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Productivity Analysis and Acid Treatment of Well AZ-9AD at the Los Azufres Geothermal Field, Mexico

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Acid job, Los Azufres, stimulation treatment, enhanced production

ABSTRACT

Well AZ-9AD is located in the northern zone of Los Azufres geothermal field and it was drilled from January 7 to April 22 on 2003, to a total depth of 1500 m. The well produced 22 t/h of dry saturated steam, which was found to be lower than expected, despite the persistent drilling losses in the openhole section and good thermodynamic conditions. Early testing and survey analysis indicated that the low output of AZ-9AD was caused by considerable drilling induced wellbore damage in its open hole section, where 1326 m³ (8341 barrels) of mud were lost. Skin factor of 16 was causing additional pressure drop equivalent to 41 bars, reducing its optimal flow rate. The success of earlier acid treatment jobs in Mexico and the analysis of the available information encouraged the company to apply the same technique for this well during 2005. Acid treatment of well AZ-9AD introduced very significant improvement in the wellbore showing 174% increase in production capacity. The results of this job, have been used for encouraging new stimulation programs, such as those in wells Az-56R and Az-9A located in the north zone of Los Azufres geothermal field.

Introduction

The Los Azufres, México, geothermal field is located in the northern portion of the Transmexican volcanic belt, 80 km east of Morelia city and 250 km of Mexico city (Figure 1). It is a heavily fractured and faulted volcanic hydrothermal system, located in a sierra at an average elevation of about 2800 masl. It is found in a forest area with abundant vegetation, considered forest reservation zone (Torres-Rodriguez et al, 2000).

The studies of the geothermal system at Los Azufres started in 1972 consisting of geological, geophysical and geochemical surveys. Drilling activity began in 1976 and in 1977 the first producer well was completed. Currently, 78 wells have been drilled at depths ranging between 700 and 3500 meters (Tello et al, 2005). In 1982, commercial exploitation of the field started with the start-up of the first five backpressure units of 5 MW each. In 2002 the installed capacity was 88 MW, and in 2003 four Alstom power units of 25 MW each were installed increasing the power capacity to 188 MW. In order to supply steam to the new power plants, several wells were drilled. Well AZ-9AD is one of those wells, which is located in the northern part of the field and was drilled to supply steam for Unit No. 16 of 25 MW.

Well Characteristics

Az-9AD was drilled directionally to a total depth of 1500 m and was completed on April 22, 2003, with slotted liner from 590.3 to 1495.6 m. Temperature surveys conducted after completion, showed two main permeable zones located around 800 and 1150 m depth, respectively, and stabilized temperatures...
similar to nearby producer wells (Figure 2). However, several attempts to discharge the well were made without success until March 19th, 2004, when finally it sustained production continuously. The well produced 22 t/h of dry saturated steam, which was lower than expected, despite the persistent drilling losses in the openhole section. It was therefore suspected that the low output of Az-9AD was caused by considerable drilling induced wellbore damage in its open hole section, where 1326 m$^3$ (8341 barrels) of mud were lost. Therefore it was decided to perform a series of surveys to diagnose the reasons for the lower output. Temperature-pressure-spinner (TPS) surveys were then conducted at flowing condition to initially quantify the contribution of the permeable zones, finding seven feed zones contributing to the well mass flow rate output: 630, 650, 712, 940, 1190, 1380 y 1400 m depth. According to the measurements the main producer zones, under this flowing condition were at 630, 650 y 712 m depth (Figure 3). After the TPS survey, a pressure transient test was done to evaluate the transmissibility of the formation and the skin factor (Figure 4).

According to several sources, formation damage can be obtained from the analysis of pressure transient tests, such as pressure fall off or buildup test. A positive skin factor indicates a damaged well, while a negative skin indicates a stimulated well (Economides et al, 1989, Earlougher, 1977). The effect of the damage has been interpreted as a radius of reduced permeability near the well which adds an extra pressure drop to the fluids from the reservoir to the bottom hole of the well. For the Az-9AD well, a pressure buildup test was conducted and analyzed using commercial software named Pansystem™. The results are summarized on Table 1 and Figure 4. The positive skin factor confirmed the drilling induced wellbore damage in the openhole section of the well.

According to the pressure test analysis, the flow efficiency in well Az-9AD under the damage conditions was 0,3, therefore the maximum discharge output after removal of damage was estimated at 72 t/h of mixture (Flores et al, 2004). Considering the steam quality of nearby wells (53% in well Az-9 and 70% in well Az-45), it was expected a range from 38 to 50 t/h of steam after removal of damage. The success of earlier acid treatment jobs (Jaimes et al, 2003), and the analysis of the available information encouraged the company to apply the same technique on this well during 2005. Two additional wells were selected for acid treatment jobs (Az-8 and Az-64), but this paper deals only with the results of the stimulation job conducted on well Az-9AD.

### Table 1.

<table>
<thead>
<tr>
<th>Well</th>
<th>$K_h$ (d-m)</th>
<th>Skin (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZ-9AD</td>
<td>31.5</td>
<td>17</td>
</tr>
</tbody>
</table>

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Well Stimulation Design

Five sections of 50 meters each were selected to be treated with a mixture of 10% HCl- 5% HF main flush solutions to dissolve the mud and cement sheath near the wellbore. The main flush acid volume used, was equivalent to 931 liters/meter (75 gallons per foot) thickness of target zone to be stimulated, following the same technique used for previous acid jobs conducted by CFE (Jaimes et all, 2003) and in the Philippines (Bunning et al, 1995 and Malate et al, 1998).

Injection of the main flush was preceded by a pre flush solution of 10% HCl, with volume equivalent to 620 liters/meter (50 gallons per foot) of pay zone. This solution dissolves the iron and carbonate compounds that may later deposit insoluble minerals with the HF acid. The main flush was immediately followed by a post flush of 10% HCl and an over flush of geothermal water for “scavenging” of the dissolved minerals and for rinsing the injection tubing and metal casings of unspent acid in the wellbore. This volume was twice the acid main flush. The same procedure was repeated for each target interval. The target intervals were selected from the compound analysis of permeable zones from TPS, temperature logs, circulation losses during drilling and mineralogy and petrography correlations (Table 2). The target zones were as follow (Flores et al, 2004):

a) 612-662 m (50 meter)
b) 662-712 m (50 meter)
c) 900-950 m (50 meter)
d) 1150-1200 m (50 meter)
e) 1380-1430 m (50 meter)

Pre Acid Treatment Test

Pre acid treatment tests were conducted on June 4TH, 2005 as a way of gauging the wellbore condition before the job and as a reference of improvement gained from the stimulation job. The test normally involves the use of a water lost test and injectivity and pressure fall off surveys. However, due to the fast temperature and well head pressure recovery of the well, when injection was suspended, it was decided to conducted a drawdown test reducing the pumping rate from 131 t/h to 63 t/h, instead of the fall of pressure test. Tests analysis yielded

Table 3. Pre-treatment test results.

<table>
<thead>
<tr>
<th>Injectivity Test</th>
<th>Drawn-Down Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injectivity Index (T/hr-Bar)</td>
<td>ΔP skin (Bar)</td>
</tr>
<tr>
<td>6.1</td>
<td>+21.7</td>
</tr>
</tbody>
</table>
an injectivity index (II) of 6.1 t/h-bar, transmissivity (kh) of 15.5 darcy-meters and a positive skin factor (s) of +17.8 (Figure 5 and Table 3).

**Job Execution**

The acid job execution proceeded from the shalower zone to the deepest one on June 11th, 2005. Two divergent stages were used between the target zones “a” and “b” and between target zones “b” and “c”. According to the behavior of the downhole pressure during pumping, the target zones that better react to the acid injection were 612-662 and of 900-950 m depth (Figure 6).

During the acid job a close and continuous monitoring of pH and temperature of the neighboring wells (Az-9, Az-9A and Az-69/45) was done that did not reveal any anomaly. However, it is important to note that a slight increase in water production rate of well Az-9A was observed, as well as a small increase in its wellhead pressure.

When operations finished, the well continued with an injection rate of around 70 t/h to perform the post acid treatment test, but when recovering the last 439 meters of injection tubing, the well kicked and reached a wellhead pressure of 35 bar (500 psig), within a few minutes. Due to the lack of sufficient water to control the well and conduct the test, it was decided to cancel the post treatment test.

### Results of Stimulation

As mentioned before, it was not possible to perform the post acid treatment test; however, the pronounced wellhead pressure increase showed a favorable result, since wellhead pressures that high were never measured before at that well. Nevertheless, the final and most important measure of wellbore improvement is the productivity of the well.

On June 17th, the well was opened through two 2" diameter lines to the silencer. Before opening the wellhead pressure was 42 barg (600 psig), which decreased to 36.5 barg (520 psig) when flowing partially through the lines (Tello et al, 2005). The pH of the fluids varied between 6.5 and 7, confirming that the acid was totally spent in the formation. The well was in that condition until June 22nd, 2005 when the measuring surface equipment was installed. At this date, the well head pressure increased to 39.3 barg (560 psig). The post stimulation medium term discharge test (MDT) is shown in Table 4 and Figure 7. In the first line the original discharge output is included for comparison.

According to these data, the well increased its steam production by 174%. Moreover, after one year flowing, the well is supplying 73 t/h of steam to unit No. 5, reaching the production capacity that had been inferred from the pre treatment pressure test. Both tests (MDT and LDT) confirmed the remarkable gain in mass flow rate and wellhead pressure after the acid job.

<table>
<thead>
<tr>
<th></th>
<th>WHP (Barg)</th>
<th>@ 10 Barg</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Treatment</td>
<td>14.5</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Post Treatment</td>
<td>20.9</td>
<td>68.5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

![Figure 6. Monitoring during acid treatment.](image-url)
Conclusions

Acid treatment of well Az-9AD introduced very significant improvement in the well. The increases in the steam flow rate and wellhead pressure suggest that the damage in the formation was eliminated.

The maximum discharge capacity of the well was 68 t/h at 10 barg of separation pressure, with a wellhead pressure of 20 barg, immediately after the treatment. One year later the maximum production is 73 t/h. According to the history of the well, its maximum production capacity, before the treatment, was 25 t/h at a wellhead pressure of 12 barg. Therefore the acid job increases its production capacity by 174%.

Good analysis of the information available for the prospect as well as multidisciplinary team approach, to select the target intervals during the acid job, has proved to be essential to reach the objectives of the job.

Moreover, it can be said that proper analysis of pressure transient tests led to excellent estimation of discharge gain after treatment, confirming this is a useful screening tool to select candidates.

The results of this job have been used for encouraging new stimulation programs, such as those in wells Az-56R and Az-9A located in the northern zone of Los Azufres geothermal field.

Acknowledgment

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References


