

PAPER • OPEN ACCESS

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To cite this article: Riviani Kusumawardani *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **254** 012023

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Study of hydraulic fracturing stimulation to improve geothermal wells productivity

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Abstract. Wells that experience decrease in its production can be optimized by wells stimulation in order to increase its productivity. Stimulation have two types, they are reservoir stimulation and wells stimulation. Stimulation methods could be done with mechanical and/or chemical processes. Reservoir stimulation is divided into 3 methods. There are hydraulic stimulation, thermal stimulation, and chemical stimulation. This paper would be focusing the study in hydraulic fracturing method. Hydraulic fracturing method includes injecting fluids that could make fractures in the formation. Injection fluids contains proppant that could maintain the fractures after the fluid is injected to the formation. The purpose of this study is to analyze hydraulic fracturing stimulation method that could be done in geothermal wells to improve wells productivity.

1. Introduction

Geothermal wells are generally divided into self-discharge well and non self-dicharge well. Self discharge well is a well which can flow naturally when the wellhead opened so that no well stimulation is needed to make the well produce. Non self-discharge well is a well that can not flow naturally when the wellhead is opened so it takes effort to make the well producing . However, not all non self-discharge wells have poor production performance. Many of the non self-discharge wells can drain fluids with large flow rates after stimulation.

Stimulation is an effort to increase the production of wells by increasing permeability of rock formations. Stimulation also as a process of repairing the well to increase the level of permeability of the damaged formation so it can have a large production rate. Types of stimulation are reservoir stimulation and wells stimulation. The objective of reservoir stimulation is to enhance the near wellbore's reservoir permeability. Whilst wellbore stimulation is aimed to reduce the wellbore pressure. Both types of stimulation has the same final outcome which is to produce fluid from the reservoir to the surface through the wellbore.

Stimulation is done on production wells that have been decreased due to formation damage around the wellbore by improving the permeability of the formation rock. Wells stimulation can be done by creating new fractures, eliminating scaling, lengthening fractures, repairing well casing, deepened well depth, well side tracking, and/or combination of those methods. The methods that usually used in well stimulations are acidizing, hydraulic fracturing, acid fracturing, and chemical injection [3].



Hydraulic fracturing method is process of transmitting pressure, using fluid or gas, to create cracks or open existing cracks in the near wellbore reservoir. This method is used if the problem of the well is lack of permeability (not problem in water column or scaling problems). In this paper, one geothermal well hydraulic fracturing case was studied. The case proved that hydraulic fracturing stimulation can improve geothermal wells productivity by opening formation fractures around the well. The opening fractures improved steam productivity of the well by around 50%.

2. Basic Theory

2.1. Hydraulic fracturing

Hydraulic fracturing is a well stimulation technique which create formation rocks fractured by a pressurized liquid. The process involves the high-pressure injection of fracking fluid (primarily water, containing sand or other proppants suspended with the aid of thickening agents) into a wellbore to create cracks in the deep-rock formations through which natural gas, petroleum, and brine will flow more freely (see figure 1). When the hydraulic pressure is removed from the well, small grains of hydraulic fracturing proppants hold the fractures open. While the main industrial use of hydraulic fracturing is in stimulating production from oil and gas wells, hydraulic fracturing is also applied to stimulate groundwater wells, to precondition or induce rock cave-ins mining, as a means of enhancing waste remediation. Usually, hydrocarbon waste or spills to dispose waste water by injection deep into rock to measure stress in the Earth, for electricity generation in enhanced geothermal systems, and to increase injection rates for geologic sequestration of CO₂.

Determination of wells for hydraulic fracturing are:

1. The volume of fluid in the formation to be fractured is enough and economical for doing the fracturing;
2. The well which to be done hydraulic fracturing still has sufficient reservoir pressure to make the reservoir fluid flow into the fracture and then enter the wellbore;
3. The well to be produced is from low permeability feedzone;
4. Wells with formation damage caused by the drilling process (invasion of drilling mud, mud filtrate invasion), cementing process (cement filtrate invasion) and others.

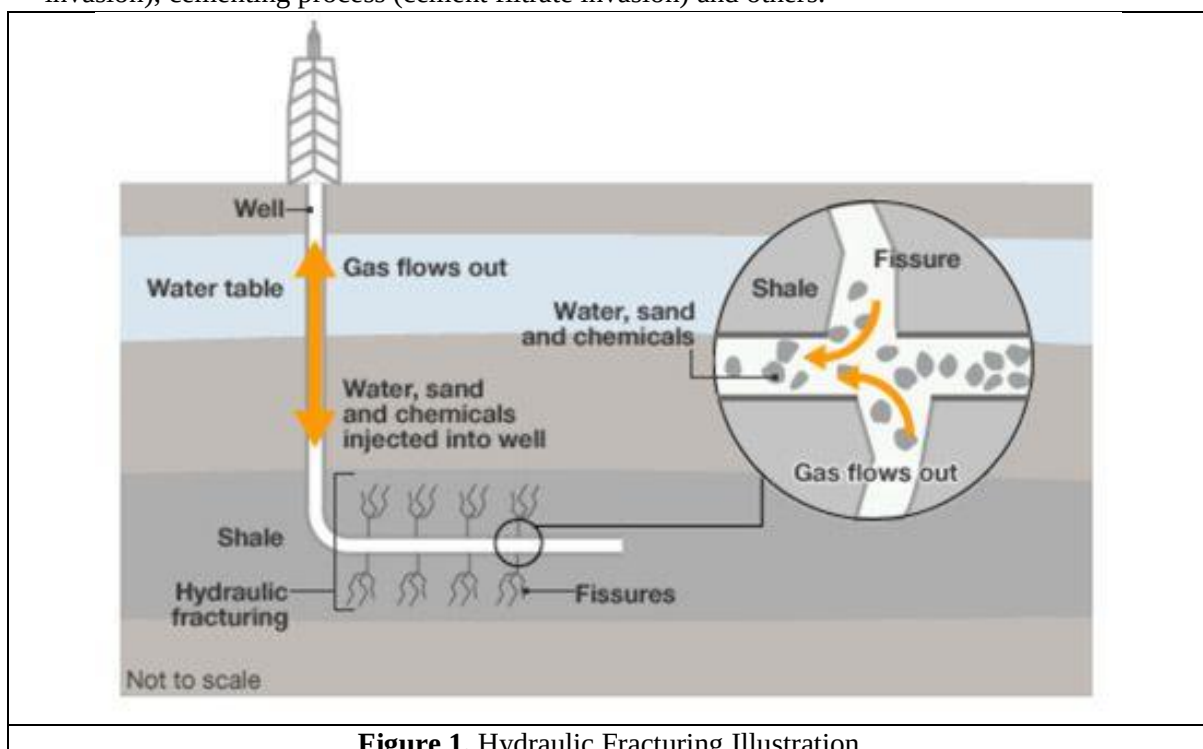


Figure 1. Hydraulic Fracturing Illustration

2.2. Fracturing Fluids

The fracturing fluids is fluid used in hydraulic fracturing to distribute the pumping power to the rock formations, to start the fracturing and expand the fracture and to carry and place proppants.

The fracture fluid will be pumped at several stages which has its own function (Table 1). Generally, in addition to being used to start the fracturing and expand the fracture, the fracture fluid must also be able to widen the fracture and place the proppant. In the fracture, the fluid will flow in some geometric shape with shear conditions and varying temperatures.

There is 2 (two) fracturing fluids are commonly applied in hydraulic fracturing: a pad which fluids without proppants and cracking fluid which used to deliver pumping power to formation rocks to form fractures, and also as proppant carrier into the fractures (see figure 2).

The fracturing fluid to be used is expected to have the following properties:

- Large viscosity around 100 to 1000 cp at normal temperature;
- Matches with the rock formation and the production fluid;
- Can create wide fracture to be filled by proppant, especially near borehole with minimum fracture width 3 times from proppant diameter;
- Can maintain its viscosity during fracture and may break after the process is finished;
- Easy to clean from the formation;
- The price is relatively cheap.

In the hydraulic fracturing process, rheology is an important fluid property which used to obtain sufficient viscosity. The viscosity of the friction fluid needs to be planned because the viscosity is one of the important parameters in the success of hydraulic fracturing. Other important properties of the fracturing fluids is leak off which means the loss of fluid by fracturing fluids enters the rock formation. Leak off could reduced fracture volume which may cause proppant to bridging or screen out. Leak off rate is an important factor in determining the fracture geometry.

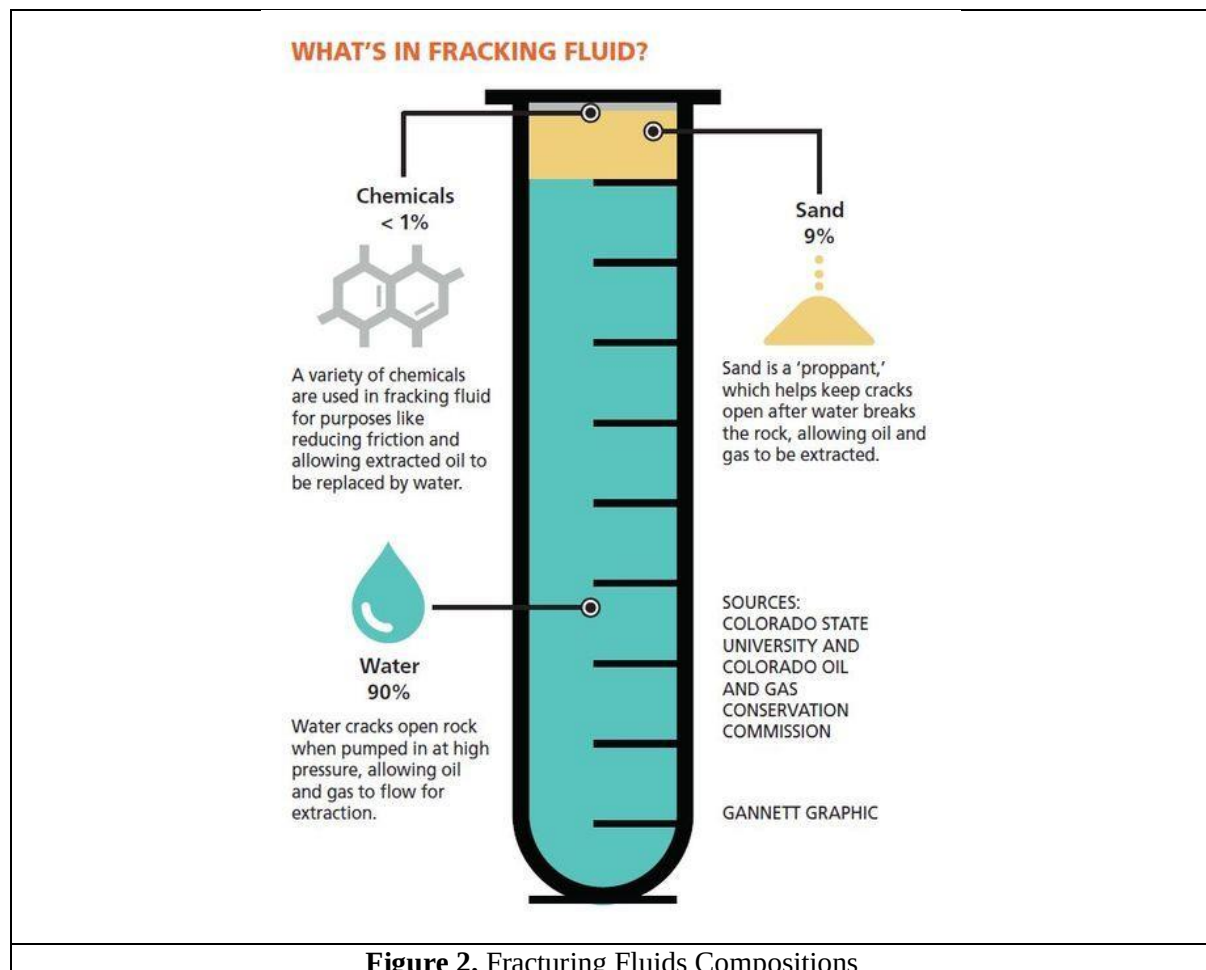


Table 1. Fracturing Fluids and the Conditions for Their Use [1]

Base Fluids	Used For
Water	– Short fractures, low temperature – long fractures, high temperature – moderate length fracture, moderate temperature
Foam	– Low-pressure formations – Low-pressure, carbonate formation – Low-pressure, water-sensitive formations
Oil	– Short fractures, water-sensitive formations – Long fractures, water-sensitive formations – Moderate length fractures, good fluid loss control
Acid	– Short fractures, carbonate formations – Longer, wider fractures, carbonate formations – Moderate length fractures, carbonate formations

2.2.1. Fracturing Pressure

The surface pressure required for fracturing can be determined by the following equation:

$$P_{wh.i} = P_w + P_f + P_{pf} + P_h$$

Where:

$P_{wh.i}$ = fracturing pressure in the surface (psi)

P_w = Fracturing pressure in bottom of well (psi)

P_f = Pressure loss due to friction in pipes (psi)

P_{pf} = Pressure loss due to friction between the fracturing fluids with the production zone (psi)

P_h = Hydrostatic pressure of the fracturing fluids (psi)

2.3. Proppants

Proppants used to prevent the fracture will close again after the fracturing. The proppants will keep the formed fracture open so the production fluid could flow from the feedzone to the wellbore. The choice of proppants will determine the result of conductivity. Proppant or fracture size selection will affect productivity result but still should be economical.

2.3.1. Proppants Criteria

There are criterias that need to be considered in the selection of proppant:

2.3.1.1. Fracture Conductivity

The size of proppants is very important for the success of hydraulic fracturing because fracture conductivity in each part is not the same. Therefore, in consideration, the average of fracture conductivity formed by the proppants arrangement which affected by the pressure, temperature and concentration of proppants in the fracture.

2.3.1.2. Proppants concentration

The proppants level is defined as the amount of proppants per unit of fracture area or lb/ft^2 . If the proppant settles to the bottom of the vertical fracture, the concentration determined by the fracture width, but if the proppant float in the fracture fluids until the fracture closes, the concentration determined by the fracture width when pumping and by the proppants concentration in the fluid.

2.3.1.3. Proppants strength

When a fracture has been formed then formation pressure will tend to close the fracture called as closure stress.

2.3.1.4. Proppants shape

Proppants shape is determined by the smoothness of the proppants (roundness) and sphericity that are very important depend on its closure stress. The higher value of the surface stress is the more smooth or rounded and more resistant to the pressure so that the conductivity will constantly high (see figure 3).

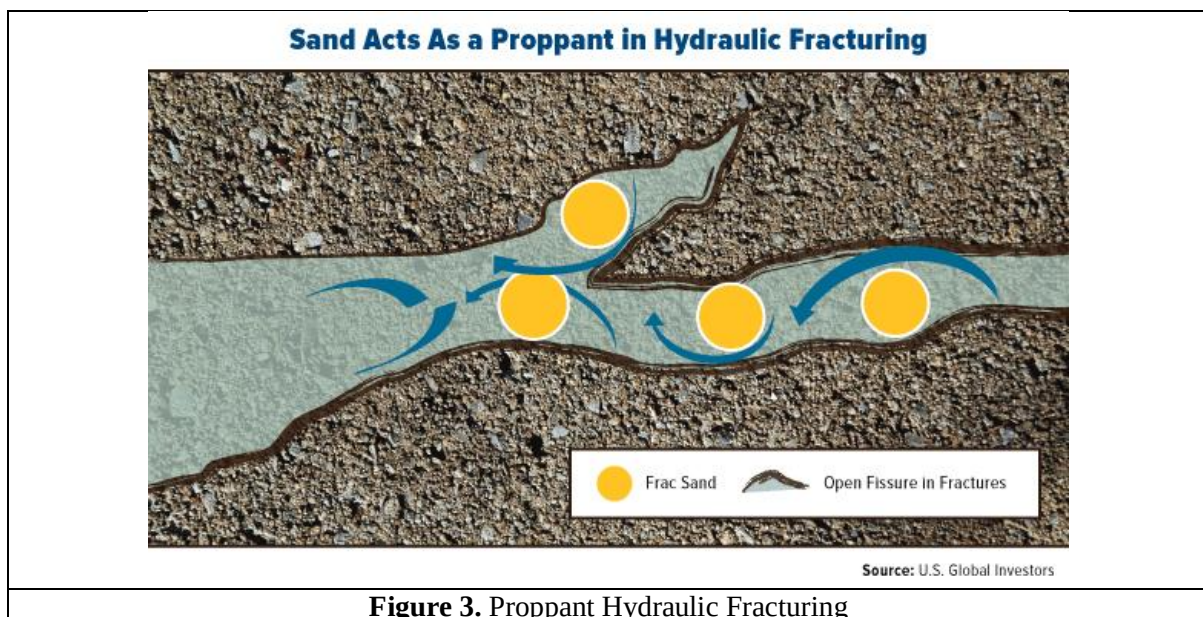


Figure 3. Proppant Hydraulic Fracturing

2.3.2. Proppants Transportation

Proppants transportation process of hydraulic fracturing is divided into several stages:

1. *Prepad*, is low-viscosity fluid and without proppant (oil, water or foam with low-grade gel or friction reducer agent, fluid loss additive and surfactant or KCl for prevent damage) pumped to start the fractures. Its also used to cool the formation and prevent gel degradation.
2. *Pad*, is a fluid with a higher viscosity and also without proppant which pumped to open the fracture and make preparations for the slurry opening by proppant.
3. *Slurry*, is a proppant mixed with viscous fluid, and added into bit by bit during pumping to a certain amount depend on the characteristics of the formation, fluid system and gelling agent.
4. *Flushing*, is fluid that pushes the slurry to close to the production zone with low viscosity and friction.

In the hydraulic fracturing process to be expected that the proppants dispersion are solid and uniform with maximum conductivity, and the distribution is distributed across the fracture and the proppants stay in the fracturing fluids until the fracture closes. Proppants that precipitate before to far is caused by proppant that gathered because of settling and can not move away with uneven distribution.

2.4. Test Stages of Hydraulic Fracturing

2.4.1. Break down test or mini fall off

Break down test or mini fall off is an early stage done on hydraulic fracturing. The test is performed to determine the breakdown pressure value when the fracture first occurs, and the permeability value of the formation before it is discharged.

2.4.2. Step up test

Step up test is the stage that is done after break down test. This test increased pumping rate serves to determine the pressure when the rock is breaking down (breakdown pressure) and the pump rate for the pressure extension rate. Then, it can estimate the pressure and rate required to keep the pressure open. The step up test is performed by pumping the base gel at stable rate and increasing bit by bit in periodically.

2.4.3. Step Down Test

Step down test is used to determine any obstacles around the wellbore either caused by the obstacles in production zone or caused by tortuosity. This test is generally done before the mini fract stage from the variations in pressure graphs versus reductions in pump rates could indicate obstacles around the wellbore.

2.4.4. Mini Fract Test

The mini fract test is fracture for calibration and smaller than the actual fracture. In this operation, the same fracturing fluids will be used in the main fract but only without the use of proppant. In practice, fracturing fluids will be pumped at constant rate until fract occurs and then it will be discontinued. Because it does not use proppant, the fracture will close again and all well pressure are recorded.

The mini fract test phase is an important step in the hydraulic fracturing because in this stage will get the fracture data required in the implementation of main fract. In the analysis of mini fract test results can be known the amount of leak off coefficient, closure pressure, fluid efficiency and rock mechanics parameters such as stress gradient, modulus young and fracture toughness.

2.4.5. Main Fract

Main Fract is the main process in hydraulic fracturing. At this stage the proppants will be injected into the production zone to keep the fracture opened. Proppants concentration will be injected periodically to allow the proppants enter the fractures completely.

3. Case Study

3.1. Field Overview

Hydraulic fracturing method is very rare in its application in geothermal field, because this method is still in the research. But there are several geothermal field which have conducted this hydraulic fracturing method. Those geothermal field can be seen in the Table 2 below.

Table 2. Hydraulic Fracturing in Geothermal Fields [4]

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

This paper discusses about geothermal field A which located in Insonesia. Position of this area at an altitude of 1700 m above sea level and has a work contract area 14.400 ha. The field is interpreted to be two-phase mixture of vapor and liquid with liquid-dominated conditions although it has several steam zone in reservoir. Geothermal Field A has started to generate 110 MW (unit 1) and 117 MW (unit 2). There is an additional unit (unit 3) with 127 MW that made total electricity generation of this field become 354 MW. Recently, the wells are two-phase producers except well X-3. The enthalpies of those wells are around 2183 up to 2787 kJ/kg depending upon the feed zone. The wells have low productivities of below 10 kg/s. Well X-4 is a two-phase producer with an enthalpy of 1369 kJ/kg. The well has had a production decline. Production has decreased from 5 kg/s to 3 kg/s. The transient analysis was conducted to identify the whether its performance is affected by the reservoir or wellbore issues.

3.2. Methods

Hydraulic fracturing has been done in Geothermal Field A in 4 wells, there are well X-1, X-2, X-3 and X-4. The objective of this paper is to document production improvement by creating hydraulic fracturing due to cold water injection. Before hydraulic fracturing, there are few methods that has been done in all four wells. The methods are injection test, multiple step rate injection and pressure transient analysis.

Injection test is injecting fluid to obtain data for reservoir evaluation and to measure the reservoir characteristics (i.e. permeability thickness product (transmissivity) and skin). The multiple step rate injection (cold-water injection) and transient tests were conducted on all wells. In the multiple step rate injection were conducted fall off test sequentially to well X-1, X-2, X-4, and X-3. The cold water (condensate fluid) was injected to the reservoir with multiple step injection rates. Design of multiple step injection rates was set from lower injection rate to high injection rate to initiate hydraulic fracturing due to effect of hydraulic thermal fracturing in the rock. The newly created fracture in the rock was initially from creating closure pressure in the fall off pressure period. Closure pressure performed due to injection rate exceeded maximum stress magnitude in the rock. Pressure transient analysis was conducted to assess reservoir characteristic and to identify the issue of wellbore damage. The procedure usually is to assess the quality of data, to choose the appropriate model, the method to interpret data and finally to apply this methods to estimate formation parameter such as transmissivity and skin factor [2].

4. Result

Series of multiple step injection rate followed by fall off tests have been conducted in well X-1, X-2, X-3, and X-4 between April – August 2007 [2]. The result can be shown in Table 3.

Table 3. Hydraulic Fracturing Result Test in Geothermal Field A

WELLS	RESULT
X-1	✓ Open fracture
	✓ Production improvement
	✓ Permeability improvement
X-2	✓ Open fracture
	✓ No production improvement
X-3	✓ No open fracture
	✓ No production improvement
X-4	✓ Open fracture
	✓ Production improvement
	✓ Permeability improvement

Well X-1 (Production Well). This well is a two-phased producer. The test took around 68 hours (killing well 6 hours, multiple step injection rate 60 hours, fall off test 3.5 hours) and recorded at 1671 meter MD. Injection rates are around 22 l/s up to 54 l/s. The result shows that it creates open fracture while

productivity and permeability are improved. Mass steam productivity increased around 50% from 4 kg/s to 8.5 kg/s. Pressure decline was recorded after the injection finished.

Well X-2 (Production Well). This well is a two-phased producer. Fall off test took around 4 hours and recorded at 1435 meter MD. The last injection rates for this well are around 40 l/s. The result shows that it creates open fractures but no production improvement recorded. It is presumed that this is due to well X-2 has lower permeability. Pressure decline was recorded after the injection finished.

Well X-3 (Production Well). The test for this well shows that there are no open fracture created and no production improvement recorded.

Well X-4 (Production Well). This well is a two-phased producer. Prior the test, the well had production decline from 5 kg/s to 3 kg/s in January 2007. The test took around 35 hours (killing well 5 hours, multiple step injection rate 22 hours, fall off test 6.8 hour). Injection rates are around 10 l/s up to 35 l/s. Result shows that it creates open fracture while productivity and permeability are improved. Mass steam productivity increased from 4 kg/s to 6 kg/s.

5. Discussion

Stimulation is an effort to increase the production of wells by enhancing permeability of rock formations. Stimulation is a process of repairing the well to increase the level of permeability of the damaged formation to have a large production rate. Hydraulic fracturing has been done in Geothermal Field A and shown that has achieved production improvement after multiple step injection rates. Hydraulic fracturing has been done in 4 wells and fractures opened in all wells as the result, but permeability and production only improved in 2 wells: well X-1 and well X-4, that shown hydraulic fracturing could used to repairing the well formation for increase the permeability and production rate. In well X-2, there is open fracture occurred but no production improvement. In well X-3, there is no open fracture occurred and effected to no production improvement. The successful method on well X-1 and X-4 have possibility because the injection rate is matched with the stress formation rate, and the unsuccessful method on well X-2 and X-3 have possibility because the injection rate is less than stress formation rate so the fracture that formed in two wells is not optimum.

The other stimulation methods such as gas injection could be used in problem because of water level in the well, and acidizing could be used in problem because of scaling. In this case, for repairing the wells to increase the level of permeability of the damaged formation, so it can have a large production rate could be done with hydraulic fracturing because the main problem is on the rock permeability. The method that should be done is creating the fracture to increase the permeability, but also must pay attention to calculations in determining the injection rate and stress formation rate.

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