Presented at "Short Course on Geothermal Development and Geothermal Wells",
organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, March 11-17, 2012.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo S.A. de C.V.

AERATED DRILLING

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ABSTRACT

The technique of aerated drilling in the geothermal wells of El Salvador has solved a series of obstacles that occurred previously in drilling, well completion, and intervention. The last drilling stage in commercial production wells and reinjection wells is carried out with a fluid mixture made up of water-air or water-air-foam. The main objective of this operation is to achieve return of circulation to the surface, preventing the accumulation of the cuttings in the production or reservoir zones. This brief study is based on the drilling and completion of well CHI-3A in the Chinameca Geothermal Field in 2009. It presents in detail the experiences encountered during operation, where air was primarily been used as the drilling fluid, and then to stimulate the wells, and lastly, to obtain early production characteristics before having the final evaluation. This was the first well where Perforadora Santa Bárbara provided this service to LaGeo.

1. INTRODUCTION

1.1 Aerated drilling

Drilling with aerated fluid is a technique used in drilling of geothermal wells, mostly in the last stage, which it is carried out in search of zones of interest, where partial and/or total loss of circulation occur and where the production reservoir (permeable zone) is located.

In El Salvador, the methodology for the final well drilling stage, whether it is for production of fluids or for residual fluid reinjection, is presented as follows:

The first stage starts with a water- based drilling fluid with low viscosity and density. This fluid is prepared with the following materials such as lignites, lignosulfonates, polymers such as sodium carboxymethyl cellulose and partially hydrolyzed polyacryl amide (PHPA). Due to the low viscosity of this drilling fluid, not all of the rock cuttings can go up to the surface. Therefore, 60 to 70 s/L Marsh high-viscosity pills are prepared, which are pumped to the bottom the well. The fluid rises up through the annular space, carrying all the cuttings with it, thereby ensuring the well free of these materials. This technique is called a borehole cleaning.

As drilling proceeds, the drilling fluid is gradually lost once the zone of interest is reached until total loss of circulation is encountered. As a result, the cuttings no longer rise to the surface and this becomes a serious problem as they may accumulate in the zones of interest (reservoir zones for a production well) and high permeability zones for a reinjection well). The well, production or re-injection well, can decrease its efficiency when connected to the Geothermal Plant System.

Aerated drilling or aerated fluid drilling has provided a solution to the aforementioned problems, which is also known as the "underbalanced drilling", using a drilling fluid mixture of water-air or water-air-foam.

The advantages of this technique are presented in the following:

a) Fluid return is achieved, thereby transporting the cuttings to the surface;
b) The guarantee of a thorough cleaning of the well and of the zones of interest (reservoir and permeable zones);
c) Higher drilling speed;
d) Diminished damage to the formation;
e) Reduced density of the drilling fluid and consequently reduced hydrostatic pressure, which lowers the probability of the drill string to become stuck due to differential pressure;
f) Decreased cooling of the reservoir due to the use of water for drilling;
g) Identification of the changes in formations with the corresponding depths by having the cuttings brought to the surface, which aids in establishing the stratigraphy; and
h) Faster response upon finishing the drilling operation; and discharging the well for its evaluation.

This paper is a summary of the experiences during the 8½" drilling stage (the last stage) of well CHI-3A in the Chinameca Geothermal Field.

2. AERATED DRILLING IN WELL CHI-3A

2.1 Background

Well CHI-3A was drilled directionally on the 8½" stage. From the 9 $^5/_8$" casing shoe drilling was carried out from 1080 m up to 1248 m depths, with a low viscosity and low density fluid, which was prepared with water base, lignites, lignosulphonates and polymers, such as sodium carboxymethyl cellulose and partially hydrolyzed polyacrylic amide.

The first loss of circulation was encountered at 1248 m depth, from 10 to 20 m^3/h. Drilling continued up to 1258 m depth with partial loss of circulation from 30 to 60 m^3/h and continued up to 1267 m depth, where total loss of circulation occurred.

It should be emphasized that the drilling fluid became diluted gradually until it completely transformed into water at a depth of 1267 m. The final depth of this well was 1720 m.

2.2 Objective of aerated fluid drilling

At 1267 m depth , preparations were made for aerated fluid drilling in order to obtain circulation, with the objective of keeping the well clean, preventing the drill string from becoming stuck due to differential pressure, obtaining cuttings on the surface to be analyzed for the construction of the stratigraphy of the well, drilling with higher rate of penetration, and minimizing the cooling of the well as the drilling fluid is a water-air-foam mixture.

2.3 Description of the equipment used in the aerated drilling for well CHI-3A

A description of the equipment used in the aerated drilling for well CHI-3A is given in Table 1.

TABLE 1: Description of the equipment used in the aerated drilling for well CHI-3A

Qty	EQUIPMENT	DESCRIPTION
3	Compressors	Air compressor, Ingersoll Rand, Model XHP 1170 scfm to 350 psi, Rotary screw, After cooler, CAT Engine diesel, Model C-15 ACERT, 540 BHP to 2100 RPM .
1	Booster	Air Booster, Gardner Denver JY-500, Joy WB12, 2475 scfm to 2500 psi, and 3200 scfm to 800 psi. Two stage 5.5" x 7" and 3.5" x 7", Piston stroke 7", with after cooler, CAT Engine diesel, Model C-18 ACERT, 630 BHP to 2100 RPM.
1	Mist pump (Injection pump)	Triplex Pump, plunger $1^3/_4$", stroke $4^1/_2$", 49 GPM to 2500 psi, Brand West Texas, Model HP-100-M, with engine diesel, Deutz, model BF-4L914 – 97 BHP to 2300 RPM. Two tanks, 20 bbl/tank, open top.
2	Texsteam pump (Injection pump)	Plunger size $1^1/_4$", work pressure 2000 psi, 500 gallons/day, DI Buna-n packing. For injecting chemical materials: Foaming agent, corrosion inhibitor agent, oxygen scavenger agent and other chemical products.
1	Rotating head	Rotating Head $13^5/_8$" Assembly, Brand Washington, dressed with: Viton seal and O-rings, consisting $13^5/_8$"-3000 Air bowl complete with clamp, 10"-2000 outlet, Lubrication system, HD $5^1/_4$" Hexagonal drive bushing, Stripper rubber wrench, 4 BU Butyl Stripper rubber.
1	Air / Fluid separator	Vertical Air – Fluid Separator (Figure 1), type Keystone, capacity of separation: Air 2400 scfm and Liquid 1200 gpm to 20 psi. Outside Diameter 61.2" and Length 5.2 meters.
1	Flowmeter (Daniel)	Daniel Simplex Orifice Plate Holder, Type of fitting welding neck end, ANSI CLASS 1500, 707C-TSC, 3705 psi work pressure, Sch 80, Orifice plate 2" x $^1/_8$" model 500, universal type and Teflon seal ring.
1	Flow recorder (Barton)	Barton Flow Charts Recorder, model 202E, 9A – Recorder-DP-OD, Differential Pressure 0.0 to 100" water column, Static Pressure 0.0 to 2000 psi, Safe Working Pressure 2500 psi.
1	Choke manifold	Choke Manifold with Choke Valve Adjustable, 2" DN, LP, FIG. 602 M x F, Work pressure 6000 psi, Ball Valves 2" x 6000 psi work pressure and Daniel Flowmeter 2" DN, 1.939" ID, Sch 80, ANSI 1500.
	High pressure line and connections	Pup Joint, Chiksan Hose and flexible Hose 2"x 12 feet, FIG 602 M x F, work pressure 6000. Swivel Joint 2", Style 10 and Style 50, M x F, work pressure 6000 psi. Swing check valve flapper 2", work pressure 3000 psi, Ball valve 2" x 6000 psi work pressure.
1	Temperature register	Borehole return fluids temperature register from 0.0 – 350 °C.

As can be observed in the layout of the air drilling equipment used in the last stage of 8½" in well CHI-3A (Figure 2), the primary rotary screw compressors are of low pressure, discharging the air flow at a pressure of 350 psi. Depending on the air flow requirements, one, two or all of the three compressors can be operated, with the total flow at the injection manifold. The air is then driven through a flexible hose, 3" in diameter and at a pressure of 1000 psi, until it reaches the other high pressure piston compressor, called BOOSTER (Figure 3), which operates at a maximum pressure of 2500 psi. The air is cooled at the booster output and is led through the 2" x 6000 psi high pressure line towards the choke manifold, which is comprised of the choke valve, the flowmeter and the Barton recorder. The choke valve is then regulated depending on the air flow needs for the drilling operation, where a certain amount of air flow is discharged to the atmosphere and the rest passes through the flow meter connected to Barton Recorder; the injection pressure is given in psi and the differential pressure in inches of water. With the two pressure values, the air temperature at the booster output and the compressibility factor of air, together with the design features of the flowmeter, these data are then entered into an "Orifice Flow Calculator" software, provided by the company that designed the "DANIEL MEASUREMENT AND CONTROL" flowmeter, and thus obtaining the air flow rate that is being injected into the well that is being drilled.

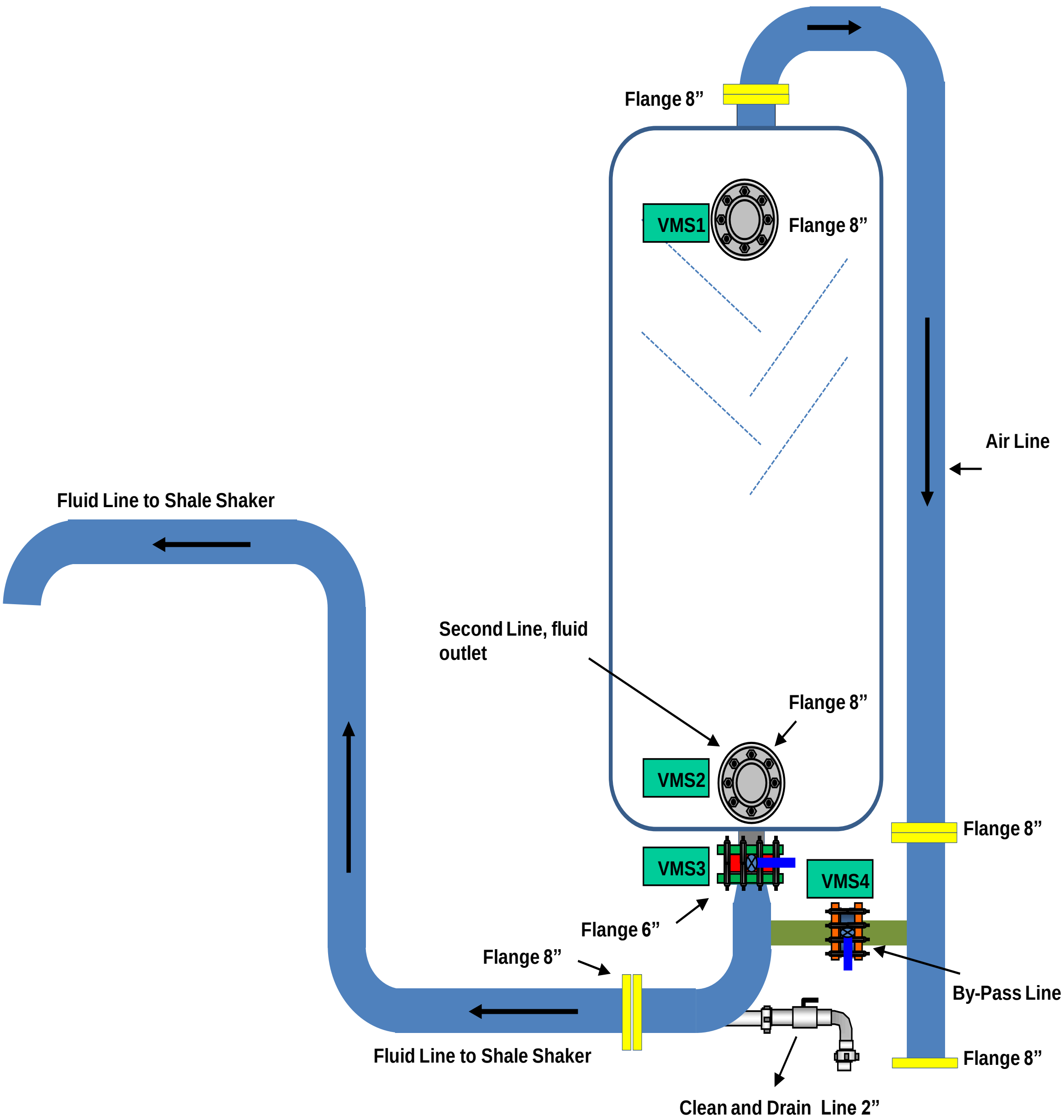

FIGURE 1: Air/fluid separator installed in air drilling system, well CHI-3A

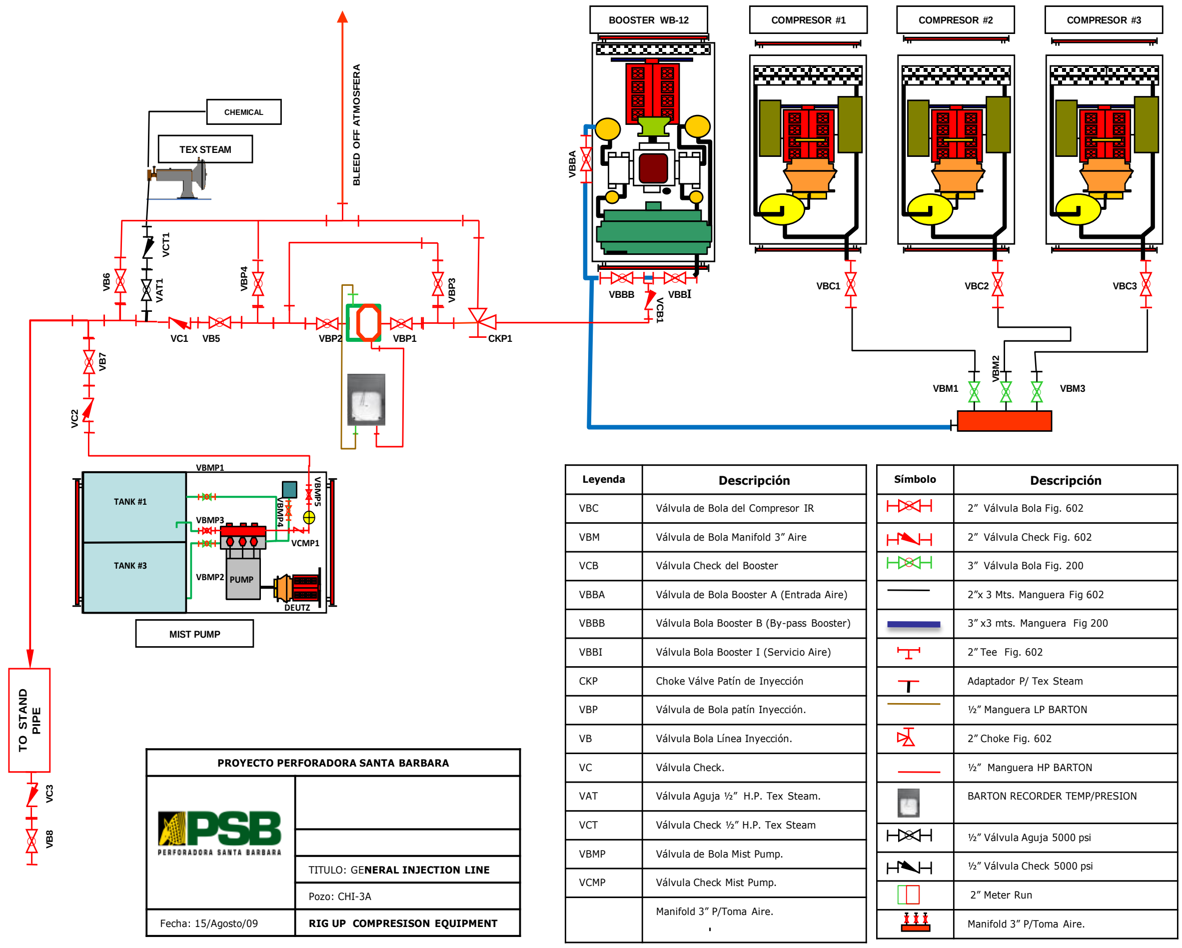

FIGURE 2: Aerated drilling equipment layout in well CHI-3A

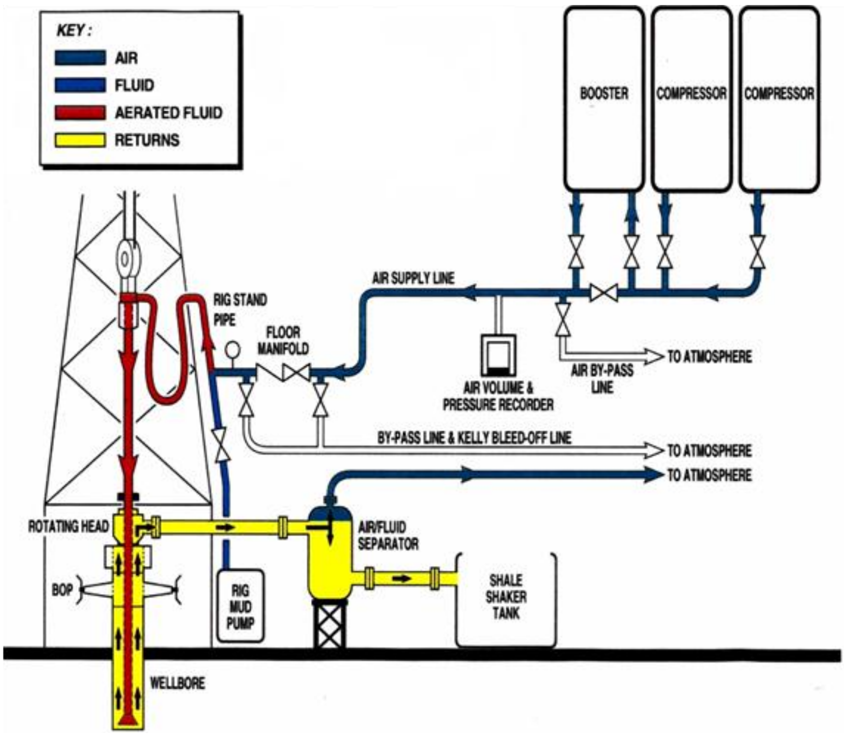

FIGURE 3: Complete diagram for aerated fluid drilling

2.4 Description of the operations with aerated fluid in well CHI-3A

On August 13th, 2009, when the well encountered total loss, circulation was undertaken for cleaning and observation of the well at 1267 m depth. Viscous pills with polymers were pumped to do a borehole cleaning and maintenance of the drill bit. A lubricating pill was then pumped and sent to the bottom of the well. The SINGLE SHOT survey was then performed at 1252 m, with the following results of Inclination 29.75° and Azimuth 116.50°.

Drilling was resumed with water until it encountered a total loss of circulation at 1277 m depth. A complete cycle of circulation was carried out and the $8^1/_2$" drill bit was recovered to the surface to modify the drill string.

The hydrostatic level was measured in the well, the result of which was 690 m. The drill string with a diamond crown bit was connected to cut the core sample from 1277 m to 1279.05 m depths by only using water at total loss and a rate of 436 gpm.

After having cut the core sample, a new $8^1/_2$" diameter drill bit was connected and was lowered to the $9^5/_8$" casing shoe . The accessories for aerated drilling were then connected with the $13^5/_8$" API 3000 Rotating Head and the 4" Stripper Rubber.

The safety meeting was held with all involved personnel; among them was the Superintendent of the Compressed Air Equipment who briefed everyone on the details, precautions, dangers, and possible accidents that could occur when carrying out aerated drilling. The $8^1/_2$" drill bit was then lowered to a depth of 1277 m pumping water in total loss of circulation at a rate of 262.0 gpm.

The drill string was retrieved up to the $9^5/_8$" casing shoe (1088 m) to start the aerated fluid operations. Circulation was carried out with a 262 gpm water flow rate and a 700 cfm air flow rate for 2.5 hours without obtaining any return to the surface. Afterwards, it was lowered to 1200 m using the same water and air flow ratio with the purpose of decreasing the hydrostatic column. The $8^1/_2$" drill bit was lowered to 1322 m. Circulation was carried out for two hours, with a water flow rate of 349 gpm and an air flow rate of 1700 cfm , presenting a 57 bar pressure without obtaining any return to the surface. A foaming agent, with concentration of ranging from 0.05% to 0.20% V/V, was added to the water-air mixture to obtain return of circulation to the surface (Figure 4).

Drilling was performed until reaching 1358 m depth with the same water-air flow rates and the same foam concentration, observing return of circulation to the surface. Circulation was carried out for an hour to completely clean the well.

Drilling was continued up to a depth of 1444.5 m with the water-air-foam mixture, a water flow rate of 240 gpm, air flow rate of 1700 cfm, foaming agent at 0.18% V/V and a pressure of 50 bars, and with return of circulation to the surface. Thus, circulation was carried out for 1.5 hours to clean the well. Afterwards, a lubricating pill was pumped and sent to the bottom of the well. The SINGLE SHOT survey was performed at 1430 m depth, yielding the following results of Inclination 32.7° y Azimuth 114.50°

Drilling of the $8^1/_2$" stage was completed on August 31st, 2009 at a depth of 1720 m, with water flow rates ranging from 250 to 350 gpm, air flow rates from 700 to 1700 cfm, a foaming agent with a concentration between 0.05% and 0.20% V/V, and pumping pressures between 45 and 50 bars, with return of circulation to the surface.

FIGURE 4: Return of the mixture water-air-foam-cuttings on the surface

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