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Use of Stress Cycling to Remove Downhole Scale from Geothermal Wells using Coiled Tubing

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ABSTRACT

This paper describes the first application of a relatively new oil field technology to the geothermal industry. The technology is referred to as stress cycling and provides a method of removing hard deposits, such as silica or calcium scales, from tubulars using only jetting action. This new technology lends itself to coiled tubing operations and results in a very fast and efficient clean out operation.

The paper describes the theory of stress cycling and lists the operational procedure used on the first job attempted on a geothermal well. The results of the operation are included.

Background

The formation of scales in both geothermal producers and injectors is an ongoing problem. Several methods for dealing with the problem have been practiced for some time now, such as pumping down scale inhibitors, drilling out the scale (with either a drill rig or more recently coiled tubing units), chemically dissolving the scale, and even pulling out the tubing and cleaning it on surface (completed producers only).

The new technology involves running a slowly rotating jet nozzle on the end of coiled tubing. The nozzle breaks up the scale, leaving the tubulars themselves in tact.

Well Candidate

The first candidate was a water injector that had scaled up to the point that injectivity was almost completely lost and indeed the well had been shut in for the previous four.

The casing schedule is shown in Figure 1 and the last recorded caliper log is shown in Figure 2. The caliper log shows where the scale tends to form but does not show the magnitude of the problem. Injectivity has decreased significantly since the point when that caliper log was taken.

The formation is largely tuff, limestone and chert and is very heavily fractured. During conventional drilling operations, the drilling is largely conducted under "lost returns" conditions, demonstrating the formations ability to accept not only fluid but also solids.

The hydrostatic gradient is slightly below 9.8 kPa/m and the wells maximum deviation is 12 (in the cased section and 42.5) in the open hole section.

Scale Analysis

The scale was analyzed using a scanning electron microscope and also a solubility test was conducted. The scale was found to be 49% soluble in 15% HCl. The insoluble portion of the scale is silica. The soluble portion of the scale was composed of the following:

<table>
<thead>
<tr>
<th>Composition (wt%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgCO₃</td>
<td>CaCO₃</td>
</tr>
<tr>
<td>41.7</td>
<td>7.5</td>
</tr>
<tr>
<td>49.4</td>
<td></td>
</tr>
</tbody>
</table>

Environmental Problems

The geothermal power plant is located very close to a town and there are well defined guidelines for operations under such conditions. The following operational and environmental constraints had to be taken into account during the design of this work:

- Operations were limited to 12 hours per day. This greatly effects the economics if a large amount of capital equipment is tied up during operations.
- Noise levels had to be minimized.
- Chemicals with an unpleasant aroma had to be avoided.
- Acids were not desirable for fear of contaminating the reservoirs and because of disposal concerns, on top of the above mentioned aroma limitations.
Road access to the power plant is quite limited, increasing the cost of moving very large equipment.

**Possible Solutions**

**Drilling out the Scale Using a Conventional Drill Rig**

This is historically how the wells are cleaned out. The operation, however, is extremely expensive, due to high rig daily rates and particularly high mobilization costs in this area.

The advantage of this method is that it is well proven. Also, the drill rig can drill through collapsed casing or other well problems if they should occur.

**Drilling out the Scale Using a Coiled Tubing Unit**

This method was seriously considered. It involves running a down hole moinneau motor and a bit on the end of coiled tubing. Coiled tubing drilling has been successfully practiced for many years now. However, the conditions on this particular well made this a very risky approach.

The well candidate has no completion, instead it has large diameter casing, with changes in diameter along its length due to scale and casing size changes. This makes coiled tubing operations very difficult. Unlike drill pipe, coiled tubing is thin, flexible and bent when it is run into the well. This makes pushing on the coil a delicate operation. Pushing too hard results in buckling the coil. The force required to buckle the coil may only be a few thousand pounds, making the operators job very difficult. The problem can be offset using larger diameters of coiled tubing but remains a problem when in 9 5/8" or larger casing.

The exact nature of when coiled tubing will buckle is complex, depending largely on the well's inside diameter and diameter step changes. A sophisticated computer program is used to define the operational limits during the coil operation. Generally, the bigger the casing and the smaller the coiled tubing, the more delicate the operation is.

Another problem with drilling is that a large drill bit is required (approximately 8”). The torque required on this size of bit is quite large for coiled tubing. This makes motor size selection critical. Too small a motor will result in the motor stalling out easily, again making operations difficult, too large a motor will develop enough stall torque to actually break the coiled tubing.

**Impact Hammer on Coiled Tubing**

Impact hammers have also been successfully run on coiled tubing for many years now. They are particularly good at removing hard deposits.

The problem with an impact hammer in this scenario is that likely several runs would have to be made to gradually enlarge the hole size inside the casing. Also, the extreme vibration generated by the impact hammer could damage the cement behind the casing. Thirdly, if the scale was too soft, the impact hammer may not penetrate the scale, it would gum up.

**Chemical Dissolution of the Scale**

As mentioned earlier, the scale is approximately 50% soluble in acid. Dissolving the soluble portion might render the remainder unconsolidated. The remaining scale might just fall off or at least be easily removed using conventional jetting technology.

The problem with acidizing is that large volumes of acid would be required, creating operational problems and disposal problems, not to mention a significant cost element. (50 tons of 50% soluble material would require 30,000 gal of 15% HCl).

Acid treatments could also be combined with stress cycling jetting.

**Conventional Jetting Tools on Coiled Tubing**

Conventional jetting technology only works when the scale is relatively soft or when the standoff between the jet and the target is small (a rule of thumb is eight times the nozzle diameter).

To achieve a successful cleanout, it is likely several runs would be required to gradually open up the hole and even then, there is the risk that the scale will be too hard for the jetting tool.

**Stress Cycling Tool Run on Coiled Tubing**

A stress cycling jetting tool has far greater destructive power than conventional jetting tools. This means that the clean out could likely be conducted in only two runs, cleaning out to the full inside diameter of the 9 5/8" casing.

Like conventional jetting tools, the stress cycling tool does not damage the steel tubulars in any way and does not require any set down weight on the tool. This makes jetting tools ideal for coiled tubing.

The disadvantage of jetting solutions is that jetting tools cannot pass through collapsed casing. They cannot remove steel. Also, some scale may be so hard that even the stress cycling tool cannot remove it, necessitating a drill motor and bit.

**Theory of Operation of Stress Cycling Jetting**

Stress cycling means that a target scale is repeatedly pressurized and depressurized. This cyclic loading causes the scale to break up.

The method of inducing this stress cycling action is to repeatedly hit the scale with a high pressure jet, holding that jet on the scale for a predetermined length of time and then removing the jet. This is achieved in practice by using a slowly rotating jet nozzle. The following pictures show the operation.

Much experimentation has been done to find the optimum residence time of the jet on the scale. Fortunately, the range proves to be quite broad and equates to an optimum rotational speed of between 300 and 700rpm.

Clearly, this type of tools achieves full wellbore coverage as it rotates. It does this with only two jets, meaning that the total jet energy available down hole is not divided up unnecessarily. This results in larger jet diameters and so larger standoff distances or better jetting performance.
Two high pressure jets impinge on the scale. The high pressure jets invade the natural porosity in the scale and pressurize a local section of the scale.

1. The rotating jets move away from the pressurized areas of scale.

The pressure cycling weakens the scale and the pressure differential behind the scale causes it to implode into the well bore.

The slow rotation is achieved by using a down hole turbine and a magnetic eddy current brake. The stress cycling tool specifications are shown in Table 1.

**Well Program**

The well program chosen was to run the stress cycling tool. The job was planned to take two runs. The first would be with a 2 1/8" stress cycling tool. The purpose of the run would be to open up the hole and determine how soft the scale really was and what kind of penetration rates could be achieved. This run would be taken only to the top of the open hole; the restriction was believed to be in the cased section of the well.

The second run would be made with the same tool fitted with a 160 mm centralizer and larger nozzle housing. This serves two purposes. First, it acts a gauge ring to ensure that the

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**Table 1. Tool Specifications**

<table>
<thead>
<tr>
<th>Bit Size</th>
<th>Casing Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>26&quot;</td>
<td>105m</td>
</tr>
<tr>
<td>17 1/2&quot;</td>
<td>452m</td>
</tr>
<tr>
<td>12 1/4&quot;</td>
<td>605m</td>
</tr>
<tr>
<td>9 5/8&quot;</td>
<td>394.5m</td>
</tr>
<tr>
<td>9 3/4&quot;</td>
<td>447.2m</td>
</tr>
<tr>
<td>8 1/2&quot;</td>
<td>1150m</td>
</tr>
</tbody>
</table>

**Figure 1. Casing schedule.**

---

1.2/" Stress Cycling tool

<table>
<thead>
<tr>
<th>Specification</th>
<th>Imperial</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside diameter</td>
<td>2 1/2&quot;</td>
<td>54.8mm</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>400°F</td>
<td>200°C</td>
</tr>
<tr>
<td>Maximum liquid flow rate</td>
<td>1.56bl/min</td>
<td>240L/min</td>
</tr>
<tr>
<td>Maximum nitrogen flow rate</td>
<td>750scf/min</td>
<td>22scm/min</td>
</tr>
<tr>
<td>Weight including filter</td>
<td>60-70lb</td>
<td>27-32kg</td>
</tr>
<tr>
<td>Maximum differential pressure</td>
<td>5,000psi</td>
<td>35MPa</td>
</tr>
<tr>
<td>Overall length</td>
<td>83&quot;</td>
<td>211cm</td>
</tr>
</tbody>
</table>

1/2" and 2 1/8" tools are also available.

2The cooling effect of circulating fluid means that wells with higher static temperatures can be accommodated.
hole has been opened up to the required diameter. Second, it permits the jets to be positioned closer to the casing wall so improving jetting effectiveness.

Schematics showing the tool string configurations are shown in Figures 3 and 4.

**Equipment Used**

The equipment used was as follows:

- A 1 ½"-0.109" wall coiled tubing unit with 10,500ft of pipe.
- High pressure fluid pump.
- Settling tank and filter system to treat the geothermal water before injection into the coiled tubing. (the geothermal water was filtered but had no chemicals added to it for the well treatment).
- A 2 1/8" stress cycling tool with a selection of different nozzles and centralizers. The tool was run in conjunction with a down hole filter and an emergency release tool.

**Job Execution**

The job ran largely according to plan. However, the following problems arose:

- The 2 1/8" stress cycling tool with no centralizers could not be run past the top of the 9 5/8" casing at 394m. It hung up at this point. The tool had to be pulled from the well and fitted with the 160mm centralizer. With the centralizer, the tool easily progressed into the top of the 9 5/8" casing.
- After successfully cleaning to the bottom of the 9 5/8" casing, injectivity had still not been restored. There was obviously also a restriction in the upper section of open hole. The decision was taken to run the tool into the open hole to a depth of 762m, which would traverse a known lost circulation zone. This was done and the well injectivity was restored.
- Throughout the job, some of the cutting were being accepted by the well, most were coming to surface. Because of the limited flow rates achievable through coiled tubing, the fluid velocity up the annulus was very slow. This made it difficult keep the cased section of the well bore clean in order to minimize the possibility of cutting settling down on top of the stress cycling tool, causing it to become stuck in the well bore.

**Summary**

The first ever use of a stress cycling tool on a geothermal well was a great success. The job was completed in five, 12 hour days, one day rig up, three days jetting and one day rig down.

It is hard to know exactly how much scale was removed but it is estimated to be at least 40-50tons. Interestingly, it was clear from the cuttings returned to surface that the hole was actually
opened up to the full 160mm on the first trip without the centralizer. The scale was, if anything, softer than anticipated.

The well injectivity numbers were as follows:

<table>
<thead>
<tr>
<th></th>
<th>Injection Rate (m³/hr)</th>
<th>Injection Pressure (Mpa)</th>
<th>Injectivity Index (m³/hr/MPa⁰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to cleanout</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Post Cleanout</td>
<td>48</td>
<td>1.2</td>
<td>43.8</td>
</tr>
</tbody>
</table>

Cost Comparisons

The cost of the cleanout using the Stress Cycling tool was about $100,000. However, this included $25,000 in mobilization charges and is operating in a very high cost area. A similar job in California would likely cost between $20,000 and $50,000 depending on scale deposit and volume, as well as location and work volume.

The price for drilling with coiled tubing is very comparable with that of stress cycling jetting. However, the job may take much longer if several trips are required with new drill motors.
and different size bits. This is also true for conventional jetting on coiled tubing. The day rates would be cheaper but the job may take two or three weeks rather than two or three days.

The cost of acidizing would be prohibitive. 30,000 gal of inhibited HCl would cost at least $50,000 excluding the disposal costs. Then there are pumps and tanks required on top.

Finally, conventional drill rigs can be used to drill out scale. These currently cost about $7,000 per day in the US. A five day job would cost then $35,000, again comparable to coiled tubing. In the operating are which is the subject of this paper, this cost is very much higher.

The benefits of stress cycling jetting on coiled tubing are partially saving costs but also technical advantages such as no damage to the tubulars.

**Conclusion**

A stress cycling tool run on coiled tubing offers a viable alternative for the cleaning out of scaled tubulars in geothermal wells.