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Evaluation of Acid Treatments in Mexican Geothermal Fields

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ABSTRACT

Since 2000, the Federal Commission of Electricity (Comision Federal de Electricidad or CFE) began to use the matrix acidizing technique to improve the production / injection capacity of wells in geothermal fields in Mexico. Since that time, 13 production wells and 4 injection wells have been acidized. Savings as a consequence of the gain in production and injection capacity was found to be equivalent to the cost of 11 new production wells and 2 new injection wells.

In this paper, the successes and failures realized when choosing the acid mixture, volumes and targets in every well are explored, and the overall results of the application of this technique are discussed.

1. INTRODUCTION

Matrix acidizing is a common method of stimulation treatment used to remove damage near the wellbore, with the objective of restoring the well and reservoir formation to its natural undamaged inflow performance. This chemical treatment involves the injection of a reactive fluid, normally an acid, into the porous medium at a pressure below the fracturing pressure. The acid works through a process of dissolution of material deposited in some of the porous formations, such as carbonates, metal oxides, sulfates, sulfides or chlorides, amorphous silica, drilling mud and cement filtrates from invasion. Treatment volumes, injection rates, acid placement techniques, acid system selection, and the evaluation of the results in stimulation of geothermal wells follow the same criteria as is used for oil wells. However, the formation temperature is of particular importance, because it influences the efficiency of corrosion inhibitors and reaction rates. This technique has been used in the oil industry for many years, but it took several years to achieve its adoption in Mexican geothermal fields.

As shown in Figure 1, the actual geothermal electric capacity in Mexico is 958 MWe and is installed in four geothermal fields (Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes). The operating capacity of each field, the projects under construction, and future plans to increase capacity are shown in Table 1. The fifth field, La Primavera (Cerritos Colorados project), remains on stand-by, even though a potential of 75 MWe was assessed a long time ago. The installations of the first units in this field are expected to begin soon, since the Environmental Impact Assessment has been approved for a 25 MW power station.

That present geothermal electricity capacity represents 1.93% of the total electricity capacity for public service in the country.

Thirty six power plants of several types (condensing, back pressure and binary cycle) operate at capacities of 1.5 – 110 MWe in those fields. They are fed by 229 geothermal wells with a combined production of 7,530 tonnes of steam per hour (t/h). The production wells have depths of 600 – 4,400 m. The steam is accompanied by almost 9,000 t/h of brine, which is injected into 23 injection wells or treated in a 14 km^2 solar evaporation pond in Cerro Prieto. During 2008, steam produced in those fields reached 65.93 million tonnes, and the power plants generated 7 243.1 GWh of electricity, representing 3.16% of the electric energy produced in Mexico.

All the power plants and the geothermal fields are operated by the CFE public utility.

Table 1. Geothermal Capacity in Mexico.

Geothermal Capacity in Mexico				
Geothermal Field	Start up year	Running Capacity (MW)	Under Construc-tion (MW)	New Projects (MW)
Cerro Prieto, BC.	1973	720	-	-
Los Azufres, Mich.	1982	188	-	40
Los Húmeros, Pue.	1990	40	25	25
Las Tres Vírgenes, BCS.	2001	10	-	-
Cerritos Colorados	--			25

Figure 1: Locations of Mexican Geothermal Fields.

The first matrix acidizing job in Mexico was performed at the Los Azufres Geothermal field in 2000. The Los Azufres geothermal field is located in the northern portion of the Transmexican volcanic belt, 80 km east of Morelia city and 250 km east of Mexico City. It is a heavily fractured and faulted volcanic hydrothermal system, located in a sierra at an average elevation of about 2800 m. It is located in a forest area with abundant vegetation, which is considered a forest reservation zone (Torres-Rodriguez et al, 2000). At that time, there were many questions to solve and the technique was only applied in two injection wells. The results were not very surprising, mainly because the treatment flow rates and chemical composition were very low.

Three more years were needed to apply a better technique in production wells, now applying the flow rates and acid mixtures that were used in the Philippines at that time (Bunning et al, 1995 and Yglopaz, 2000). A second attempt was made at Las Tres Virgenes Geothermal Field, a granite type reservoir where a high skin factor and a resulting marginal steam flow rate and wellhead pressure were identified in the two production wells (Jaimes et al, 2003). The results were encouraging, showing production increases of up 367%. Since that date, several acidizing jobs have been performed at the Los Azufres and Las Tres Virgenes geothermal fields.

2. CANDIDATE SELECTION

The improvement in each of the wells depends on a consensus analysis of the mud losses, pressure and temperature logs, locations of feed zones, pressure transient tests, and dissolutions tests of the scale products in different acid mixtures. This helps to design the best strategy for each well in order to achieve the optimal economic return of each project (Flores et at, 2006). The selection of wells, analysis, and acid treatment desing have been largely documented in several papers (Bunning et al, 1995 and Yglopaz, 2000, Jaimes et al, 2003 and Flores et al 2006). Wells with large skin factors and low production rates compared to neighboring wells and large mud losses during drilling or scaling that reduces well productivity or injectivity are generally considered when selecting wells for an acidizing jobs. The typical data collection and data analysis for well candidates is shown in Figure 2 (Flores et al 2006).

3. ACID TREATMENTS DESIGN

The acid treatment design for the wells was performed with the following criteria.

Wells damaged with calcite scaling are treated using the same concentration for the pre- and post-flush operations, while the main flush was settled in 12% HCL- 3% HF.

With the exception of well LV-3, all wells damaged with bentonitic mud or scaled with amorphous silica during their commercial operation were treated using a pre- and post-flush concentration of 10% HCl, a main flush of mud acid (10% HCL- 5% HF), and an over-flush with geothermal water. A higher concentration of HF was used to accommodate the significant amount of mud lost in the formation. Injection of the main acid was preceded by a pre-flush solution of 10% HCl to dissolve the iron and carbonate materials that may later deposit insoluble minerals (e.g. CaF_2) with the HF acid and will serve as a spacer between the main flush and the formation brine.

In all cases, a volumetric flow rate of 75 gallons of main flush acid per foot of payzone interval was used to inject the acids into the formation, and a flow rate of 50 gallons of pre-flush volume per foot of payzone thickness was also used in the wells.

The main flush acid was followed by a small volume of 10% HCI post-flush solution to act as spacer between the main acid and formation brine and to reduce possible precipitation damage. Brine over-flush was then injected to displace the acid treatment solution and rinse the tubular and metal casings of unspent acid in the wellbore, using twice the volume of the main flush.

Circulation losses (m depth)	Permeable zones from temperature logs (m depth)	Feed Zones from TPS (m depth)	Mineralogical zones (m depth)	Petrologic zones (m depth)	Target zones
590-708 (PCL)		630 650		530-630 (high shearing)	a
708-712 (TCL) 712-789	700-900	712	690-740 (shear stress, evidence of fault)		b
		940		820 (low alteration)	c
112*-1146 (PCL)	1100-1200	1190		1190-1210	d
1431-1500 (PCL)		1380 1400	1430-1460 (fault planes)	1360 (abundant shearing) 1470-1500 (abundant shearing, main zone)	e

PCL: parcial circulation lost TCL: total circulation lost

Injectivity Test		Draw-Down Test	
Injectivity Index (t/hr-Bar)	ΔPSkin (bar)	Skin (s)	kh (d.m)
6.1	21.7	17.8	15.5

Figure 2: Summary of data for candidate well Az-9AD (Modified from Flores et at, 2006).

Corrosion inhibitors and intensifiers were also added to the acid mixtures (pre-flush, main flush and post-flush) to reduce the corrosion rate of the tubular well and equipment by the acid. Chelating or sequestering agents were also used to address iron control during acid injection. A large amount of surfactant was also added to the main flush mixtures in order to suspend the significant amount of drilling mud and minerals dissolved by the acid. Foam diversion was conducted between the payzone targets.

Well LV-3 was treated with an organic clay acid (OCA HT) as the main flush. The pre-flush was performed using a mixture of NH_4Cl, 7.5% HCl, and acetic acid for the post flush, followed by geothermal brine for over-flushing. The same volumes per foot of payzone as mentioned previously were used to inject the acids into the formation. The pressure, flow rates and volumes observed during a typical acid job are shown in Figure 3.

4. ACID JOB RESULTS

17 jobs have been performed (13 production wells and 4 injection wells), and two placement techniques were used (WO rig and 2 3/8” Coiled Tubing). One parameter that is specific for geothermal wells is the pumping rate (8 to 12 bpm), which is significantly high compared to conventional matrix treatments (0.25 to 1.0 bpm). The high rate increases the carrying capacity of the fluids, suspending fines and precipitates outside the critical matrix without fracturing the already highly conductive formation. Bullheading pumping is not suggested due to high corrosion risks and thermal shrinkage.

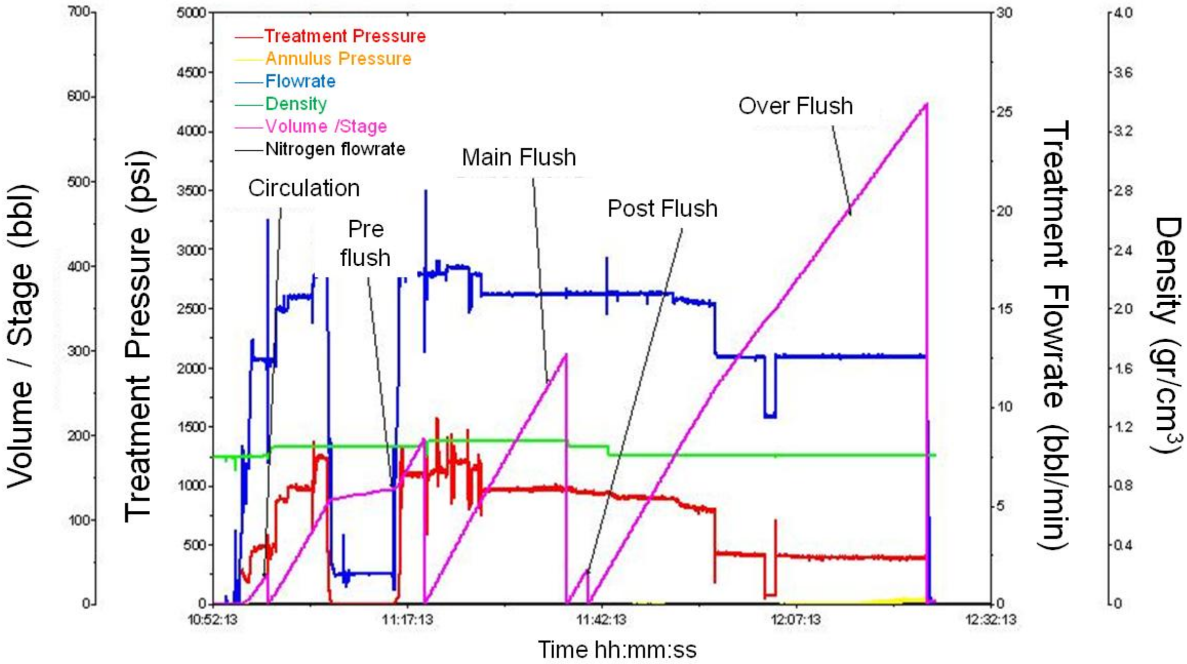

Figure 3: Parameter monitoring during acidizing of well Az-9AD

Table 2. Stimulation results in Mexican geothermal wells

I. Producer wells

Well Name	Mud Losses during drilling (m^3)	Production Capacity Original (t/h)	Pre-acid (t/h)	Post-acid (t/h)	Improvement %	t/h
1. LV-13 2002	5583	0	0	21	100%	21
2. LV-11 2002	5119	12	12	35	191%	23
3. LV-04 2004	amorphous silica	32	9	42	366%	33
4. LV-13 2004	calcite	21	14	28	100%	14
5. AZ-64 2005	3759	6	6	0	0%	0
6. AZ-9AD 2005	1326	22	22	68	209%	46
7. LV-3 2006	calcite	25	0	0	0%	0
8. AZ-9A 2006	505	15	25	67	168%	42
9. AZ-56R 2006	10921	15	15	70	367%	55
10. LV-4A 2007	2700	0	0	20	100%	20
11. LV-13D 2007	1326	0	0	20	100%	20
12. AZ-25 2008	amorphous silica	40	16	30	88%	14
13. AZ-68D 2008	8238	10	10	64	540%	54

II. Injector Wells

Well Name	Mud Losses during drilling (m^3)	Injection Capacity Original (t/h)	Pre-acid (t/h)	Post-acid (t/h)	Improvement %	t/h
1. AZ-7 2000	amorphous silica	600	750	850	13%	100
2. AZ-15 2000	amorphous silica	350	340	450	32%	110
3. AZ-8 2005	amorphous silica	290	180	410	127%	230
4. AZ-52 2008	amorphous silica	350	70	130	143%	60

The acidizing treatment statistics in México from 2000 – 2008 for production and injection wells is shown in Table 2. The name of the well and the year in which it was acidized are shown in the first column. The second column shows the volume of mud that was lost to the formation when drilling the well in the open hole section. Otherwise, it indicates the type of scale that was present in the well derivate of the production or injection stage. LV denotes wells acidized in Las Tres Virgenes, while AZ means wells at Los Azufres.

As can be seen in the table, 15 of 17 acid treatments were successful in these two geothermal fields. The wells were improved by 13 – 540%, with an average improvement of 176%.

5. BASIC ECONOMICS

CFE typically uses (COPAR, 2008) the following parameters for the economic evaluation of technical proposals:

- Discount Rate > 12%
- Median Well life ~ 5 years
- Electricity cost ~ 0.065 US$/ kWh
- Operation & Maintenance Cost ~ 0.005 US$/KWh
- Specific Consumption in power units ~ 7.5 t/hMW

This economic analysis will assume that capital investments only include the cost of the stimulation treatment, without taking into account the cost of drilling the well, surface equipment, and power plant. This implies that the wells have produced sufficient steam to pay off these previous expenses, or that they are regarded as a sunk cost, which is not considered when evaluating future expenditure. The mean well lifetime is about 5 years due to casing and formation scaling, such as that in Las Tres Virgenes. Excessive scaling reduces the production rate (or wellhead pressure) below the minimum values to allow connection to the power station (Flores et al, 2005). Different scenarios exist for other fields, such as Los Azufres or Los Humeros, where the median lifetime of the wells is above 15 years.

In order to simplify the economic analysis in this paper, a base case was developed that considered all 13 production wells to be acidized at the same time and used the latest acid treatment price at Los Azufres (Dec 2008). The estimated cost included all mobilizations, chemicals and additives, labor, equipment and personnel needed to perform the acid treatment.

A production decline rate for this base case was set at 5% per year, even though lower declines have been observed in the real cases in the five years considered for the analysis.

The results of this basic analysis show that the benefits of applying the technology are about five times higher than the expenditures, with an investment return in less than a year, as shown in Figure 4. The calculated TIR is 86%, with a net present value of 71.7 million US dollars.

It can be said that these acid treatments have saved the equivalent amount of money required to drill eleven new production wells and two new injection wells (considering a mean production of 30 t/h of steam for the production wells and -250 t/h for the injection wells) over 8 years.

6. UNSUCCESFUL CASES

So far, only 2 of 17 cases have been unsuccessful in their stimulation design, but these cases should not been ignored, since they provided information for future acid jobs.

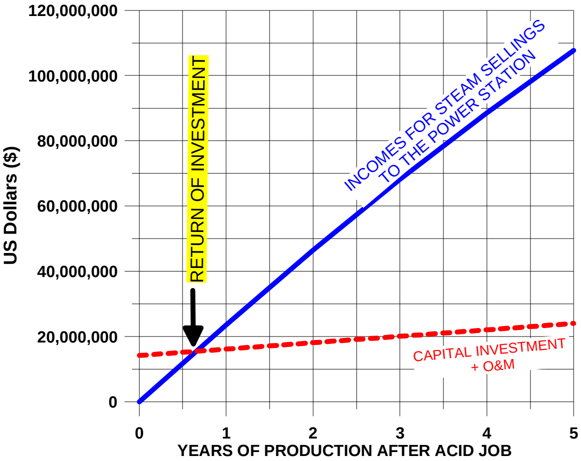

Figure 4: Economic analysis for acid jobs in production wells in Mexico

The first unsuccessful case was well AZ-64 located at Los Azufres Geothermal Field. This well is located in a very productive zone, surrounded by excellent production wells. However, a marginal production rate was achieved after drilling, because the well was severely damaged by invasion of drilling fluids. Well testing analysis showed a relatively high skin factor, so an acid job was designed and executed in 2005, using the standard acid concentration and volumes that were selected for wells with similar characteristics, including mineral content in the host rock. Post acid testing was performed, showing the elimination of the skin factor, including an improvement in the permeability, which led to the conclusion that the job had been successful. However, due to logistical issues, the well could not be opened quickly, and it took about 40% more time to discharge the well compared to the traditional time. That made it impossible to discharge the acid reaction products of the acid treatment, since the products that helped suspend the precipitates lost their effect, and therefore those products were deposited back into the formation, creating an irremediable damage to the well. For the next well (AZ-9AD), logistics were dramatically changed, and its output rate was tripled (Flores et al, 2006). Further stimulations followed in 2004, 2006 and 2007 with very good results.

The second unsuccessful case is well LV-3 at Las Tres Virgenes, in which a different fluid was used. It was decided to try an organic retarded acid, since laboratory tests indicated further penetration into the formation, and it was assumed that better results would to be obtained.

Well LV-3 was treated with an organic clay acid (OCA HT) as the main flush. The pre-flush was performed using a mixture of NH_4Cl, 7.5% HCl, and acetic acid for the post-flush, followed by geothermal brine for the over-flush. The same volumes per foot of payzone were followed to inject the acids into the formation. Since the well head pressure increased shortly after stimulation, post-treatment acid testing was not performed. However, when the well was discharged, it never attained the required well head pressure to supply steam to the power stations.

It was found that several retarded or slow reacting HF acids such as fluroboric, fluroaluininic and hexa-fluro-phosphonic were also developed to increase the depth of permeability improvement (Gdanski, 1985; Ayorinde et al., 1992). Most of these acid systems rely on the use of weak organic acids and their secondary reactions to slowly generate HF acid. Stimulation results using these acid systems were found to be better but were not substantial, since it is believed that live acid penetration is marginally increased, and separation and precipitation effects are slightly retarded. The marginal reduction of reaction rate of these acid systems could not overcome the large contrast in surface area between clays and quartz minerals. Various "in-situ generated' HF acids were also developed with questionable to poor results due to the premature or improper mixing of solutions, both in the tubes and in the formation (Malate et al, 1998). Further investigation needs to be performed in order to determine whether the use of retarded acids in well treatment should be discarded, since many cases have reported positive results.

CONCLUSIONS

15 of 17 acid treatments were successful in the Los Azufres and Las Tres Virgenes geothermal fields, which are hosted in volcanic type rock. The average percentage of improvement ranges from 13 – 540%, with an average of about 176%.

At present, all acid treatments being conducted by the CFE in Mexico use the mud acid (HC1-HF) system to treat formation damage caused by drilling mud and mineral (silica) deposits. The acid treatments conducted have generally used a pre-flush of 10%HC1 and a main flush of 10%HC1-5%HF.

Basic economic evaluations showed that the benefits of applying the technology are about five times higher than the expenditures, with an investment return in less than a year.

In terms of drilling savings, these acid jobs saved the equivalent of the drilling cost of 11 new production wells and 2 new injection wells over 8 years.

Several campaigns are running in Mexico to increase the number of wells treated with acid mixtures, not only at Los Azufres and Las Tres Virgenes, but also at Los Humeros and Cerro Prieto, due to the productivity/injectivity recovery and low cost compared to the construction of new wells or make overs of existing wells.

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