Geothermal Well Stimulation Using Water Jet Cutting in Mexico

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ABSTRACT

When a geothermal well needs to be stimulated due to low permeability in the reservoir, the first solutions usually proposed are the acidizing and fracturing with hydraulic or thermal methods. All these techniques have been proved worldwide with acceptable results but sometimes with high cost or sophisticated equipment and procedures. In this paper the water jet well stimulation technique for geothermal application is described. This technique is extensively used for downhole mining and has demonstrated excellent results in reservoir enhancing in Mexico with an easy implementation and competitive cost.

Introduction

In many geothermal fields worldwide one of the most common challenges to be faced is the reservoir low permeability, especially in fields where the reservoir is hosted in a matrix with limited porosity (e.g. granite).

This document presents a geothermal well stimulation technique using water jet cutting as an option for well finishing, improvement or even as a rescue alternative when low permeability scenarios are found after drilling.

Fundamentals

As the conventional stimulation techniques, the main goal of water jet cutting is to increase well production by cleaning or amplifying existing fractures as well as creating fissures in the surrounding area of the well skin.

The stimulation is developed by crashing the jet water directly against the wall of the wellbore. This abrupt impact produces impingement; its depth into the wall is function of the jet power and exposure time. Unlike hydraulic fracturing, where the compression stress reaches the rupture gradually, in the water jet cutting it is the impact that produces localized erosion.

The main factors that can influence this hydraulic process are jet velocity and flow rate; hence the pumping system, tubing and nozzle design are key features that must be set and customized for every study case.

Special analysis in the mechanical behavior of the rock should be performed to get accurate results since the pumping system should be selected to meet jet requirements. Better results will be reached with the best coupling of rock mechanical properties and water jet power.

Hydraulics

The first challenge is the design of the hydraulic system; this selection must allow getting a good enough performance for cleaning and eroding the formation. A precise model of behavior prediction for several scenarios is required: The optimization will be made by minimizing friction losses along the piping and at the same time increasing, as possible, the exhaust water jet speed to be impacted against the wellbore wall.

Starting with the Bernoulli's principle, the model can be simplified assuming that in any point within the system the below condition is satisfied:

$$\frac{v^2}{2g} + H = constant$$

Where v is the fluid velocity, g is the gravity and H is the piezometric head. If friction losses are included and a balance between upstream (at the pump discharge) and downstream (at the exit of the nozzle) is done, the analysis becomes:

$$P_{pump} = \frac{\rho v_{jet}^2}{2} + f\,\frac{L}{D^5}\,\frac{8Q^2}{\pi^2 g}$$

Where P_{pump} is the discharge pressure from the pumping system, v_{jet} is the jet velocity, ρ is the fluid density, f is the friction losses factor, L and D are the piping length and diameter, Q is the volumetric flow rate and g is the gravity. Finally the needed flow rate could be determined by:

$$Q = \frac{n\pi v_{jet}}{4} d^2$$

Where n is the number of nozzles and d is the nozzle exhaust diameter.

Note that friction losses will likely consume an important amount of the pump delivery pressure, this is an important issue especially when pumping pressure is technically limited, small diameter piping is available and the stimulation zone is as deep as 3000 meters. For example, if it is required to pump 300 gpm through a 4" API FH drilling pipe with 3000 meters length, 500 psi will be lost; meanwhile if the requirement is to pump 600 gpm, up to 2500 psi will be lost due only to friction, and if the pumping pressure is limited to 3000 psi only the remaining pressure will be converted to jet speed.

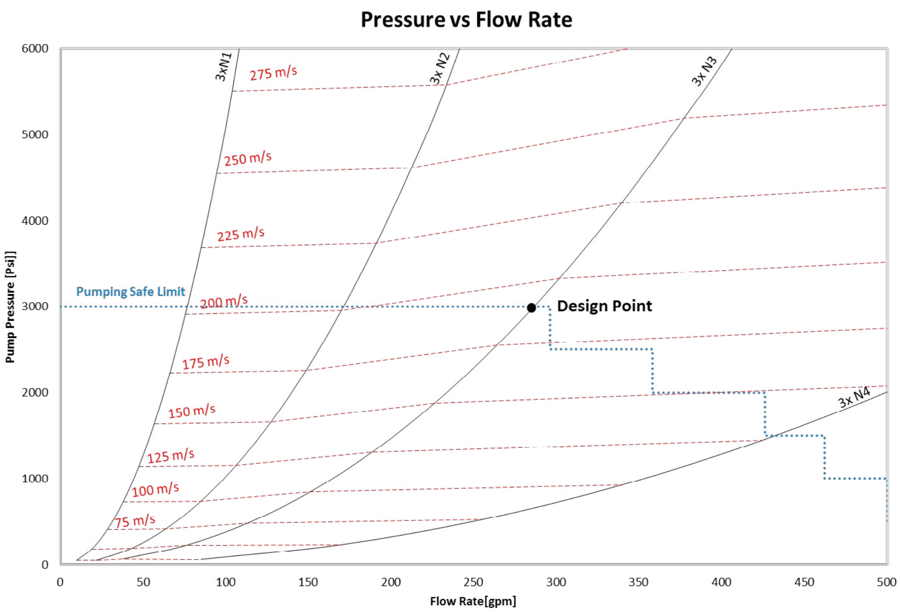

Figure 1. Water Jet Cutting Performance Chart.

Finally after doing the above analysis and including an appropriate operating margin, it is possible to select and correct a pumping configuration. Below is shown the performance chart that presents different scenarios of nozzle configuration using 4" API FH drilling pipe, and using a triplex pump available on the drilling rig. Note that the design point is selected to allow maximum flow rate, achieving an adequate jet speed level within the pump operational limits. Additionally the nozzle configuration allows enough diameter at the nozzle exit for avoiding stoppers.

Rock Mechanical Behavior

In hydraulic fracturing the cracking is obtained by increasing gradually the wellbore pressure until reaching enough stress level. In other words, sufficient amount of water must be injected until fracture gradient is exceeded. In thermal fracturing this stress level should be attained suddenly by an abrupt thermal shock. On the other hand, acidizing will not allow to get new fracturing but will clean existing fractures by dissolving deposits contained within.

In the water jet cutting technique, the impingement process involves several wear mechanisms occurring by plastic deformation or brittle fracturing that produce local and abrupt material detachment. The abrupt change of jet velocity will produce a localized cutting in the wellbore wall; this phenomenon helps to increase the orifice diameter and creates fissures that will help cracking in further hydraulic fracturing.

The impingement effect in brittle rocks has been extensively studied since different scopes but most of the authors of that work agree that the best manner to predict the erosion behavior during the jet impact is referring to the water hammer pressure definition:

$$P_{WH} = \rho c v_{jet}$$

Where P_{WH} is water hammer pressure, ρ is fluid density, c is speed of sound through the fluid and v_{jet} is the speed of the fluid exactly before to the impact; the water hammer pressure due to the water jet deceleration will reach rock compression strength producing punctual cracking.

Tool Design

Once the pumping system has been selected and the rock parameters estimated, an adequate tool has to be designed in order to perform the stimulation task. Of course it is required for this device to comply with the hydraulic requirements as well as compatibility issues with pumping system and standard drilling pipe.

The geometry has to be defined for a suitable nozzles location since these nozzles will direct the water jet against the borehole wall; the material selection is a key feature as API standards must be in compliance. The tool design should also be easy to manufacture, and finally the planning must consider that a drilling pipe entrapment is always latent. API grade E75 steel was selected due to its mechanical properties and its machinability. Tooling was manufactured following required standards and the proposed geometry was defined for entrapment free work.

The nozzles assembly, profile, and material deserve special attention because through this device the highest possible speed jet

Figure 2. Tool design.

will be reached. The assembly is proposed to be as in the drilling bit nozzles. This means a steel jacket that hosts the nozzle made of anti-wear material e.g. tungsten carbide. The profile should be optimized to minimize turbulence, discharge divergence and friction losses; the nozzle assembly used an arrangement of three nozzles which together cover the required area to meet hydraulic requirements.

Well Stimulation Operations

Target Zone Identification

Before starting well stimulation execution many essential tasks have to be done. One of them is the target zones identification. It is easy to understand that the stimulation success depends on how precise are defined the promising horizons for hot fluid delivery.

The parameters below are usually used for feed zone identification:

Temperature Inversion in Logs: The inversion zones identified in temperature logs which were taken after cold injection tests can be associated with zones with hot fluid intake.

Rate of Penetration (ROP): This parameter is always measured during drilling stage is an indicator of the instant penetration of drilling bit through the formation. Zones with high ROP can be assumed as interesting zones since it could be related to fractured zones or interphase contacts.

Lithological Column: Allows clear identification of changes in rock formation or interphase contacts.

Epidote Content: The Epidote content in lithological sampling can be associated to interesting zones since Epidote is the main hydrothermal alteration mineral.

Mud Return Reduction: Mud return reduction is associated with zones with fluid losses; these zones should be stimulated to increase further production.

Well Conditioning

Well condition requirements are briefly described below:

Wellbore Cleaning: When the stimulation process is about to start, the entire hydraulic column should consist only of clean water since is not desirable to have slurry that will probably obstruct the permeable zones.

Mud Dam Cleaning: An extensive mud dam cleaning is a mandatory task to be performed before starting any water pumping into the drilling pipe when water jet tool has been already installed.

Wellbore Cooling: In order to avoid nozzle detachment due to the thermal expansion, have the well bottom as cool as possible.

Equipment

This stimulation method has been developed assuming that this operation will be a part of well finishing, however, the practice can be applied for an old well that requires stimulation due to declining production. In this part the minimum equipment requirements that must be available at site for completing satisfactorily the procedure are shown:

Pumping System: Plenty pumping capacity should be a parameter selection for an appropriate drilling rig since a pumping system big enough for delivering pressure and flow requirements must be installed. Note that it will be useful to have at least 50% of pumping capacity for backup in case of unplanned outages. The best configuration should be to have 3 pumps with 50% of pumping capacity each, working with 2 pumps online and 1 for backup.

Tubing: Can be used conventional drilling pipe if drilling rig is still onsite otherwise an economic option can be evaluated taking care about friction losses, pressure and flow requirements.

Swivel: One of the most important things to be considered as strictly needed when talking about equipment is the swivel (top drive in drilling rig); this joint will allow tubing movement as well as high pressure water injection.

Rotary system: A driven device for pipe rotation is also required; it can be a conventional rotary table or even the top drive in a big rig.

Tooling & Nozzles: nozzles and tooling previously designed for this application must be onsite and ready to be used.

Operation Method

Once the complete equipment, tooling and prerequisites are ready for running, the stimulation process can begin; below are described the key parameters to provide the best performance identified at time.

Intervals and Stations: As the technique has a localized effect, the stimulation efforts should provide intervals of interest to be worked. Additionally, specific points of huge potential can be defined in order to do stations where the cutting will be deeper.

Slow Cutting: The exposition time is a key factor as it is in any other cutting process. It is preferred to execute the process in a slow manner to get better results and deeper effect, this means slow rotation (5-15 rpm) and vertical movement (5-20 m/h). Punctual stations can be stimulated with no vertical movement and slow rotation as well.

Experience Obtained in Successful Cases

The results of successful geothermal well stimulations are described below.

When drilling stage was completed with *partial* circulation losses, really low permeability was found, and production potential zones were located within a brittle matrix; then the well stimulation with water jet cutting was selected as the best choice.

The tooling was designed for the borehole diameter and the pumping system available at the drilling rig was used. Interesting zones were selected using temperature logs, ROP records and Epidote content in geological sampling resulting in a complete range to be stimulated of around 200 m and the well conditioning was concluded.

Once the above tasks were completed the operation started using the maximum allowable pressure at the pump discharge. The jet speed was estimated near to 200 m/s. The cutting effect became evident when deep cuttings were collected in the surface. These geological samples were a mix of very fine sand and water which formed a peculiar slurry.

Some sediments drop to the well bottom forming stoppers, this phenomenon produces large fluctuations in the flow return which sometimes reaches total circulation. This issue forced to do borehole recognition after works to eliminate obstruction (using drilling bit), and finally reach the **total** lost circulation. The permeability was estimated around 10 times greater than the original value and steam production was finally big enough for commercial production.

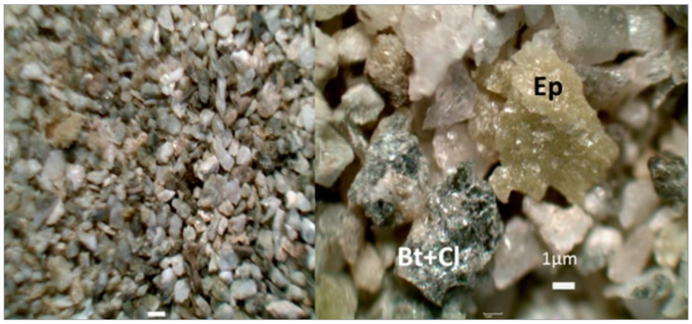

Figure 3. Cutting sample.

The contingencies faced were pumping system outages, high torque in drilling bit rotation, tooling erosion and nozzle obstruction.

Conclusions

- Geothermal Well Stimulation Using Water Jet Cutting is a competitive technique when low permeability is found after drilling; it can be a good choice for well enhancement.
- Well stimulation using water jet cutting is a simple method that is able to use pumping system available at drilling rig.
- High speed water jet is capable of cutting rocks if it is impacted near to the borehole wall even hard brittle rocks e.g. granite
- Target zone identification is a key task to be performed before starting operations since working range have to be defined as well as specific horizons for stimulation.
- Piping selection must allow operating with hydraulic requirements since friction losses could limit the range operation if they are not adequately chosen.
- Fissure creation in the borehole wall will help the new cracking growth if further hydraulic stimulation is performed.

References

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