frac{\pi}{5} X W_{(0)} \quad (7)$$

$W_{avg} = \frac{3{,}14}{5} X\ 0{,}02231$
$W_{avg} = 0{,}04596\ ft$
$W_{avg} = 0{,}01401\ m$

• Calculate fracture conductivity using the equation:

$$Wkf = W\ x\ k\ proppant \quad (8)$$

Comparison of actual geometry, design, and manual calculations

The comparison between actual and design and manual can be seen in Table 5, below:

Table 5.Actual Comparison, Design and Manual Fracture Geometry Calculations

Parameters	Actual	Design	Manual Calculation
Fracture Length (Xf)	167.4 ft	160.2 ft	160.41 ft
Fracture Height (hf)	45.7 ft	45.9 ft	45.9 ft
Fracture Width (W_0)	0.698 in	0.695 in	0.878 in
Average width (w)	0.345 in	0.340 in	0.5518 in
Fracture Conductivity (Wkf)	11526ms ft	11488 ms ft	13192.87 ms ft

The following are the results of fracturing carried out on the AFG-01 Well based on the parameters that have been obtained

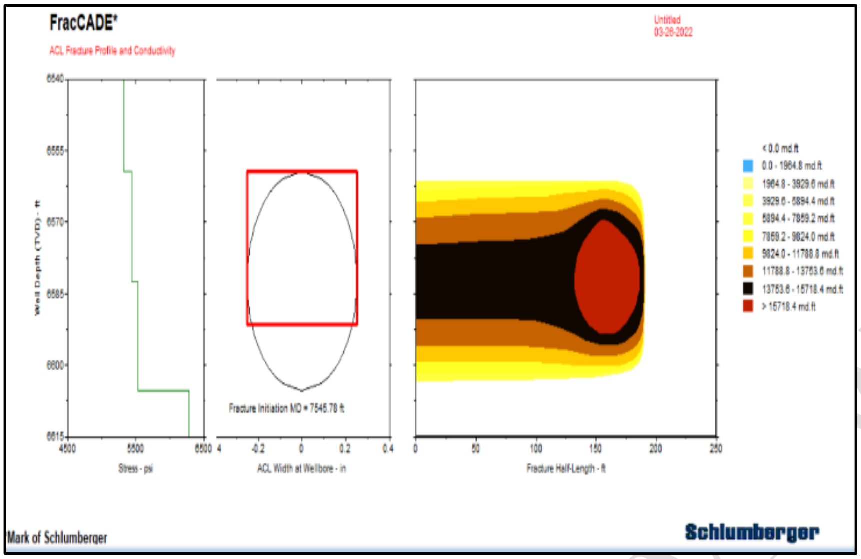

Fig.2. Fracture geometric

3.2.2. Proppant Size Design

To determine the size of proppant used, it is necessary to determine the fracture conductivity, productivity index and maximum flow rate for each proppant size. Following are the calculation results for each proppant size to determine the size of the proppant to be used.

Table 6. Proppant size parameters

	Proppant Size					Unit
	12/18	16/20	20/40	30/50	40/70	
Conductivity Formation	5696	5885	6047	4265	834	md ft
Productivity Index	3.51007	3.41684	3.74077	3.69878	3.65679	
Production Rate Maximum	118.22935	115.0891	126	124.58565	123.17131	BOPD

Based on the table above, a graph of Fracture Conductivity vs Propant Size can be plotted, which can be seen in Figure 3, below.

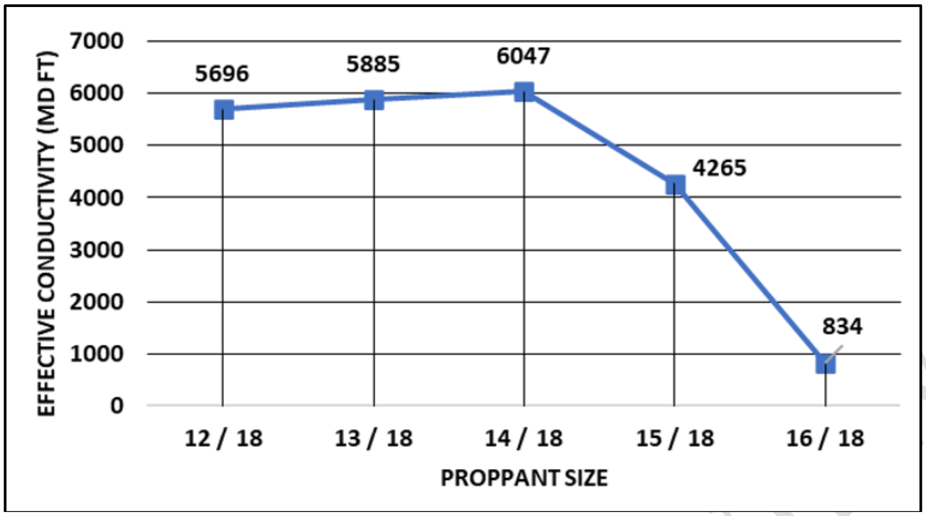

Fig. 3. Fracture conductivity vs proppant size

Meanwhile, the graph of Productivity Index Versus Propane Size can be seen in Figure 4 below.

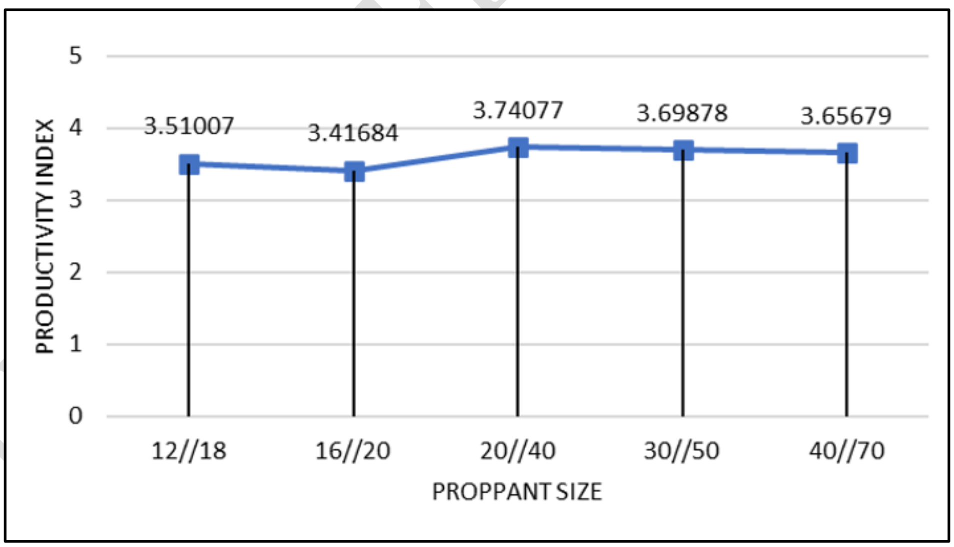

Fig. 4. Productivity index vs proppant size

<u>3.2.3.</u> <u>Injection Pressureand Horse Power Pump</u>

The following is the data needed to determine the injection pressure at the surface, where in Table 7 the surface injection pressure data.

Table 7.Surface injection pressure calculation data

Parameters	Value	Units
Injection Rate (Qi)	20	bpm
ID DP	2,992	in
K' (Consistency Index)	0.16	
n'(Flow Behavior Index)	0.24	
Fracturing fluid density	8.33	ppg
	62,4	lb/ft^3
tubing length	2301	M
	7550	Ft
Specific gravity frack fluid	1.01	
N	100	Perforations
perforation diameter	0.4	in
	0.033	Ft
	3	
Mid perforation	2297	M
	7535	Ft
Gradient cracked	0.83	psi/ft
P_{net}	2960	Psi
Closing Pressure	2236	Psi

In this section, we will discuss calculations for evaluation of treatment for the implementation of hydraulic fracturing, including calculations of injection pressure and pump horse power. To calculate injection pressure, the following formula is used:

WHTP=BHTP+Ppf+Pf-Ph (9)

To calculate the horse power of the pump, the following formula is used:

HHP= (q_iP_wtr)/40.8 (10)

Calculating wellhead pressure

WHTP=BHTP+Ppf+Pf-Ph (11)

WHTP=4641.56+0.3126+3920.86-3263.86

WHTP=5298.87 psi

Calculating the Horse power of the pump

HHP= (q_iP_wtr)/40.8 (12)

HHP= ((20)(5437.2))/40.8

HHP=2597.48 HP

3.3. DISCUSSION

1. Increased formation permeability

Calculation of the average permeability value was carried out using the Howard and Fast equation. The following is the formula used to calculate the average formation permeability:

$$K_{avg} = \frac{\log\left(\frac{re}{rw}\right)}{\left(\frac{1}{Kf} x \log\frac{xf}{rw}\right) + \left(\frac{1}{Kf} x \log\frac{re}{xf}\right)} \quad (13)$$

Implementing a hydraulic fracturing simulation on a rock formation can increase the rock permeability value, which can affect the fluid flow rate in the formation where the hydraulic fracturing simulation is carried out. Permeability increased from 2.3 mDto 11.97 mD.

2. Skin Factor

In productive formations that have experienced damage, the Skin Factor value will be (+), while in productive formations that have undergone repair due to stimulation with hydraulic fracturing the skin factor will be (-). In this case, the initial skin factor of 1.2 after stimulation changed to - 6.31, meaning improvement occurred.

3. Increase in Productivity Index

The methods used to calculate the productivity index are the Cinco-Ley, Samaniago, and Dominiques methods. This method is a method used in fracture conductivity and for quick evaluation of the estimated increase in productivity (K2P) in hydraulic fracturing. The Cinco-Ley, Samaniago, and Dominiques methods are used to calculate PI by mathematically modeling fluid flow in reservoirs and wells. This method also considers skin factors and pressure changes in the reservoir [10]. This method assumes a cylindrical dewatering area, cased hole well completion, the reservoir is a homogeneous reservoir, limited by an impermeable layer above and below the productive layer., has a constant productive layer thickness, permeability and porosity, the produced fluid has constant compressibility and viscosity values, Fluid produced through vertical fracture, fully penetrating and finiteconductivity fracture, Gravity effects are ignored and the flow is laminar type.

Here's the mathematical calculation:

$$Fcd = \frac{wKf}{Kxf} \quad (14)$$

Information :

W = Average fracture width (ft)
Kf = Proppant permeability, (ms)
Xf = Fracture length of one wing (ft)

The increase in productivity index is expressed by increasing the production rate, namely from 28 Bopd to 129 Bopd so that the productivity index increases from 0.4 bbl/day/psi to 3.74 bbl/day/psi. Increasing the Inflow Performance Relationship will be in accordance with increasing the Productivity Index. The following is a comparison table before and after hydraulic fracturing is carried out. Shown in Table-8 below.

Table 8.Increased production performance after hydraulic fracturing

Parameters	**Befor e**	After	**Units**	**% Increase**

Average permeability	2,3	11.97	mD	420,4 %
Skins	+1,2	-6.31		improvement
Production rate	28	129	Bopd	360,71 %
Productivity Index	0,4	3.74	Bopd/psi	835

1. Inflow Performance Relationship (IPR)

To calculate the production rate, the Pudjo Sukarno method is used, where this method is one of the methods used to calculate the IPR based on well production fluid data. The empirical equation used describes the relationship between fluid flow rate and the pressure difference between the well and reservoir [11]. Based on the IPR graph, the oil rate obtained after hydraulic fracturing was carried out on well A and well B using the Vogel IPR method showed an increase in the oil flow rate. The following is a comparison of the IPR graph before and after hydraulic fracturing can be seen in Figure 5 below.

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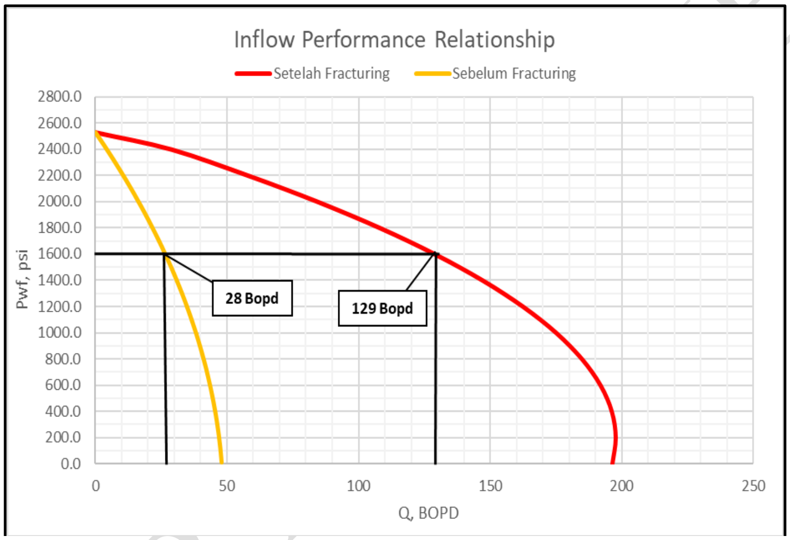

Fig. 5 Comparison of IPR charts before and after hydraulic fracturing

Based on the IPR graph in Figure 5 the oil rate after the fracturing process using the Pudjo Sukarno IPR method at Pwf = 1600 psi is 129 Bopd. The hydraulic fracturing stimulation process can be said to be successful, because there is an increase in oil flow rate from 28 Bopd to 129 Bopd. The results of this research indicate that the effectiveness of hydraulic fracturing in sandstone formations can be influenced by various factors. It can be seen from the fracture geometry, proppant selection, fracturing fluid selection, determination of injection pressure, and increased production performance.

Modeling results show that the success of hydraulic fracturing depends on fracture orientation, fracture size and shape, and rock properties such as permeability and strength. These results are proven by an increase in production performance in the form of permeability, productivity index, skin, and production rate. Permeability, which was previously only 2.3 mD after fracturing, increased to 11.97 mD. The skin value which was previously 1.2 then improved to -6.31, which means the damage to the formation has been repaired. The productivity index, which was previously only 0.5 after the cracking, rose to 3.71. Lastly, the production rate also increased significantly from 28 BOPD to 129 BOPD. It can be said that the implementation of hydraulic fracturing on the AFG-01 Well was successful and effective in increasing production performance.

4. CONCLUSION

1. This research evaluates the planning, implementation and results of hydraulic fracturing operations. The method used for fracture geometry design is the PKN method due to the thin thickness of the reservoir and long fractures.
2. There was an increase in permeability of 420.4%, formation improvement, production rate increase of 360.71%, and PI increase of 835%.
3. From the results of the hydraulic fracturing operation, it can be said to be successful because there was an increase in production performance in the form of permeability, skin, productivity index and oil production rate. So it can be said that implementing hydraulic fracturing for reservoirs that have small permeability and low productivity is very effective.

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