

## Coiled Tubing Acid Stimulation of Alaşehir Geothermal Field, Turkey

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### ABSTRACT

Alaşehir geothermal field located in Alaşehir Graben, West Anatolia – Turkey is the current target for geothermal field development. Several wells drilled in Alasehir geothermal reservoir were below expectations. Static and dynamic pressure – temperature, pressure transient tests and a short term flow test were conducted to characterize the problem and to characterize the initial state of the permeable zones. It was observed that several of these wells had debris at the bottom of the well blocking permeable zones resulting in low injectivity indices obtained from the analyses of multi rate injectivity and pressure transient tests. Cleaning and acid treatments using a coiled tubing unit were designed and carried out to improve well performance of such wells. The criteria for the design of the acid treatment were type of rock formation, number and thickness of the permeable zones, extent of skin damage, and level of steam fraction. The acid treatment used 18% HCl that was placed at the target zones using coiled tubing. Post-acidizing production tests and well test analysis demonstrated that the cleaning and acid stimulation improved the permeability significantly, resulting in production increases more than twice of the initial values in some wells. It was concluded that the parameters such as volume of the fluid treatment, and the selection of additives and the operation parameters are very important to take into account in order to obtain excellent results.

### 1. INTRODUCTION

Since the 1980's hydrochloric acid (HCl), hydrofluoric acid (HF) or both have been used in geothermal wells (Combs et al, 2004). HCl is used to treat limestone, dolomite and calcareous zones whereas HF is used to dissolve clay minerals and silica. The acid additives necessary in a typical geothermal acid job are corrosion inhibitor, and inhibitor intensifier and high-temperature iron-control (reducing) agent. Water-wetting surfactants as well as suspending agents (nonemulsifier surfactants), necessary in oil well stimulation, are not needed in geothermal wells because of the absence of hydrocarbons. A clay stabilizer is not needed since geothermal wells usually produce from volcanic rock that does not have clays. Conventional acid placement techniques are less effective for the long, open-hole or liner-completed intervals typically encountered in geothermal wells (Portier et al, 2007). High-temperature foam systems may improve zone coverage. Gelling agents for thickening acid have been shown to be ineffective in geothermal liner completions. The best way to maximize acid coverage in geothermal wells completed in fractured formations is by pumping at maximum injection rates.

Geothermal wells acidizing is used for the reservoir development or to treat formation damage caused by drilling mud and scaling (mineral deposits) in geothermal wells (Buning et al, 1995; Buning et al, 1997; Malate et al., 1997; Yglopaz et al., 1998; Malate et al., 1999, Barrios et al., 2002, Jaimes-Maldonado and Serpen and Tureyen, 2000). A technique involving three main steps is usually practiced. First a preflush, usually with hydrochloric acid (10%) is conducted. The objective of preflush stage is to displace the formation brine and to remove calcium and carbonate materials in the formation. The preflush acid minimizes the possibility of insoluble precipitates. Following preflush, main flush with HCl or HCl – HF acid mixture (A mixture of 10% HCl – 5% HF (called Mud acid) is generally prepared by dissolving ammonium bifluoride ( $\text{NH}_4\text{HF}_2$ ) in HCl) is conducted. A mixture of 1% of HCl and 56 kilos of  $\text{NH}_4\text{HF}_2$  will generate 1% HF solution. Regular mud acid (12% HCl-3% HF) is made from 15% HCl, where 3% HCl is used to hydrolyse the fluoride salts. Finally a postflush/overflush usually by HCl, KCl,  $\text{NH}_4\text{Cl}$  or freshwater is applied.

Concerning the injected amounts for the cleaning out of the geothermal wells, the main flush volume was based on a dosing rate of 900 liters per meter of target pay zone. The preflush volume was based on a dosing rate of 600 liters per meter of target zone (Malate et al., 1997; Barrios et al., 2002). Gdanski (2005) recommended 1  $\text{m}^3$  of 15% HCl per meter acidized borehole as a rule of thumb for matrix acidizing. Even higher amounts were advised for fractured formations. Coiled tubing (CT) applications are getting popular since the acid can be placed to the target interval that maximizes control over the acid treatment (Passiki and Gilmore, 2006). The use of CT unit does not affect the amount of acid used.

In this paper coiled tubing fill cleanout, acidizing treatment design and execution conducted in Alaşehir geothermal field will be presented. First candidate well selection based on well test analysis will be discussed. Following that selection of acidizing formation depths and zones will be introduced. The paper will be finished by giving results and discussions.

### 2. ALAŞEHİR GEOTHERMAL RESERVOIR

Alaşehir geothermal area that is located in southern part of the Alasehir Graben (also known as Gediz Graben) in western Turkey is one of the most important geothermal areas. The Alasehir Graben is situated approximately 140 km east of Izmir in the Western Anatolian extensional province (Dewey and Sengor, 1979). Both the southern and northern margins of the Alasehir graben are

dominated by non-marine sediments that show marked lateral and vertical facies variation (Purvis and Robertson, 2005). The Alaşehir Graben contains four sedimentary units developed under an extensional tectonic regime and is a superimposed graben containing possible traps as well as a high potential for hydrocarbon generation. The stratigraphy of the region is mainly represented by metamorphic rocks of the Menderes Massif and the synextensional Salihli Granitoid as basement rocks, which are tectonically overlain by Neogene-Quaternary aged sedimentary rocks. These rocks are cut by two detachment faults, which are also cut by younger various high-angle normal faults. The graben fill is composed of four sedimentary units: Alaşehir formation (Iztan and Yazman, 1990), overlain by Kursunlu (Seyitoglu, 1992) and Kalatepe (Iztan and Yazman, 1990) formations, and finally alluvium at the top (Figure 1).

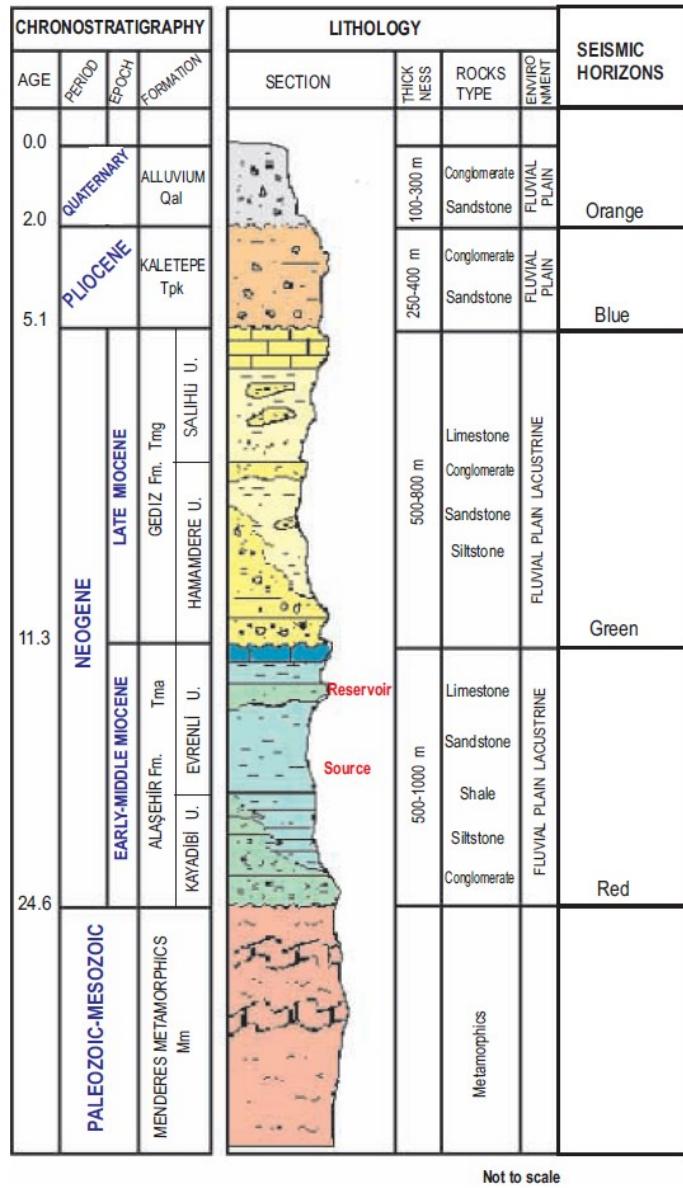
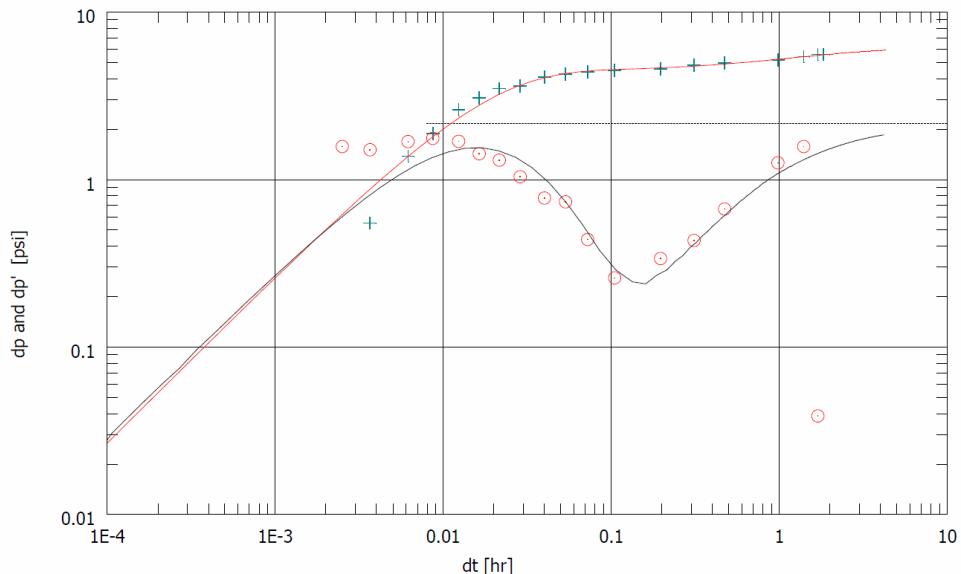


Figure 1: Generalized stratigraphic column of the Alaşehir area (After Yilmaz and Gelişli, 2003)

The Alaşehir geothermal field is located between Alaşehir and Salihli towns. There are several deep wells whose depths vary between 1100m to 2500 m. The high temperature ( $> 190^{\circ}\text{C}$ ) geothermal reservoir with fracture permeability in the upper section of the Paleozoic basement, with the major feed zones in the upper Paleozoic carbonaceous metamorphics at approximately 1150 m and 1600 m depth, respectively is liquid dominated with 2% to 4%  $\text{CO}_2$  by weight suggesting that the gas breakout pressure is between 90 and 115 bara - gas breakout occur between 800 to 1200m, depending on the well flow rate.. The reservoir has good permeability-thickness and probably from intersecting fractures.

The waters of wells located in Alaşehir-Piyadeler, Bayramyeri and Çağlayan districts are of Na-(K)-  $\text{HCO}_3$ -  $\text{Cl}$  in character, and contains 2200 to 2500 ppm TDS and 5 to 10 ppm  $\text{Ca}^{++}$ , with pH ranging from 7.5 to 8.5, depending on separation pressure. During the pressure decrease in the production wells and hence in the reservoir,  $\text{CO}_2$  separation occurs and may lead to calcite scaling even in the reservoir fractures, due to the high pH and super-saturation of calcite and other carbonate minerals. The original flow of the wells may be prevented both by drill cutting or later formed scaling due to pressure loss in the wells and reservoir fractures. It is estimated that 90% of the calcium is precipitated in the production wells before fluid reaches the surface.

The log – log analysis of buildup tests conducted in several wells indicated double porosity reservoir behavior (Figure 2) corresponding to flow mainly through a major fracture path (or fault) and auxiliary flow from side fractures. Large, negative skin values calculated were consistent with the theory that since geothermal wells generally produce from fractured volcanic rocks they show stimulated behavior (Home 1995). On the other hand, skin factors of several wells were below expectations indicating a damage zone possibly by drill cuttings and drilling mud. Weighting material of the drilling mud was bentonite clay. For example BY-6 and BY-5 had larger skin values, -2.42 and -3.34 respectively, compared to that of BY-2 (-5.67), BP-1 (-5.86) and BY-1 (-6.91). It was also observed that several of these wells had debris at the bottom of the well blocking permeable zones resulting in low injectivity indices obtained from the analyses of multi rate injectivity tests. Of these wells DP-1 had the highest amount of debris (311 m), followed by BY-2 (226 m).

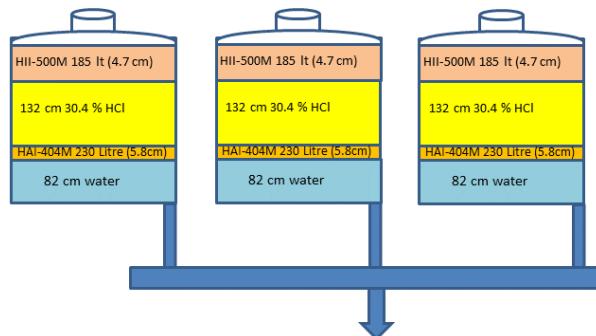


**Figure 2: Log – log analysis of pressure buildup test data of BY-4.**

## 2. COILED TUBING FILL CLEANOUT AND ACIDIZING

To enhance the production and reinjection capacities of the Alaşehir geothermal wells that suffered from both drill cutting deposition at the bottom of the wells and mud damage coiled tubing cleaning and acidizing operations were implemented. In all operations first fill cleanout operation was carried out to move the solids to surface. A tool that has two sets of tangential side-jets was used to optimize the transport of fill deposits out of the wells. Run in hole with CT to the top of the fills constituted the first step. Reverse circulation with a gel volume  $2.8 \text{ m}^3$  was used in all operations. Due to the smaller internal flow area of coiled tubing high circulation velocities were achieved inside the CT and fill were effectively transported through by reverse circulating up the coiled tubing. The fill cleanout was confirmed by comparing the lowest depth CT unit was lowered with the final depth recorded during drilling. Despite some operational problems in the field all trials were successful. Only in one of the wells (BP-3) coiled tubing collapse prevented further operation.

Acidizing operations started with cooling down the well with  $100$  to  $130 \text{ m}^3$  of fresh-cold water, followed by injectivity confirmation with the CT unit at a rate of  $0.14 \text{ m}^3/\text{min}$ . Acidizing operations were conducted using diluted HCl (18 % by weight) with retarder (to avoid wormhole reaction in the slotted liner vicinity) and anti-corrosion additives at a rate of  $0.50 \text{ m}^3/\text{min}$  to  $0.57 \text{ m}^3/\text{min}$ . Six tanks each with a volume of  $9.4 \text{ m}^3$  of acid solution were prepared for each well. Hulliburton HII-500M™ corrosion inhibitor intensifier and cationic acid corrosion inhibitor (Hulliburton HAI-404M™) were thoroughly mixed with acid and water that will result in 18 % HCl by weight (Figure 3).



**Figure 3: Acidizing solution of each acidized well in Alaşehir geothermal field**

Acidizing operation was performed with a CT unit to desired depths. The acid amount was calculated based on the aforementioned “rule of thumb” values. A two-inch coiled tubing unit was utilized to maximize acid pumping rates and decrease total treatment

time. Coiled tubing offers advantages to place the acid via a dedicated conduit adjacent the desired zones of interest (Mitchell et al, 2003). The selection of the zones was based on water loss tests, static and dynamic p-T surveys and loss circulation information gathered from drilling logs. In this regard, total mud loss zones possibly corresponding to faults and high intensity fracture zones were selected. For some wells more than one potential reservoir zones were acidized (Figure 4). In such wells the acid stimulation was subdivided into two phases: lower and upper wellbore sections. In the first phase of treatment, the acid was pumped to the deepest interval with a total treatment interval of half of the available acid volume (Figure 3). The acid was pumped at an average rate of 0.50 - 0.57 m<sup>3</sup>/min with 193.4 bar pressure through the coiled tubing. After injection of the diluted acid solution, the acid was forced with cold water to move the acid further in the fracture system. After waiting at least 8 hours for reaction time with the formation in the reservoir, the resulting solution was discharged from the well by back flow. Then the CT unit was moved up to the second zone and the same operational stages were followed. In all acidized wells the same procedure was repeated. At the end of acidizing operations, the following results have been obtained from cleaned and acidized wells of the Alaşehir geothermal field (Table 1). As an example to acid stimulation achievement, it was observed that the deliverability of BY-6 increased more than twice at same operational wellhead pressure (Figure 5). The success of acid stimulation was more than 100 % in this well. In all stimulated wells more or less similar stimulation increases were obtained.

**Table 1. Production improvement of wells after fill cleanout and acidizing.**

Well	Wellhead Temperature, °C	Production Capacity (tons/h)		Improvement
		Before acidizing	After acidizing	
DP-1	159	190	800	421 %
BY-2	175	268	450	68 %
BY-6	175	250	500	100 %
BY-5	154	137	202	47%

## DISCUSSION

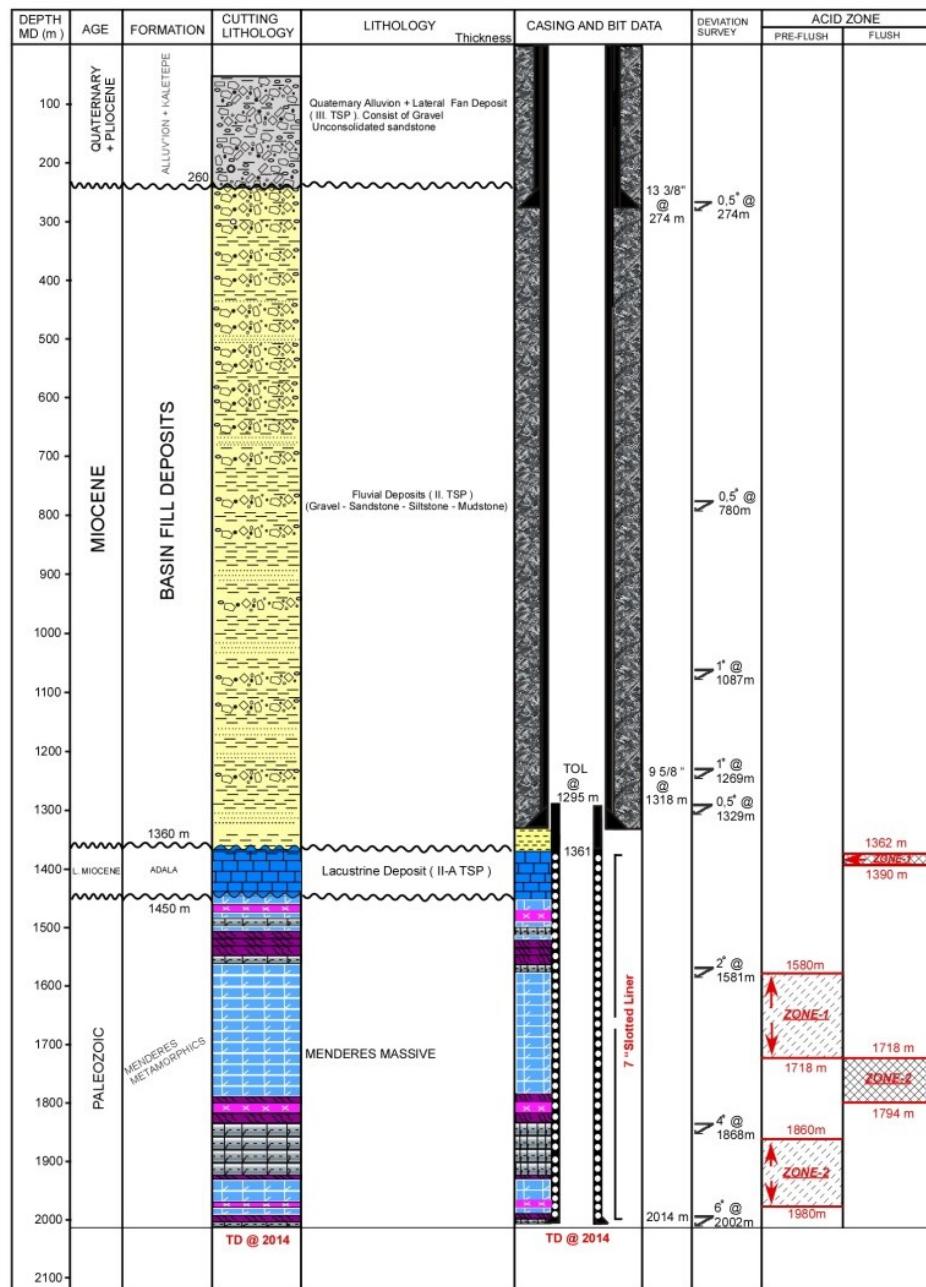
Lund et al (1974) and Allen and Roberts (2005) indicated that acid consumption rate increased as the application temperature increased. Although the temperature dependence of the reaction of hydrochloric acid has not been studied on purpose, no clear correlation between temperature and effectiveness of acidizing could be observed for the stimulated wells in Alaşehir geothermal reservoir. Both of the wells responded positively to acid stimulation regardless of the down hole temperatures.

Apart from a possible temperature effect, acid injection rate as well as amount of acid spent may have a pronounced effect. The penetration depth of the acid depends primarily on the injection rate as a higher injection rate means higher pressure within the well. So for a given porosity, a higher injection rate means that the acid will penetrate deeper into the formation before it is spent. As a rule of thumb, for matrix acidizing conditions Gdanski (2001, 2005) gives about 0.7 L/s per meter of penetration depth. Given the actual pump rates (0.14 m<sup>3</sup>/min - 0.57 m<sup>3</sup>/min) for some of the stimulated wells, penetration depths according to this rule should have been about 3 m to 13.5 m. It is obvious that no wide-ranging effects can be expected, but that only near well area was treated. Thus it can be concluded that the effect of acidizing was removing the damage resulting from the drilling process in the immediate surroundings of the stimulated wells.

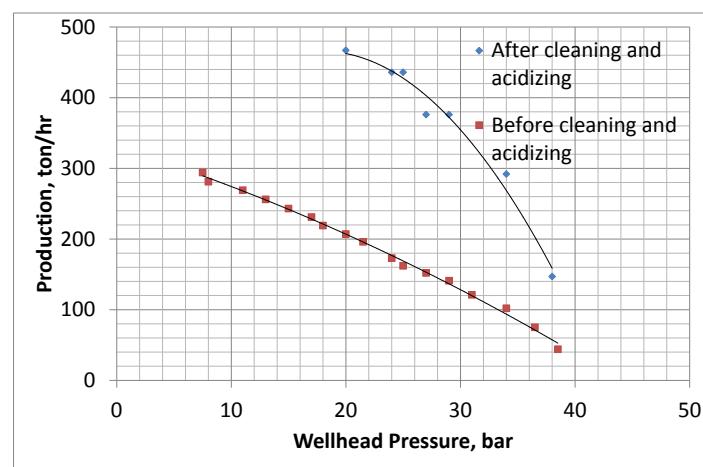
As noted above Gdanski (2005) recommended 1 m<sup>3</sup> of 15% HCl per meter acidized borehole as a rule of thumb for matrix acidizing. Even higher amounts were advised for fractured formations. In Alaşehir geothermal acid stimulation wells, the amounts of acid used were always on the lower side of acid volumes suggested by Gdanski for acidizing. On the other hand, it can be argued that geothermal wells do not require the same amount of acidizing as oil wells, since hot water is less viscous than oil and can therefore far better percolate through small fractures than oil.

## CONCLUSIONS

First time use of a coiled tubing unit in fill cleanout and acid stimulation of geothermal wells in Turkey is reported. Fill cleanout and acid treatment using coiled tubing unit was carried out to improve the production characteristics of several wells in Alaşehir geothermal field. Following successful fill cleanout the acid was placed to the target interval zone with the CT unit to maximize control over the treatment. Both single and double zone treatments were successful as demonstrated by production test results before and after CT cleanout and acid stimulation. It was concluded that the effect of acidizing was removing the damage resulting from the drilling process in the immediate surroundings of the stimulated wells. Based on the positive results obtained in the first time use of CT unit in geothermal applications in Turkey, further application of this method is envisaged for other poor-performing wells with similar characteristics.



**Figure 4: DP-1 acid zone depths.**



**Figure 5: BY-6 production improvement after CT cleanout and acid stimulation.**

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