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Treatment Design of Hydraulic Fracturing and Economic Analysis on Water Dominated Geothermal Field

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ABSTRACT

The alternative energy at this moment which called the green energy is a geothermal energy. Geothermal energy is advantages, because that energy can be exploitation or converting to electric power for people needs, if the production of geothermal energy exploited continuously, the production well will be declined and for raising the production, the well must be stimulated. One of the well stimulation for raising the production well is called hydraulic fracturing.

The hydraulic fracturing in geothermal field or hydro fracturing or fracking involves the pressurized injection of fluids commonly made up of water and chemical additives into geologic formation. The main points of hydraulic fracturing treatment design are design of proppant, fracture fluid, pumping rate selection and economic analysis in the water dominated geothermal field.

To chasing the optimizing design, the sensitivity of changing variables proppant, and pumping rate must be done, so that the NPV will be optimized. The parameters optimum case are proppant agent 20/40 carbolite, PrimeFrac 30, maximum Proppant concentration 12 PPA, pumping rate 25 bpm and NPV of hydraulic fracturing treatment in 1 year reach about $ 1,623,608.5 (US) with optimum fracture 400 feet and benefit cost ratio (BCR) about 1.08.

1. INTRODUCTION

Almost 60 years development of hydraulic fracturing has been applied in the world, especially of accessing vital resources of natural gas, and oil energy. The hydraulic fracturing treatment was originated from petroleum industry in 1947 in the United States.

The technology of hydraulic fracturing treatment in petroleum wells was adapted in geothermal wells. The application of fracking in geothermal well was did at Fenton Hill, New Mexico in the late 1970 where 21,000 m^3 of water were injected into formation (granitic rock) at a depth of 3.5 km.[2] Unlike the fracking in petroleum well system use proppant, in geothermal well system use water as the fracking fluids (high viscosity), but the proppant could be recommended with special materials. The aims of technology or treatment is for well stimulation, so that the decline production will be increasing again.

The research in geothermal well especially in water dominated and not describing the origin of geothermal well, there is only clarifying the well is damage and must be stimulated using hydraulic fracturing. The research will be focused on analyzing the hydraulic fracturing treatment design using proppant, fluids fracturing, various pumping rate and economic analysis. For the evaluation of hydraulic fracturing treatment design in this study is using simulator software.

The limitations of research are based on procedures and the input parameters what the simulator software needs. The main points are design of proppant, fracture fluid, pumping rate selection and economic analysis. To chasing the optimizing design, the sensitivity of changing variables proppant, and pumping rate must be done, so that the NPV will be optimized.

2. LITERATURES

2.1 Well Problems

At every energy producing activities, there has to be problems. The main problems in geothermal well are :

- Lost Circulaation, Fractures are common because hard rock formation in seismicly active regions tend to be fractured, higher-then-normal thermal gradients are often due to convective flow of groundwater through fracture systems, and required flow rate in commercially attractive hydrothermal wells (10,000 to 30,000 barrels/day) dictate dlow from fractures. Thus, good geothermal wells are often those that intersect major fracture systems, and the best well may be the one that encounters the most severe lost circulation problems.

- Cement Displacement, In addition to the problem of cementing casing through a lost circulation zone, another cementing problem often arises in geothermal drilling-getting complete displacement by cement of the drilling mud between the casing and the formation. This problems also occurs in oil and gas drilling.

- High Temperature, Medium to high enthalphy geothermal reservoir has relatively high temperature (200 - 350 ^{o}C). This spesific characteristic effects the drilling fluids ability. Drilling fluid with high temperature effects the viscosity of itself. Table 1. below is comparison of temperature gradient on oil and gas system and geothermal system. (Ullah dan Bukhari, 2008).

Table 1. Comparison of Temperature Gradients

Oil and gas system	Geothermal system
5^{o}F/100 ft	12^{o}F-13^{o}F/100 ft

- Low Formation Pressure, As it is mentioned above, upflow zone is dominated by fracture networks which is the 'honey spot' (main target) of geothermal drilling. On these fracture networks, geothermal systems especially vapor dominated system has low formation pressure. Figure 1, below describes this phenomena. The low pressure reservoir condition is below hydrostatic pressure. Kamojang, Darajat, Travale and Geysers field are those example with subnormal pressure

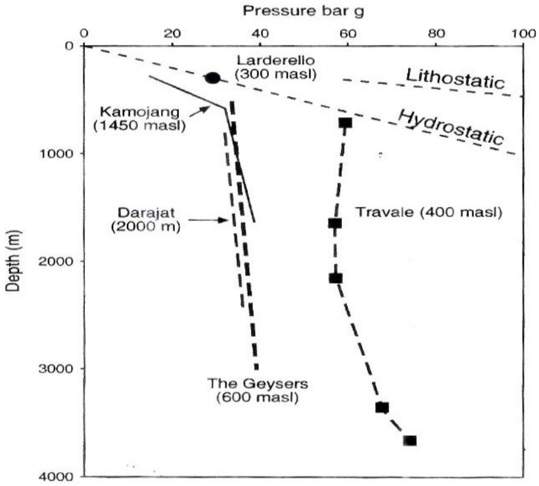


Figure 1 Vapor Dominated System Pressure Gradient (Allis, 2000)

2.2 Hydraulic Fracturing in Geothermal Field

There are two stimulation for oil and gas or geothermal wells. The stimulations are matrix stimulation and hydraulic fracturing. In this experiment the hydraulic fracturing treatment is planning to do.

Hydraulic fracturing or fracking is not new tools for the oil and gas industry. The first hydraulic fracturing experiment was in 1947 in United States of America, Kansas and the process was accepted as commercial by 1950.

The application of fracking in geothermal well was then brought into action at Fenton Hill, New Mexico in late 1970 where 21,000 m^3 of water were injected into granitic rock at a depth 3.5 km.

The application of hydraulic fracturing in geothermal fields around the world could be shown in table 2 below.

Table 2 Hydraulic Fracturing in Geothermal Field around the world (Sigit, 2010)

No.	Fields	Country
1	East Mesa	California, United State of America (USA)
2	Baca Field	New Mexico, Mexico
3	Raft River	Idaho, United State of America (USA)
4	Salak Mountain	Sukabumi, Indonesia
5	Soultz-Sous-Foretz	France
6	Landau	Germany
7	Wayang Windu	Pangalengan, Indonesia

The objective of hydraulic fracturing treatment is to promote an artificial fractures to increase near wellbore permeability, so that the well productivity is enhanced. This technique is conducted by injecting a large volume of viscous fracturing fluids under high pressure into formation. The injected fluid will transfer the high injection pressure applied by surface pump to promote a tensile opening of the rock formation. Sequentially, a propping material called proppant is injected to keep the artificial fractured open after the treatment has ceased. After years of experience, hydraulic fracturing or fracking is oftenly succeeded in enhancing the production of oil and gas wells (Figure 2).

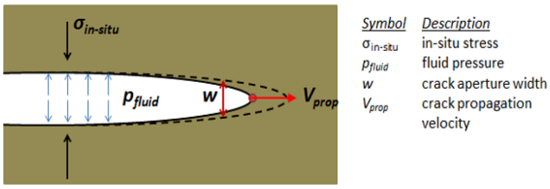


Figure 2 Fracture Grow Perpendicular to Minimum Principal Stress (Knudsen, 2012)

2.3 Permeability and Porosity

Porosity is the fraction of the total formation volume that is not occupied by solid rock. Porosity is classically divided into two groups: Primary porosity consist of the original space between the grains that form the rock matrix or the space present within sedimentary particles at the time of deposition, and Secondary porosity consist of the space that was created by tectonic forces creating microcracks and water dissolution creating cavities.

permeability is a measure of the ease with which fluids can flow through a formation. As the others know, the properties of rock around the world are different, so that, it have a different handling too. Table 3. Showns the rock properties of rock geothermal fields in the world. In contrary, the formation which is introduced to hydraulic fracturing treatment is the formation of which permeability is low (tight formation), other attempts should be made to find references that define the range of permeability of tight formation.

Table 3 Rock Properties of Existing Geothermal Fields in the World (Bjornsson and Bodvarsson. 1988)

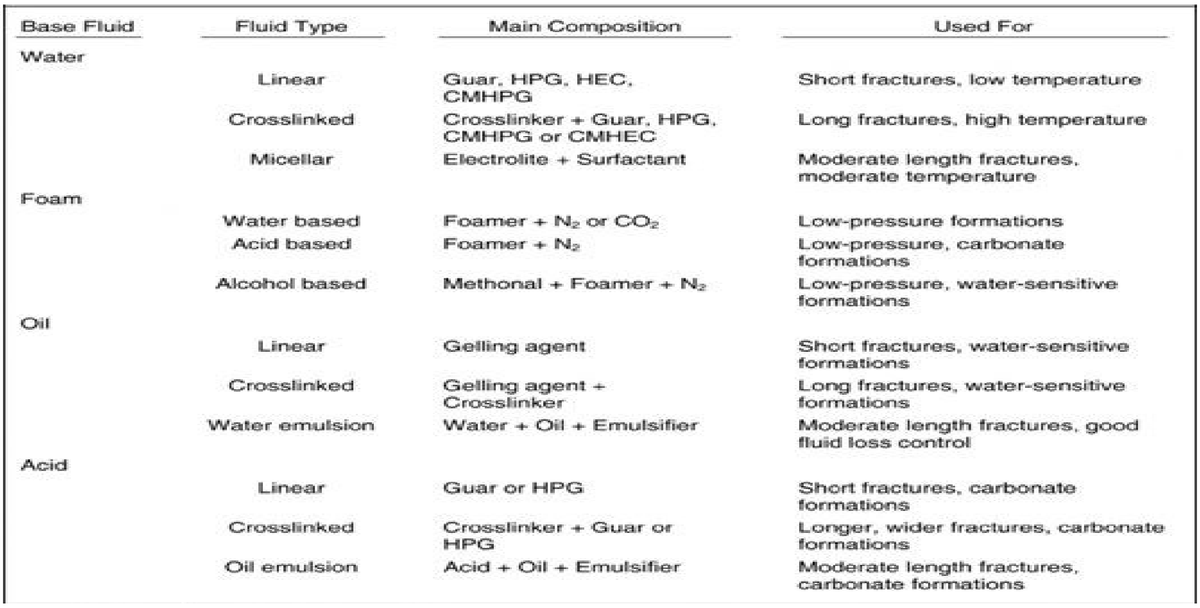
No.	Fields	Country	Porosity, ϕ (%)	Permebility, k (mD)
1	Krafla	Iceland	3 - 5	2 - 10
2	Langarnes	Iceland	0 - 20	15
3	Nesjavellir	Iceland	5	1 - 5
4	Svartsengi	Iceland	5 - 10	100 - 150
5	Larderello	Italy	5	
6	Olkari	Kenya	2	3 - 8
7	Cerro Prieto	Mexico	20	10 - 30
8	Broadlands	New Zealand	20	30
9	Wairakei	New Zealand	20	35 - 40
10	BacMan	Philipines	5	20
11	Tongonan	Philipines	5 - 10	10 - 50
12	The Geyser	USA	5	50 - 100
13	Baca	USA, (Mexico)	5	3 - 50

2.4 Fluid Mechanic of Hydraulic Fracturing Stimulation

The fracturing fluids is an important factor in the hydraulic fracturing process or treatment. The fracturing fluids serves to initiate fracture, and also transporting proppant agent to the formation, so that the fracture came to no bridging or settling. Fracturing fluids directly related to pumping rate, which means it affect to the equipment and the economic value of hydraulic fracturing activity (Praguna, 2014). The Example of fracturing fluids suitable conditions could be seen in Table 4.

Nowadays water based fracturing is the most common fluid applied in the hydraulic fracturing treatment, the main reason is because water based fluid has low cost, high performance level and easy to operate. Water-soluble polymers are widely used to increase the viscosity of the fluid, which important in order to lift and transport proppant to the formation. One of the polymers that are used to increase the viscosity of water-based fluid is Guar. Guar is a polymer having a high molecular weight composed of Mannos and galactose, polymers composed of sugars called polysaccharides. Guar has a high degree of affinity to water, when water is added to the guar powder, guar particles will swell and hydrate which means the polymer molecules become associated with many water molecules and unfold and extend out into the solution (Economides and Nolte 2000).

Table 4 Fracturing Fluids and the Conditions for their use (Holditch, 2006)



Base Fluid	Fluid Type	Main Composition	Used For
Water			
	Linear	Guar, HPG, HEC, CMHPG	Short fractures, low temperature
	Crosslinked	Crosslinker + Guar, HPG, CMHPG or CMHEC	Long fractures, high temperature
	Micellar	Electrolite + Surfactant	Moderate length fractures, moderate temperature
Foam			
	Water based	Foamer + N_2 or CO_2	Low-pressure formations
	Acid based	Foamer + N_2	Low-pressure, carbonate formations
	Alcohol based	Methonal + Foamer + N_2	Low-pressure, water-sensitive formations
Oil			
	Linear	Gelling agent	Short fractures, water-sensitive formations
	Crosslinked	Gelling agent + Crosslinker	Long fractures, water-sensitive formations
	Water emulsion	Water + Oil + Emulsifier	Moderate length fractures, good fluid loss control
Acid			
	Linear	Guar or HPG	Short fractures, carbonate formations
	Crosslinked	Crosslinker + Guar or HPG	Longer, wider fractures, carbonate formations
	Oil emulsion	Acid + Oil + Emulsifier	Moderate length fractures, carbonate formations

2.5 Fracture Height and Fracture Width

Fracture height id important parameter for fracture design. Lost height is controlled by in-situ variations of porosity and permeability. Fracture height is controlled by in-situ stresses, in particular by differences in the magnitude or level of stress between various geologic layers. More formally, height is controlled by the ratio of net pressure to stress differences Δσ, as illustrated in Figure 3.

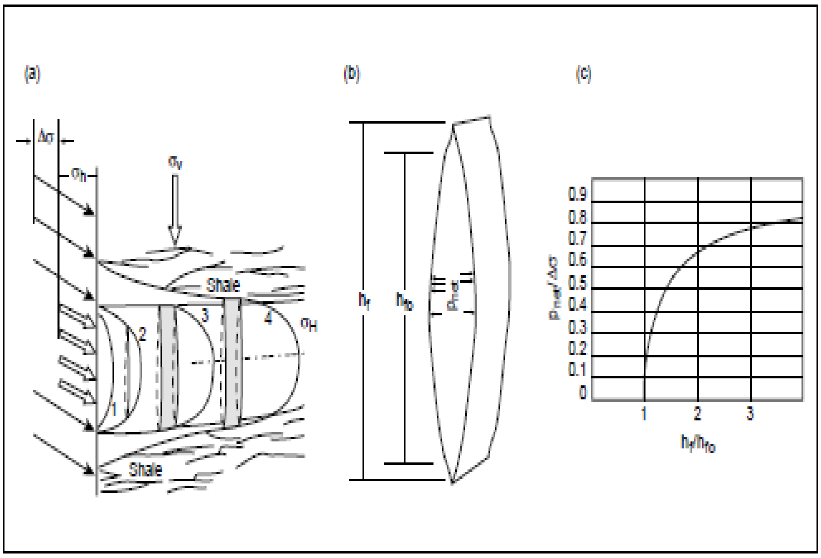


Figure 3 Fracture height growth. (a) Idealized fracture profile of the relation of fracture geometry to in-situ stresses. σ_h = minimum horizontal stress, σ_H = maximum horizontal stress. (b) Typical fracture vertical cross section illustrating the relation of the total fracture height h_f to the "original" fracture height h_{fo}. (c) Theoretical relation among h_f/h_{fo}, p_{net} and the in-situ stress difference Δσ (Simonson et al, 1978).

Consider a slit in an infinite elastic media (i.e., the earth). Also consider that the slit is held closed by a fracture closure stress but is being opened by an internal pressure equal to the closure stress plus a net pressure *pnet*. The slit opens into an elliptical shape, with a maximum width

$$w_{\max} = \frac{2 p_{net} d}{E'} \qquad (2.14)$$

Where E'. is the plane strain modulus ($E' = E/(1 - ν2)$, ν is Poisson's ratio and typically equals about 0.2), and d is the least dimension of the fracture. For a confined-height fracture with a tip-to-tip length greater than hf, d equals hf. This shows a direct relation between net pressure and width and introduces an important material property, the plane strain modulus. However, because typically $ν2 < 0.1$, the plane strain modulus seldom differs from Young's modulus E by a significant amount.

2.6 Proppant and Fracture Conductivity

The main job of proppant is propping the fracture which formed from fracture formation process and giving the good conductivity for the fluids flow into well. There are some parameters to establish the proppant selections:

1) Proppant Strength
2) Proppant Formed (Roundness and Sphericity)
3) Types of Proppant
4) Size of Proppan Granulation
5) Proppant Transport
6) Proppant Density

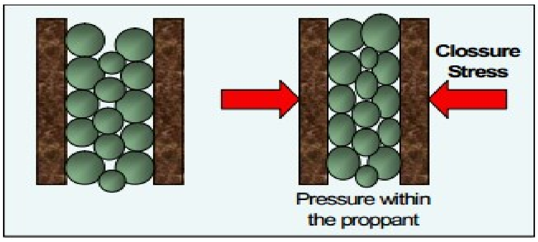


Figure 4 Clossure Stress Effect on Proppant (Lopez-Hernandez et al, 2004)

The closure stress effect the effective conductivity since the stress made the proppant compacted (Figure 4).

2.7 Fracture Geometry Modelling

Two Dimensional Model of Fracture Geometry, the Perkins-Kern-Nordgreen (PKN) geometry (Figure 5) is normaly used when the fracture length is much greater than the fracture height, while the Kristonovich-Geertsma-de Klerk (KGD) geometry (Figure. 6) is used if fracture height is more than the fracture length (Geertsma and Haafkens, 1979).

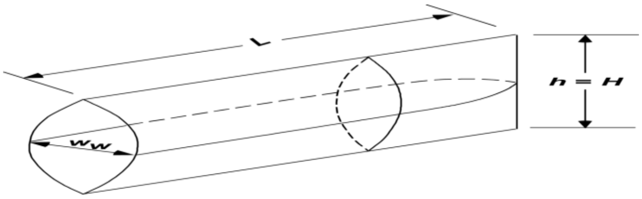


Figure 5 PKN Geometry for a 2D Fracture (Gidley et al, 1989)

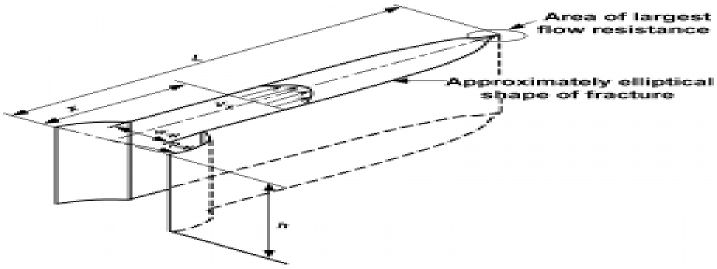


Figure 6 KGD Geometry for a 2D Fracture (Gidley et al, 1989)

Three Dimensional Model of Fracture Geometry, The 2D models have been used for decades with reasonable success. Today, with high-powered computers available to most engineers, pseudo-three-dimensional (P3D) models are used by most fracture design engineers. P3D models are better than 2D models for most situations because the P3D model computes the fracture height, width, and length distribution with the data for the pay zone and all the rock layers above and below the perforated interval.

The 3D fracture propagation theory is used to derive equations for programming 3D models, including P3D models. Figures. 7 and 8 illustrate typical results from a P3D model. P3D models give more realistic estimates of fracture geometry and dimensions, which can lead to better designs and better wells. P3D models are used to compute the shape of the hydraulic fracture as well as the dimensions.

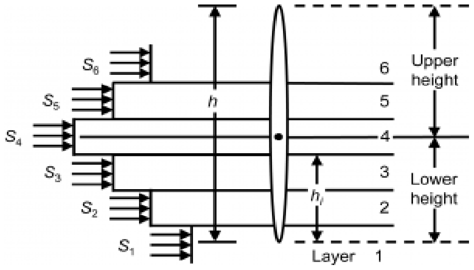


Figure 7 Width and Height from a P3D Model (Gidley et al, 1989)

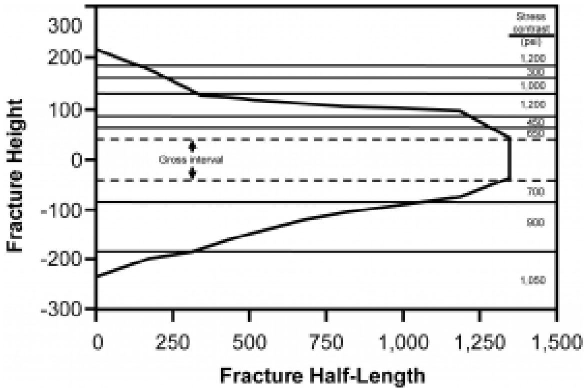


Figure 8 Length and Height Distribution from a P3D Model (Gidley et al, 1989).

2.8 Design Procedures

To design the optimum treatment, the effect of fracture length and fracture conductivity on the productivity and the ultimate recovery from the well must be determined. As in all engineering problems, sensitivity runs need to be made to evaluate uncertainties, such as estimates of formation permeability and drainage area. The production data obtained from the reservoir model should be used in an economics model to determine the optimum fracture length and conductivity. Then a fracture treatment must be designed with a fracture propagation model to achieve the desired length and conductivity at minimum cost. The most important concept is to design a fracture with the appropriate data and models that will result in the optimum economic benefit to the well operator, as Figure 9 showns.

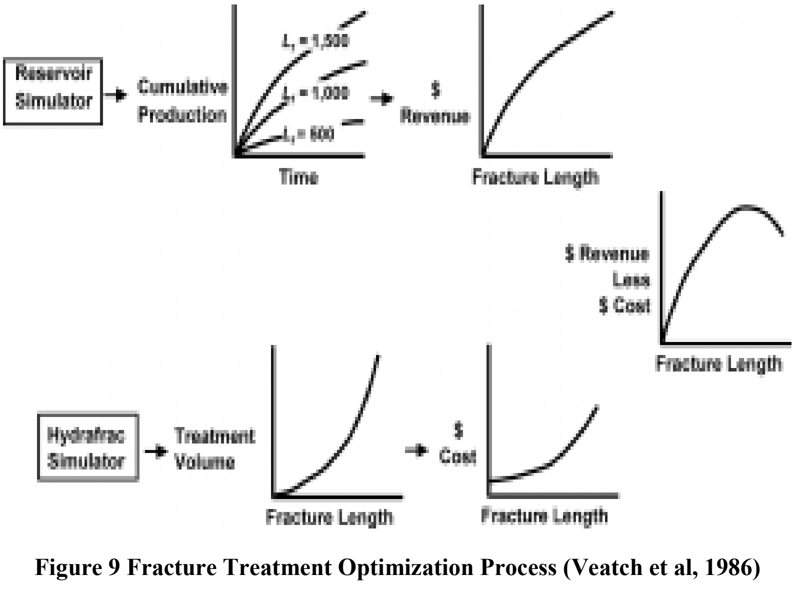


Figure 9 Fracture Treatment Optimization Process (Veatch et al, 1986)

2.9 Economic Study of Hydraulic Fracturing Stimulation

As a simple example, the process (at least for a single well) could proceed as pictured in Figure 10 (Veatch, 1986). First, reservoir-engineering calculations provide a production forecast for various combinations of fracture half-length *xf* and conductivity *kfw* (including the case of no fracture at all). Based on some future price forecast, this allows calculation of a present value, which is the future revenue from the production less future operating costs and discounted back to the present. Hydraulic fracturing calculations based on fluid loss, fracture height, etc., are used to determine the treatment volumes required to generate various combinations of fracture length and propped fracture width, and these calculations are easily converted into estimated treatment costs. Some form of net revenue economic analysis is then used to determine the best type of proppant, desired fracture length and other requirements for the optimum treatment. There are, of course, many variations of this basic process. For example, full-cycle economics includes drilling and other completion costs, along with fracture treatment costs, in determining the optimum fracture design. This type of analysis is usually appropriate in any case involving multiple wells (e.g., should a resource be developed using 10 wells with huge fractures or 20 wells with smaller or no fracture treatments?). Point-forward analysis, on the other hand, considers only the fracture treatment costs (because drilling and other completion costs are already expended) and is most appropriate for working over existing wells.

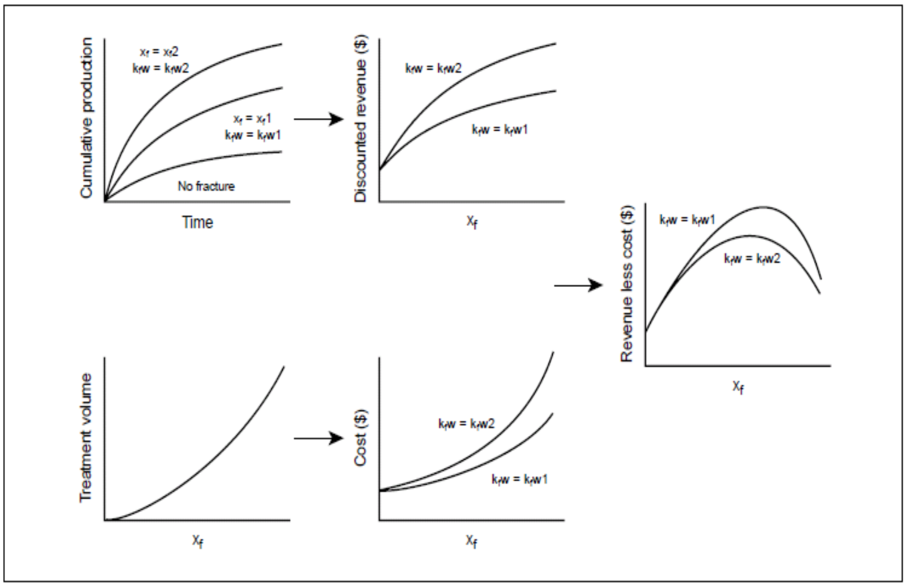


Figure 10 Veatch (1986) Economic Diagrams

3. RESEARCH METHODOLOGY

In general many data for this research, such as reservoir properties, well geometry, proppant agent, fluid fracturing, pumping rate, and fracture geometry.

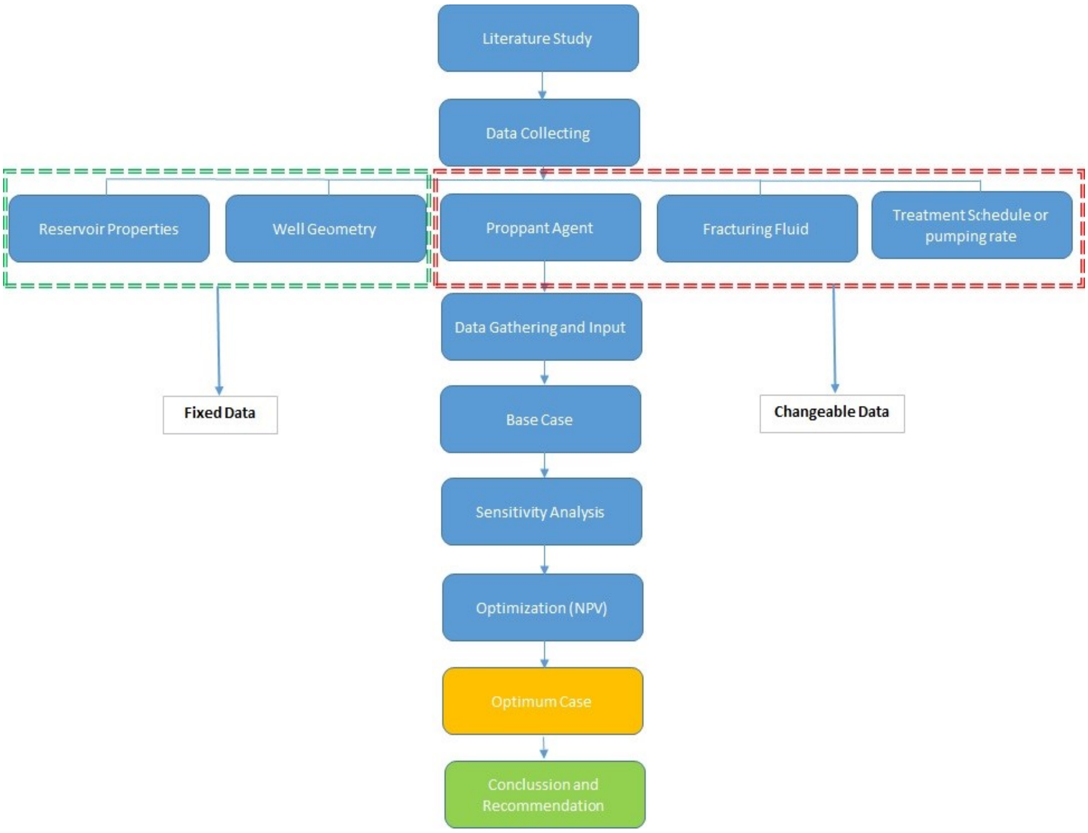


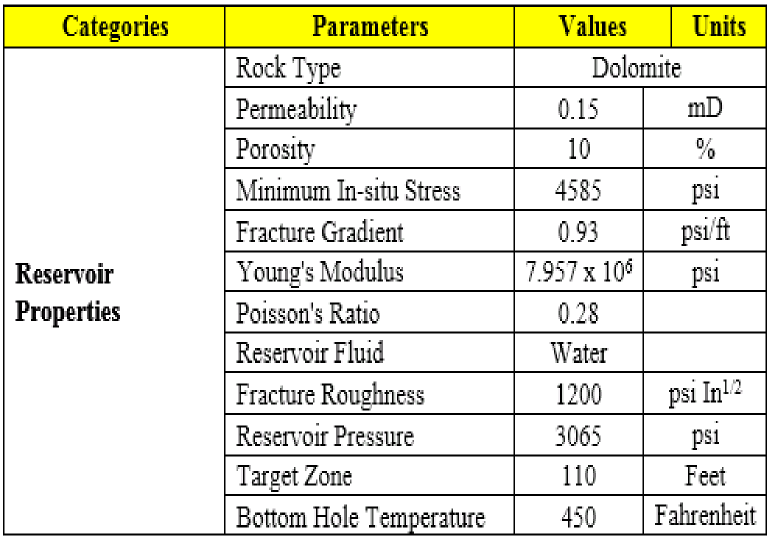
Figure 11 Work Flow of Hydraulic Fracturing Simulation

4. RESULT AND ANALYSIS

4.1 Base Case of Simulation Study

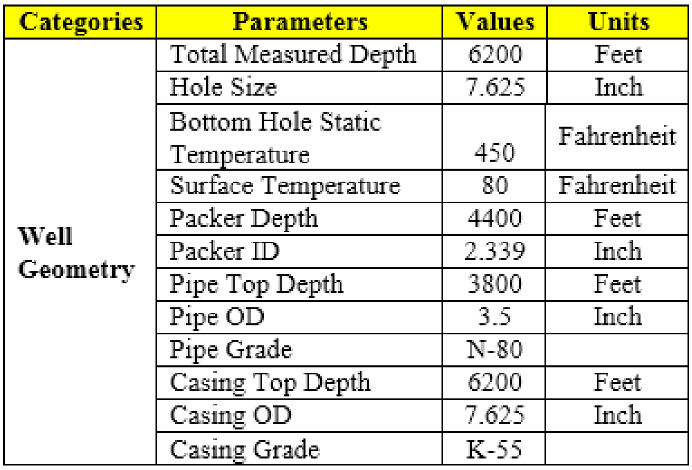
Because of limited data from water dominated field, this base case is used some assumption for the analysis, when planning the hydraulic fracturing design. The Base case consist of variable fixed data, seems Rock Properties or reservoir properties, such as rock type, permeability, porosity, minimum in-situ stress, fracture gradient, Young's Modulus, Poisson's Ratio, reservoir Fluid, reservoir pressure, target zone, and fracture toughness will be shown in Table 5. The well geometry, such as total measured depth, hole-size, tubing size, casing size, packer measured depth, perforation, and bottom hole static temperature or pressure. On this case, the hydraulic fracturing design will be conducted in a geothermal vertical well with total depth of 6200 feet and 7.625 inch borehole diameter. For the completed geometry data will be shown in Table 6.

Table 5 Reservoir Properties of Hydraulic Fracturing Treatment Design

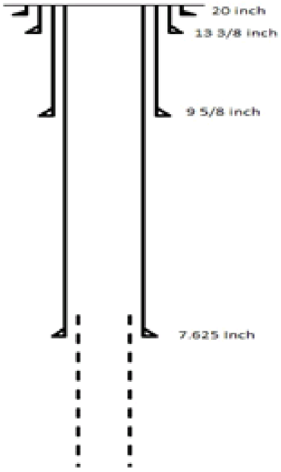


Categories	Parameters	Values	Units
Reservoir Properties	Rock Type	Dolomite	
	Permeability	0.15	mD
	Porosity	10	%
	Minimum In-situ Stress	4585	psi
	Fracture Gradient	0.93	psi/ft
	Young's Modulus	7.957×10^6	psi
	Poisson's Ratio	0.28	
	Reservoir Fluid	Water	
	Fracture Roughness	1200	psi $\text{In}^{1/2}$
	Reservoir Pressure	3065	psi
	Target Zone	110	Feet
	Bottom Hole Temperature	450	Fahrenheit

Table 6 Well Geometry of Hydraulic Fracturing Treatment Design



Categories	Parameters	Values	Units
Well Geometry	Total Measured Depth	6200	Feet
	Hole Size	7.625	Inch
	Bottom Hole Static Temperature	450	Fahrenheit
	Surface Temperature	80	Fahrenheit
	Packer Depth	4400	Feet
	Packer ID	2.339	Inch
	Pipe Top Depth	3800	Feet
	Pipe OD	3.5	Inch
	Pipe Grade	N-80	
	Casing Top Depth	6200	Feet
	Casing OD	7.625	Inch
	Casing Grade	K-55	



4.2 Hydraulic Fracturing Design

The main of hydraulic designs are pumping rate or scheduling rate of proppant and propping agent. In this study it used 20/40 Carbolite. On behalf of pumping schedule, it must be inputted to the modul of Pump Schedule Generator (PSG). The simulation for base case were used the pumping rate 20 bbl./min, the fracture length is 200 feet and the maximum proppant concentration in the rock formation is 15 PPA.(Table 7).

Table 7

Fracture Geometry Model	P3D
Design Length	200 ft.
Pumping Rate	20 bbl./min
First Proppant Concentration	1.0 PPA
Proppant Step Size	1.0 PPA
Maximum Proppant Concentration	15.0 PPA
Permeability	0.15 mD

After the data are inputted to the pump schedule generator, the simulator shows that the total time needed to conduct this treatment is 43.8 minutes, with pumping the proppant as much as 31865 gallons and weight 112100 lbs. With using this P3D hydraulic geometry model on the simulator, for the base case. The simulator will be executed and produced the fracture geometry and shows the other parameters. The detailed of fracture geometry produced from the simulator could be shown in table 8.

Table 8 Geometry of fracture produced in base case simulation

Max HF Half Length	261.4 ft	EOJ Net Pressure	324 psi
Propped Frac Half Length	225.1 ft	Efficiency	0.392
EOJ HF Half Length	261.4 ft	Effective Conductivity	1488 md.ft
EOJ Hyd Height at Well	343.7 ft	Average Gel Concentration	375.3 lb/mgal
EOJ Hyd Width at Well	0.242 in	Effective Fcd	44.1
Propped Width at Well	0.121 in	Max. Surface Pressure	3142 psi
Average Propped Width	0.071 in		

Figure 12. Showns the shape and the proppant concentration profile from fracture produced in this hydraulic fracturing process. Proppant concentrations spreads in the fracture, the proppant concentration to be uniform and in accordance with the plan that is maximum 15 PPA. proppant concentration. The width of fracture that formed slightly in the above and bottom layer. The proppant concentration is also greater near the wellbore. Proppant concentration clearly reduce towards the end of the fracture. The 3D profile of the proppant concentration in the fracture is nicely distributed in the fracture body and it could be shown in Figure 13.

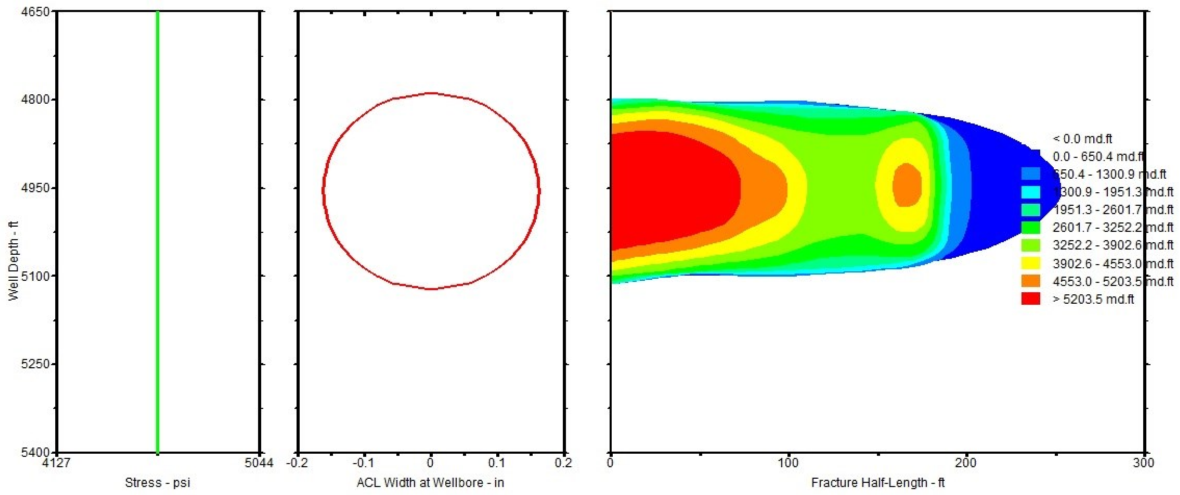


Figure 12 Fracture Profile and Proppant Concentration distribution inside the fracture produced in base case scenario.

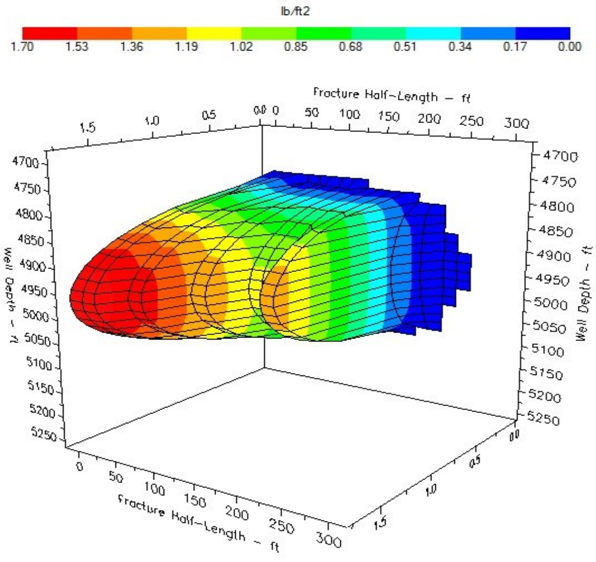


Figure 13 Proppant Concentration Contour in 3D model.

The fracture will rise from borehole perforations toward the formation. The fracture will be growth between fracture length and fracture height is always on the same constant ratio. The maximum length of fracture is located parallel in to the perforation hole-depth Figure IV. 8.

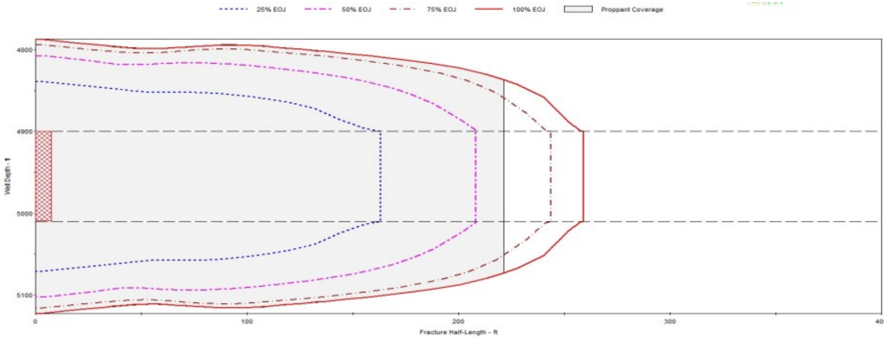


Figure 14 Fracture Geometry History for base case scenario.

Table 15 Comparison of Base Case and Optimum Case of Optimization (NPV)

	Base Case	Optimum Case	Unit
Proppant	20/40 C-Lite	20/40 C-Lite	
Frac Fluid	PrimeFrac 30	PrimeFrac 30	
Pumping Rate	20	25	bpm
Max. Prop. Conc	10	12	PPA
HF Xf	400	400	ft
Apparent Xf	375.7	348.3	ft
Fcd	375.7	33	ft
Radial Cum.	160	283	MMscf
Frac. Cum.	807	947	MMscf
Pumping Rate	20	20.0	bpm
Fluid Eff.	0.3	0.3	
Pad Vol.	56326	56353.5	gal
Total Fluid	102567	93983.5	gal
Total Proppant	229770	207829.5	lb
Est. Cost	420,709	313128.4	$(US)
NPV	1,566,188	1,623,608.5	$(US)

The net present value (NPV) is a calculation that compares the amount invested today to the present value of the future cash receipts from the investment. In other words, the amount invested is compared to the future cash amounts after they are discounted by a specified rate of return (Accounting Coach, 2015). The NPV keeps increasing as the fracture length gets higher, and increasing around 100 ft. – 300 ft. The NPV is underslung or minus, when the value permeability more than 1 mD. As shown in Figure 15. Below, that is the sensitivity analysis: net present value plot.

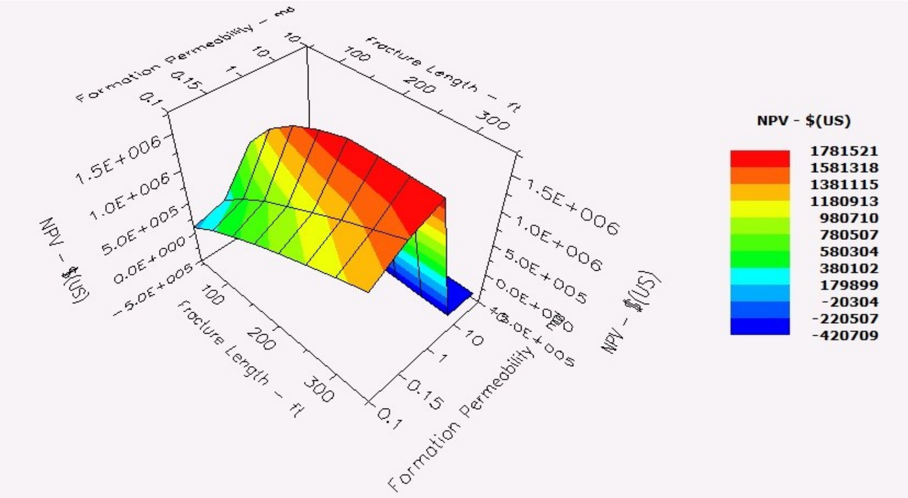


Figure 15 Sensitivity Analysis: Net Present Value Plot.

Table 16 Comparison Base Case and Optimum Case of FOI, NPV and BCR

	Base Case	Optimum Case	Unit
Propped Xf	261.4	264.3	
r_e	912.34	912.34	Feet
r_w	0.4375	0.4375	Feet
r'_w	166.5	168.3	Feet
s	2	2	Feet
s_f	-5.94	-5.95	Feet
FOI	5.67	5.7	
NPV	1,566,188	1,623,608.5	$(US)
BCR	-	1,08	$(US)

5. CONCLUSION

The combination that control the hydraulic fracturing treatment design using various proppant agent, pumping rates, maximum proppant concentration and permeability in geothermal field becomes good or fare well because their controlled by rock mechanic of the formation itselves. And the most important factor in designing hydraulic fracturing treatment is fracturing fluid selection (PrimeFrac 30), which could be transported the proppant into formation with safe and achievable cost. The fracture geometry in optimum case is gaining from selection of simulation of hydraulic fracturing from various sensitivities and the parameters needs to consisted and synchronized. More higher the maximum proppant concentration and pumping rate, the fracture geometry formed, efficiency, effective conductivity and F_{CD} will higher too.

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