**Successful Perforation Operation Experience in a Geothermal Well of Salavatli Geothermal Field**

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**ABSTRACT**

This study presents a stimulation effort in a non-productive well with no permeability in the barefoot section below the 9 5/8" production casing. A convection zone was detected with high temperature in the cased-off section of this well AS-9, and the identified horizon was twice perforated and treated by acidizing. The build-up test conducted before the first perforation operation revealed unusually high skin factor of 96.7. After a second perforation and a couple of acidizing operations skin factor is substantially reduced but still remained relatively high. Resulting well has turned out to be a respectable production one with 350 t/h at 13 barg. The operations have been successful. In this study, perforation and stimulation efforts will be reported together with supporting well testing, and results will be presented.

1. INTRODUCTION

Salavatli geothermal field in Turkey has been developed during the last 12 years, and 4 power plants with a totaling power generation capacity of 52 MW, were installed. Recently, new production wells for the fifth power plant were started to drill. One of the wells (AS-9) drilled for this purpose was aimed to tap deeper sources that are believed to exist has reached 2500 m with no permeability. But, a very hot horizon (180°C) was detected in the cased off upper part of that well behind the 9 5/8" production casing. So it was decided to induce that permeable horizon by perforating.

Perforation, though it is extensively used in oil and gas industry, it’s utilization in geothermal completion technology is very rare. As far as we know, in the 1960’s it was used in Cerro Prieto and in one well Mofete field, near Naples which was abandoned later for environmental concerns. More recently, some studies were published on perforation operations in various depths of different geothermal fields such as Philippines, Australia and Sweden (Buining et al, 1997, Reid et al, 2011, Rosberg, 2006, respectively).

This paper deals with the results of stimulation job conducted on AS-9 well, and discusses in general terms well testing and stimulation procedures applied on the well.

2. PERFORATION OPERATIONS IN GEOTHERMAL WELLS

Most experienced geothermal operators bulk at perforated and cemented completions. The arguments can be legitimate. There are supplementary costs associated with this completion, and temperatures can make cementing and perforating challenging. Plugging of existing fracture systems during casing cementation is a real problem because of formation damage that must be overcome by further stimulation efforts. On the other hand, close and interconnected natural fracture systems are required for economic viability of these projects. To effectively reach multiple fracture systems, wellbore isolation seems to be natural requirement, and this is provided by casing, cementing and perforating. A comparative analysis needed be done to assess the formation damage caused by casing cementing, perforation skin, and relative economics associated with cementing and perforating geothermal wells (Glauser et al, 2013).

To ensure an economic geothermal prospect, if there is single producer, the criterion for economic throughput is colloquially expressed as 100 kg/s by some. In any case, at 200°C this is between 114 and 125 kg/s at the sand face. To accommodate such high rates with nominal friction, large diameter casing is conventionally used with barefoot sections. This philosophy may be acceptable in conventional hydrothermal systems (Glauser et al, 2013).

3. WELL CHARACTERISTICS

AS-9 well was drilled with the aim of reaching and tapping deep hotter sections of the resource. Geochemistry surveying had already indicated deep feeding temperatures around 220-230°C in this field where the previously drilled wells have temperatures in the range 160-173°C, and in a deep well drilled close by a temperature of 212°C had been found at the bottom around 3000 m. On the other hand, a CSAMT surveying conducted in the field had also supported this model indicating a deep conductive layer in this part of the field. Conceptual geological model built for this area has also pointed out that the location of AS-9 well is situated in the peripheral area of an upflow zone. The subsequent wells drilled around this area have confirmed this zone.
The AS-9 well was drilled to 2500 m depth, and 13 3/8” and 9 5/8” casings were set at 303 m and 1464.5 m, respectively, leaving open-hole section between 1464.5 m and 2500m. No circulation losses have been observed in this barefoot section of the well. Testing conducted during completion revealed no production in this section. The well was found non-commercial after its discharge capacity test. This was an expected result since no losses had been observed during drilling of open hole.

Fig. 1 illustrates completion plan and temperature profile of AS-9 well. After quitting the drilling at 2500 m, the original plan for the future was to sidetrack the well depending upon the results of seismic surveying planned to identify close by east-west oriented graben faults, and to intersect them. The calculated costs of seismic surveying, sidetracking the well and directional drilling were rather high.

In the resource assessment, the authors believed that there was enough evidence from the temperature and pressure profiles of AS-9 and surrounding wells to suggest that this well could have intersected production zone encountered in AS-12 and AS-15 wells.

Fig. 1 shows stable shut-in temperatures. The profiles suggest a convection zone within the cased off section of the well. It was therefore suspected that this was caused by considerable wellbore damage imposed during casing cementation, and a potential production zone was inadvertently cased off. During drilling slight partial losses had been observed around this zone, and during 9 5/8” casing cementing serious circulation losses were observed indicating that cement was lost this zone. The prospects for production from the cased off zone in AS-9 and AS-5 wells also led to the decision to perforate production casings of those wells and subsequently acidize them.

The temperature peak observed around 800 m in Fig. 1 has brought another solution that is, the perforation. The temperature seen at the peak of the profile was rather high (180°C). The costs of such operation were relatively low with respect to the sidetracking option, which still had some uncertainty.

Figure 1: Completion plan and temperature profile of AS-9 well.

3. PRODUCTION CASING PERFORATION AND WELL STIMULATION DESIGN

The stimulation job was conducted in two stages: (1) perforation of cased off convective zone, and (2) acidizing the perforated interval. At first before starting stimulation job, open-hole section required the isolation, and this was provided by placing a cement plug within the 9 5/8” casing below the convection zone at 1400m. Isolation was necessary to ensure efficiency of acid injection into perforated casing.

3.1. Casing Perforation

Drilling records, temperature survey were used as initial information in designing the perforation job. Preliminary targets were determined from the temperature surveying as noted in Fig.1. And, the formation behind the casing at this interval (766m-821.5m) was identified as marble. Super deep penetrating perforating charges capable of 50.69 inches (1.29m) penetration not only in cement but also far into the formation (API RP-43) have been utilized to ensure communication around 12 3/4” wellbore. Charges were shot using 6
shots/foot \(3^{3/8}\) expendable gun in band of target (788.5–798.5m). On the other hand, charges were shot using 4 shots/foot in two long bands of target (766.2–787.5m and 800–821.5m) that have been reduced four separated intervals located as close as the convection zone. Entry hole diameter of each charge measured about 0.42 inch, equivalent to about 0.83 in\(^2\) of perforated cross-sectional area per foot interval.

Perforation was conducted very slightly overbalanced. The well was filled with fresh water before perforation. A pressure drop of 5 bar was observed immediately after firing the shots. This enabled immediate determination of communication between wellbore and formation after fires had been shot.

In order to prevent any potential damage to the perforations and the formation the AS-9 well was immediately induced to discharge. The well started to flow rapidly with a mass rate of 160 t/h and reached 4 bar WHP and 150°C WHT in 10 minutes. Later flow rate is reduced to 100 t/h.

3.2. Acid Treatment

Since the production results were not satisfying it was decided to acidize the perforated zones. The procedure of acidizing was in the following way: Before the mainflush the zone to be acidized was cooled down. Injection of mainflush was followed by a postflush of water for scavenging of the dissolved minerals and for rinsing the injection tubing and metal casings of unspent acid in the wellbore. Its volume is estimated to be at least thrice that of acid mainflush. The same procedure was repeated in subsequent acidizing operations in the same zone.

The perforated zones were treated by acidizing at 821m with 239 bbl 28% HCl, and at 760m with 170 bbl 28% HCl reaching to a total 60.6 ton acid. After the acid treatment and during the displacement of acid postflush water into formation with 120 t/h injection rate, zero WHP was observed, indicating substantial permeability improvement. Moreover, as seen in Fig. 2, the maximum discharge flow rate of the well reached 250 t/h at 8.5 barg WHP.

In order to improve the production further, a second round of perforations was carried out. The same density of shots were fired at the same interval with 15 cm of displacement to prevent casing damage of firing at the same levels, and to increment flow openings to accommodate more flow. Moreover, a second acid treatment was conducted using 58 tons of 28% of HCl.

![Figure 2: Production test results in AS-9 well before and after acidizing and perforation.](image)

4. VERIFICATION OF THE RESULTS OF OPERATIONS BY TESTING

To verify the operations conducted, pre-acid and post-acid treatment tests were conducted as a way of measuring the wellbore improvement gained from the stimulation job. The tests involved the use of build-up and discharge surveys.

Comparison of the downhole measurement pre and post casing perforation and acid treatment enabled us to evaluate improvement in the wellbore. Improvement indicators used in the analysis of the stimulation results include step-increases in the productivity index and permeability parameters, pumping pressures during the tests, increase in discharge flow rates. However, the most important measure of wellbore improvement is still the productivity of the well.
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Fig. 3 shows derivative analysis of a build-up test carried out after the first perforation and subsequent acid treatment. The results of derivative analysis are as follows:

\[ kh = 14600 \text{ md-m}, \]
\[ k = 293 \text{ md}, \]
\[ PI = 1.54 \text{ t/h-bar} \]
\[ R_{inv} = 695 \text{ m}, \]
\[ s = 96.7, \]

As the results indicate PI was very low, but on the other hand, the permeability is relatively high. This is originated from the unusually high skin factor (96.7). This anomaly may arise from two reasons: (1) insufficient number of perforations, (2) partial penetration created by the spike shaped convection zone indicated by temperature profile. Although the discharge rate increased substantially from 160 t/h to 250 t/h accompanied by increment from 4 barg to 8.5 barg of WHP, the well production has not reached the expected satisfactory values.

![Figure 3: Derivative analysis of AS-9 well after first acidizing.](image)

Fig. 4 illustrates derivative analysis of build-up the test conducted for AS-9 well after second perforation and acidizing. The results of derivative analysis of AS-9 are as follows:

\[ kh = 2.24 \times 10^5 \text{ md-m}, \]
\[ k = 4980 \text{ md}, \]
\[ PI = 121.6 \text{ t/h-barg} \]
\[ R_{inv} = 2980 \text{ m}, \]
\[ s = 10. \]
Figure 4: Derivative analysis of AS-9 after second perforation and acidizing.

This test indicates several folds of increase in permeability parameters with respect to previous one. There is a huge increase in transmissivity from 14600 md-m to 2.24*10^5 md-m, and the PI from 1.54 t/h-bar to 121.6 t/h-bar. The most interesting of all radius of investigation is extended from approx. 700 m to 5 km, indicating that a connection with fracture system might have been successfully established. The most important of all is that skin factor is reduced from roughly 96.7 to 10. At first, the enormous skin factor calculated had been attributed to the partial penetration because of the restrained convection zone around 790 m. But, it is believed that the second round of perforations has increased flow area to the well, and in addition, two further acid treatments have improved the stimulation and enhanced the well productivity. After heavy stimulation efforts the remaining still high skin factor (S=10) could be attributed to partial penetration. On the other hand, the substantial flow rate increases from the first 160 t/h at 4 bar WHP, to 240 t/h at 8.5 bar WHP, and finally (Fig. 2) confirm the success of perforation and stimulation job.

As seen from the above build-up tests the combined effect of the second round casing perforation and the acid treatment of perforated intervals was a successful stimulation job for AS-9. It is clear that a progressive wellbore improvement brought about by the stimulation job. The observed increase in permeability of the well between after first perforation and subsequent acid treatments might have been the result of several clearing discharges on the well as well. It remained damaged as indicated by its positive skin taken during the second build-up test. However, the specific contribution of either the casing perforation of subsequent acid treatments of the perforated intervals could not be clearly determined.

5. CONCLUSION

• Perforation and subsequent acid treatment of AS-9 well on a cased-off section have created a very good production well out of a dry, non-producing well.
• These operations have also created a significant economic benefit at a very low cost.
• Another candidate well is on row to conduct similar operations.

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