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The Neutralization of Acid Fluids: an Alternative of Commercial Explotation Wells on Los Humeros Geothermal Field

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ABSTRACT

The H-43 well on the Los Humeros Geothermal Field (HGF) was opened for production in February 2008 and had 61 t/h of steam flow, 4 t/h of brine flow, wellhead absolute pressure 51.7 bar and 5.2 of pH. In 10 days of constant production, the pH value diminished to 4.4, and the content of iron in the brine increased to 22.9 ppm, which is associated with corrosion of the casing by acid fluids. For steam commercial exploitation it is necessary to neutralize the fluid and so avoid corrosion in the casing and superficial equipment. For this reason, studies were carried out to determine the feasibility of neutralization of acid fluids. The tests in the well initiated in April and concluded in July 2009. Hydroxide of sodium (NaOH) with a concentration of 47 % was injected to 1350 meters depth to neutralize the acid fluid of the well. The results show that the neutralization system is successful. The estimated costs of system implementation are around USD $108,000 and the investment would be recovered in about 14 days, according to the well potential. H-43 well is projected to start production in late December of 2009.

In this paper, we present the results of the neutralization of acid fluids in the H-43 well, with the intention for commercial exploitation in the near future in this zone in the Los Humeros Geothermal Field, and with neutralization to obtain a major efficiency in the productive process.

1. INTRODUCTION

Los Humeros Geothermal Field (HGF) is located in the eastern zone of the Mexican Volcanic belt (Robin, 1982), at an average altitude of 2800 m asl and about 200 km east of México City (figure 1). The volcanic system has several geological structures. The local basement is formed by a Paleozoic metamorphic complex, chlorite-muscovite shales, a Mesozoic folded sedimentary sequence, lower Tertiary syenitic and granodioritic intrusions and Pliocene andesites. Since 1981, 43 wells have been drilled in HGF, of which 20 are producing and 4 are in use or have been in use as reinjection wells. In 1991, the first unit of generation of 5 MW was installed. At present, HGF has 8 units of 5 MW, increasing its installed capacity to 40 MW.

The appearance of acid fluids in geothermal reservoir that are associated with recent volcanism indicates that the geothermal fluid is associated with a volcanic fluid that is partially neutralized by reactions with feldspars and micas (Truesdell, 1991). In the sector former known as Central Collapse, serious problems of corrosion have been present in wells H-4, H-11, H-16, H-17, H-28, H-29, H-32 H-15 H-19 and H-30. These were finished in two permeable strata, which have temperatures between 250 and t 330°C, high pressure around 165 bar and low permeability. The brine produced is a sodium-chloride water, with values of pH between 2.5 and 4. This characteristic shows evidence of serious corrosion problems that were observed in wells, such as H-4, which resulted in its closing and abandonment. The rest of the wells were repaired between 1989 and 1993, placing cement stoppers from 1500 m.

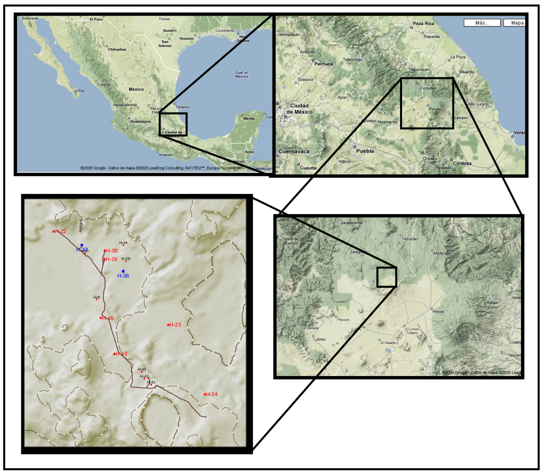

Figure 1: The Los Humeros Geothermal Field

Last year, there was drilling at the H-43 well, located in the limits of the Central Collapse at north of the field. It reached 2200 meters depth and a temperature of 395°C, which is of the highest measured in the field (figure 2). Studies of hydrothermal mineralogy detected the presence of biotite or white potassium mica (Muscovite or pirofilita) in the well, which indicates the possible presence of acid fluids. The well was opened for production on February 2008 and had 61 t/h of steam flow, 4 t/h of brine flow, wellhead absolute pressure 51.7 bar and a pH of 5.2. In 10 days of constant production, the pH value diminished to values of 4.4, and the content of iron in the brine increased to 22.9 ppm, which change with is associated with the effects of corrosion in the casing by acid fluids. Based upon the previous explanations, the well was closed, and to be able to continue with commercial exploitation of the steam, it was necessary to make neutralization tests of the well's acid fluids by adding a solution of sodium hydroxide to the geothermal fluid. This neutralizes the H+ acid groups, thus raising the pH. Experience indicated that, with the deep injection of an appropriate dosage and concentration of sodium hydroxide, it is possible to produce from acidic fluids with no corrosion.

Due to the capacity for electrical generation of this well, which is estimated in 6.7 MW, there is great interest in looking for solutions that enable this project to be integrated into the production. With this aim, a test was realized to determine the technical feasibility of the neutralization. This test was run from July 13 to July 16 and corroborated that the acid fluids produced by the well H-43 could be neutralized technically by injecting a NaOH concentrated solution to depth.

In the following sections are described the chemical characteristics of well and the design and testing developed for this study, and then we present and discuss our results and conclusions.

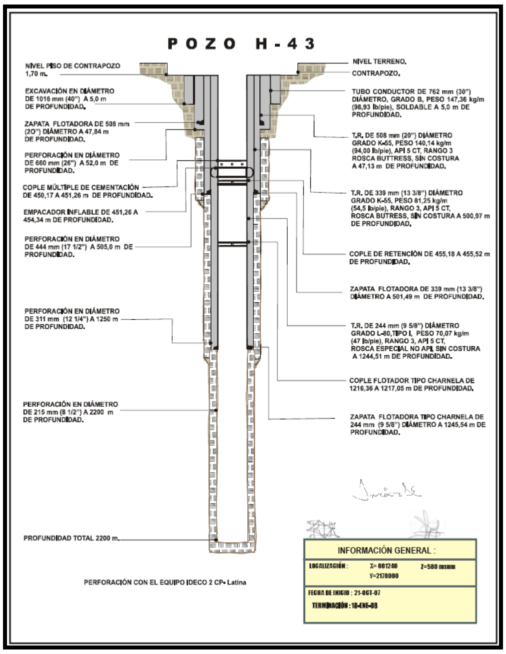

Figure 2: Scheme of casing configuration of the H-43 well

2. CHEMICAL CHARACTERISTICS OF H-43.

One of the theories about the origin of the acidity of fluids in the Humeros geothermal system is refers to the presence of two feed zones or two reservoirs, although there is no separation layer (lithological unit) differentiating them. The shallow reservoir contains vapor and liquid whereas the deeper one has only superheated steam and is at high temperature (>300°C). The production of HCl steam in deeper reservoir is a result of water-rock interaction at high temperature and a low amount of water (Verma et al., 1997). The high corrosiveness and scaling in the wells due to these deeper fluids has limited geothermal exploitation to the shallow regions of the reservoir.

The H-43 well was drilled in the boundaries of the area known as Central Collapse to a depth of 2200 m. The casing of 9 5/8" diameter was installed at 1243 m and the well completed in an open hole of 8 ½" diameter (figure 3). The well was opened on February 9, 2008, with 2 inches of diameter for the silencer and there was measured 61 t/h of steam flow, 4 t/h of brine flow, and a wellhead absolute pressure of 51.7 bar. The pH measured after the opening of the well was 5.2. However, after 10 days of continuous production, pH values decreased to 4.4 and the dissolved iron content in the separated water was 22.9 ppm, a value that is associated with the effects of corrosion in the casing caused by acid fluids. Table 1 shows typical monitoring data from the fluid and illustrates how the pH values decreased and iron values

Table 1: Composition of fluids well H-43

Date	WHP (bara)	pH	Cl^- (ppm)	Na^+ (ppm)	Fe (ppm)
19-Feb-08	51.7	5.24	33.3		4.97
20-Feb-08	50.3	5.42	39.5		5.13
21-Feb-08	50	5.62	2.55		6.83
22-Feb-08	51.6	5.3	2.5	0.21	8.81
25-Feb-08	49	4.92	10.21		6.78
26-Feb-08	48.3	4.43	35.73	0.31	22.96

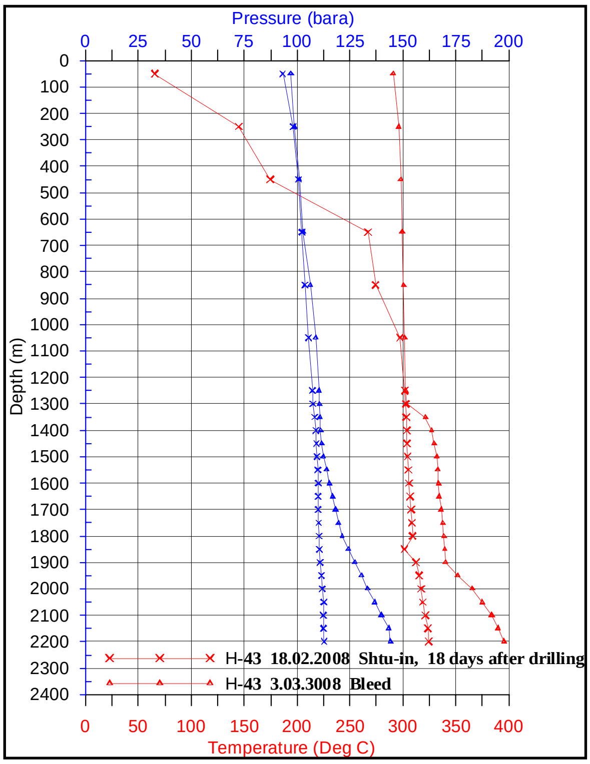

Figure 3: Temperature and pressure profile H-43 well

increased, which means that there are favorable conditions for the corrosion of casing. To avoid the corrosion of the casing and surface pipeline, the well was closed.

3. DESIGN AND TEST DEVELOPMENT.

Due to the future requirements of steam, a neutralization test of the acid fluid in the well was programmed. The process of neutralization consists of the constant addition of a solution of sodium hydroxide to the geothermal fluid at a depth adapted inside the well to protect the pipeline and the whole surficial equipment against the corrosion.

3.1 Components of the Neutralization System.

The design of the system of neutralization was based on an inhibition system of $CaCO_3$, which has been working since 2003 in the Las Tres Vírgenes Geothermal Field. Also, it was considered to have been recommended by personnel from the Miravalles Geothermal Field. The system components used for the neutralization tests were: storage tanks for the hydroxide and water, with a capacity of 5000 liters; a NaOH dosing pump; a water dosing pump; capillary tubing of steel incoloy for injection at depth 6,35 mm OD; an injection head of stainless steel; introduction and fastening elements; and an electrical supply support system.

Neutralizer chemical: The most economic alternative to increase the pH of a solution is the addition of a solution of industrial NaOH. The employment of other aggressive products was not totally rejected; however, at this stage of testing, it was considered NaOH use by the cost and the facility in the supply of the product.

3.2 Test Development of Neutralization.

The point of injection at depth of NaOH does not depend on the position of the boiling-point, as in the inhibition system of $CaCO_3$, and does will depend on the completion of the well. For the case of the H-43 well, the injection head was installed at 1350 m depth, 100 meters under the casing shoe.

The test was run from July 13 to July 15, 2009. Before starting the activities, the well was purged by line of 2 " and was registering a wellhead gauge pressure of 103.4 bar (1500 psi). First water was injected for 16 hours. The pH of fluid measured at the beginning was 5.1. During this stage there was monitoring of pH, flow of injection, and pressure of injection, and additionally samples were taken for analysis of Na, Fe, Cl and pH. The measured data are shown in Table 2.

Table 2: Data measurement of Na, Fe and Cl during the test

Date	Hora	WHP (bara)	pH	Na (ppm)	Fe (ppm)	Cl (ppm)
13/07/2009	18:45	900	5.1			
14/07/2009	12:00	880	5.28	3.5	3.205	57.58
14/07/2009	13:45	850	5.74	9.615	2.668	10.78
14/07/2009	16:00	840	5.81	1.822	2.765	7.84
14/07/2009	17:00	840	6.23	51.32	0.92	14.7
14/07/2009	18:00	840	6.51	54.64	0.429	14.7
14/07/2009	19:00	840	**6.7**	**78.91**	**0.345**	**15.68**
14/07/2009	21:00	820	6.53	23	0.588	11.76
14/07/2009	22:00	820	6.6	29.84	0.376	14.7
14/07/2009	23:00	820	5.66		1.35	
15/07/2009	12:10	820	5.47		2.42	

On July 14, the steam flow measured was 52 t/h, a wellhead gauge pressure 58.6 bar (850 psi), and an enthalpy of 2662 kJ/kg. The same day that the injection of a 47% concentration NaOH solution was initiated, the flow of injection was of 300 ml/min, with variations between 260 and 320 ml/min. The gauge pressure of injection of NaOH had a variation in the test between 137.9 and 1655 bar (2000 and 2400 psi). The measured pH was 5.1 to 5.3, and 150 minutes after initiation of the injection, an increase in the pH measured at the surface was observed, with pH measuring 5.6 to 5.7. Three hundred minutes after initiation of injection of NaOH, pH 6.2 was measured and reached a maximum value of 6.7 at 540 minutes. These results indicate that after 150 minutes, the pH measured in the fluid of the well meets specification, reaching a value of 6.7 at 540 minutes, with a flow of NaOH injection of 300 ml/min, on average. In the table No. 3 are shown the measured results of pH, injected NaOH flow and injection pressure. Due to problems with the injection pump, the test was suspended after three days.

During the test to control the chemical process of neutralization, the pH of the fluid of the well was measured every 30 minutes, and there were also samples taken every hour that were analyzed in the laboratory to determine Na, Cl, Fe concentrations and the pH of the fluid.

Table 3: Data measurement of pH, flow and pressure injection

Fecha	Hora	WHP (psig)	Injection Pressure (psig)	Injection flow	pH
13/07/2009	17:00	1150	1700	789.47	
13/07/2009	18:45	900	1700	714.28	5.1
13/07/2009	22:30	880	1756	714.28	5.1
14/07/2009	10:30	850	2000-2300	240	5.16
14/07/2009	11:00	850	2000-2400	185	5.3
14/07/2009	11:45	850	2000-2400	200	5.28
14/07/2009	12:00	850	2000-2400	200	5.28
14/07/2009	13:30	850	1900-2300	325	5.74
14/07/2009	13:45	851	1900-2300	325	5.74
14/07/2009	14:00	850	1900-2300	310	5.72
14/07/2009	15:00	850	1900-2300	250	5.8
14/07/2009	15:30	840	1900-2300	260	5.85
14/07/2009	16:00	840	1900-2300	255	5.81
14/07/2009	16:20	840	1900-2300	280	5.92
14/07/2009	16:40	840	1900-2300	290	6.2
14/07/2009	17:00	840	1900-2300	300	6.23
14/07/2009	17:20	840	1900-2300	310	6.47
14/07/2009	18:00	840	1900-2300	320	6.51
14/07/2009	18:40	840	1900-2400	320	6.64
14/07/2009	19:00	840	1900-2400	300	**6.7**
14/07/2009	20:20	820	2200-2300	320	6.25
14/07/2009	20:40	820	2100-2200	410	6.39
14/07/2009	21:00	820	1400-1500	400	6.53
14/07/2009	21:40	820	1700	660	6.57
14/07/2009	22:00	820	1600-1800	680	6.6
14/07/2009	22:20	820	1600-1800	680	6.45
14/07/2009	23:00	820	1800	666	5.66
15/07/2009	12:10	820	1800	667	5.47

4. RESULTS AND DISCUSSION

Figure 3 is presents graphically the change in pH over time. The same can be seen after stabilization NaOH injection: the fluid in the well is maintained for 5 hours at an average pH of 6.5 with a minimum value of 6.2 and maximum of 6.7. Due to problems with the injection pump, it was not possible to decrease the amount of NaOH injected in order to determine the control that it can have on the system. This confirms that, the acid fluid in the H-43 well can be controlled using technology to a value that allows the integration of commercial production and that it is also possible to maintain this value over time by permanently injecting a neutralizer. In the current trial found a spending limit of 320 ml/min with a concentration of NaOH 47%.

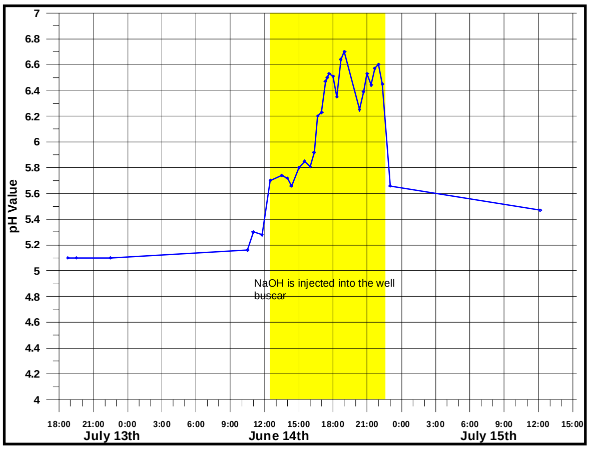

Figure 4: Behavior of the pH during the neutralization test.

Figure 4 shows that the chlorides have no variation over time and figure 5 shows the variation of sodium and iron content over time. It shows a slight decrease in sodium and iron content during the injection of NaOH, which confirms the effect of sodium hydroxide to prevent corrosion of steel.

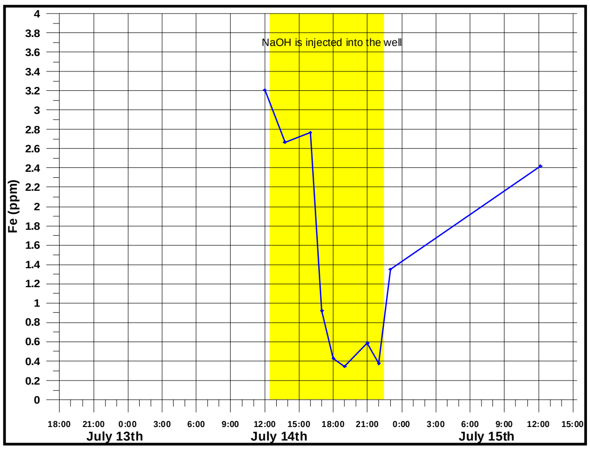

Figure 5: Behavior of the Fe during the neutralization test.

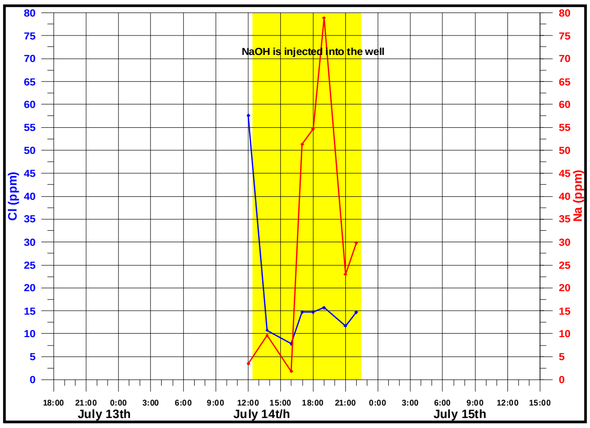

Figure 6: Behavior of the Cl and Na during the neutralization test.

The pH values measured before and after the test do not mean the test has resulted in an increase in pH caused by change in the chemical composition of the fluid, these values are more to the period of stabilization of the fluid from the well in the past, then for 48 hours to be flowing well, are close to pH 3.7.

The process of neutralization in the H-43 is quite sensitive to the injection of NaOH, as shown in the graphs above. When suspended injection hydroxide was suspended, the pH value decreased in 4 hours, the time it takes to get water to the point of injection through the steel tubing of ¼ " diameter. Before and during the test, the contents of iron in the samples were analyzed and the values were different between the fluid when it was neutralized and when it was in acid conditions. The results show that, during neutralization, the iron content is approximately 0.35 parts per million, while under acid conditions it is approximately 3.2 parts per million. From the previous, it is clear that, due to the corrosive action of these fluids, the neutralization has to be constant and provided with adequate support mechanisms to prevent any disruption.

5. FINANCIAL COSTS ANALYSIS

The investment for development of the test of neutralization was USD $61,500, and included a NaOH dosing pump, a water dosing pump, Capillary tubing of steel incoloy, an injection head of stainless steel, storage tanks, hydraulic connections and sodium hydroxide. The investment necessary for putting in the operation of the neutralization system involved the installation of on-line pH and iron content monitoring. This equipment is required to determine if the used dosage is correct for guaranteeing the system is neutralizing to depth and from the injection point. Besides the automation of the monitoring and pH control, the installation of the electric power system, including installation of on-line meters for pressure of injection and flow meters, cost USD $46,500. The total cost of the neutralization system of the acid fluid for the commercial exploitation of the well H-43 is USD $108,000

The economic income from the commercial exploitation of the well with a generating capacity of 6.7 MWe (steam consumption of 7.5 t/h/MWe) and a commercial value of energy of USD$ 0.050/kW/h is USD $2,934,600.00 per year. The quantity that we will allot annually to the purchase of hydroxide of sodium is USD $61,500.00. Subtracting this quantity from the annual income, the well would still generate USD$2,873,100.00 per year.

To recover the investment made on the neutralization system (approximately USD$108,000.00), only 14 days of production are required. To recover the total amount invested in the H-43 well, including the drilling costs (approximately USD$6,000,000), 3 years of production will be needed. Figure 6 shows the graph of recovery of the investment realized in well H-43 when cost of the construction of the well is considered (Expense, Income and Profit curves)

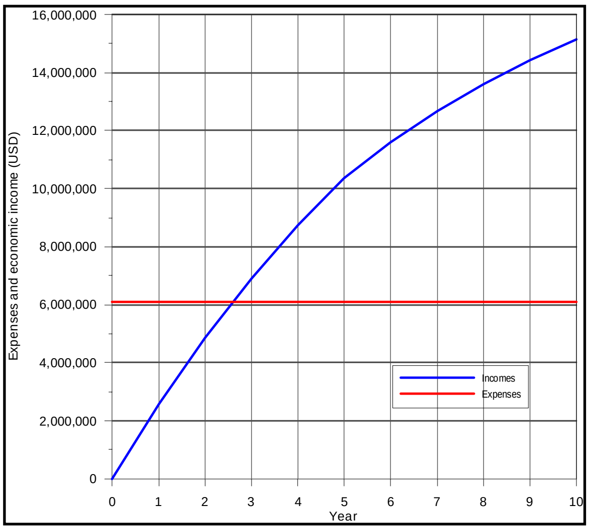

Figure 7: Expense, Income and Profit curves of well PGM-07.

6. POTENTIAL OF PRODUCTION IN THE ZONE WITH ACID FLUID (CENTRAL COLLAPSE).

The neutralization of the acid fluid in well H-43, opens the possibility for commercial exploitation of the sector formerly known as Central Collapse where have been serious problems of corrosion in the H-4, H-11, H-16, H-17, H-28, H-29, H-32 H-15 H-19 and H-30 wells. These wells were finished in two permeable strata that have temperatures between 250 and 380°C, high absolute pressure, around 165 bar, and low permeability. The brines produced are sodium-chloride waters, with acidic pH values between 2.5 and 4. This characteristic shows evidence of serious corrosion problems that were observed in wells, such as well H-4, where conditions resulted in its closure and abandonment. The rest of the wells were repaired between 1989 and 1993, placing cement stoppers from 1500 m. The production accumulated from these wells before the repair was of 343 t/h of steam; however, with the repair of the wells the steam production diminished by 138 t/h. Table 4 shows the steam production the wells before and after repair.

Table 4: Steam production before and after repair the wells in the central collapse

Well	Steam Flow (t/h)	
	Before repair	After repair
H-11D	41	12
H-15D	31	32
H-16	51	20
H-17D	53	25
H-19D	35	27
H-30	48	28
H-32	49	46
H-33	35	15

With the satisfactory results obtained from the neutralization of the acid fluid in well H-43, an alternative is opened for the steam recovery of the wells that are located in the Central Collapse zone, which has the potential of 18.4 MW, in agreement to the information of the table 4.

6. CONCLUSIONS

From the tests performed in the well, it was determined that well H-43 can be integrated into commercial production through a process of neutralization of the acid fluid and that it is possible to maintain acceptable pH values over time, provided there is an adequate neutralization system.

With the injection of 320 ml/min of NaOH, the pH of the fluid from the well was increased from 5.3 to 6.8 and the concentration of Fe decreased from 3.2 ppm to 0.35 ppm. Due to failure in the injection pump, it was not possible to decrease the amount of NaOH injected in order to determine the control that you can have on the system. However, with these results, the effect on the in the fluid produced of injection of NaOH in the well is clear.

The investment in this well was approximately USD $108,000, including the neutralization tests performed, as well as equipment required for final installation of the system.

The economic income from commercial exploitation of the well, which has a capacity of generation of 6,7 MWe, is USD $2,873,100 per year, including the annual cost of hydroxide of sodium.

To recover the investment made on the neutralization system (approximately USD $108,000.00), only 14 days of production are required. To recover the total amount invested in H-43 well, included the drilling costs (approximately US$6,000,000.00), 3 years of production would be needed. Under natural conditions, the fluids of H-43 well are so aggressive that commercial exploitation of the well without an appropriate deep chemical treatment of its reservoir fluids would not be technically or economically sustainable.

With the satisfactory results obtained from the neutralization of the acid fluid in the H-43 well, an alternative is opened for the steam recovery of the wells that are located in the zone of the Central Collapse. The potential production from these wells is 18.4 MWe.

Due to the successful results of these studies, the beginning of the commercial production of H-43 well is scheduled for late December 2009.

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