Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Design and Results of an Increasing Permeability Test Carried Out in the First Deep Well Drilled in the Borinquen Geothermal Field, Costa Rica

Sergio Castro Zúñiga

ICE, UEN PySA, CSRG, Apartado postal 10032-1000, San José, Costa Rica.

scastroz@ice.go.cr

Keywords: hydraulic fracturing, permeable zones cleaning, Borinquen Geothermal Field, Costa Rica.

ABSTRACT

The PGB-01 was the first deep well drilled in the Borinquen area to begin the feasibility studies. The temperatures measured in the well were very high (275°C). Nevertheless, the permeability was very low. The tests carried out during drilling measured the injectivity index to be 1.4 l/s/bar (Castro, S., 2006). It was considered that these conditions could be partly responsible for the low productive characteristics obtained during the first production tests carried out in the well. (Castro, S. and Torres, Y., 2006)

With the objective to improve the well permeability, a water injection test was planned. The two factors considered to increase the permeability of the well are the temperature difference between the water injected and the reservoir, and/or the increase of pressure generated in the deeper permeable levels. The theoretical reasons to expect that it would be able to improve the well permeability are the secondary fracturing of the rock (Castro, S., 2007) and the mechanically cleaning of the permeable well zones.

The injection test started on July 17, 2007 at 8:30 am, injecting a flow of 35 l/s. The flow rate was constant until July 31, 2007 at 8:28 am, when the flow rate were increased to 60 l/s for 7 hours, and finally, an injectivity test of three different flow rates was carried out to calculate the injectivity index of the well.

Data analysis indicated that the injectivity index of the well was doubled with regard to the last test carried out during drilling, increasing from 1.4 l/s/bar to 2.8 l/s/bar, and the product *kh* increased from 0.6 D-m to 1.6 D-m. The absence of seismic activity associate with the injection process seems to indicate hydraulic fracturing did not occur, so it was interpreted that the increase in permeability was related to the cleaning of the permeable zones that were partly blocked with cuts and materials utilized during the well drilling. After four months of thermal recovery an output curve was carried out during short time to evaluate the new productive conditions of the well. The output showed a positive variation of the productive parameters. Nevertheless, that is not enough to convert the well to be commercially exploitable.

From the results obtained, it was decided to carry out a new injection test in the PGB-01. Similar tests are planned in others wells of Las Pailas geothermal project and in the future wells that will be perforated in the Miravalles geothermal field in order to increasing the permeability of the wells.

1. INTRODUCTION

Costa Rica is located in the south part of the Central American Isthmus. The Borinquen geothermal field is located in the southwestern side of the Rincón de la Vieja, an active volcano that is located in the northwest sector of the country (Figure 1). Borinquen is the second field developed in the Pacific flank of this volcano, after the Las Pailas geothermal field. According to the plans of I.C.E. Las Pailas will enter in operation in the year 2011, generating 35 MWe from a binary power plant.

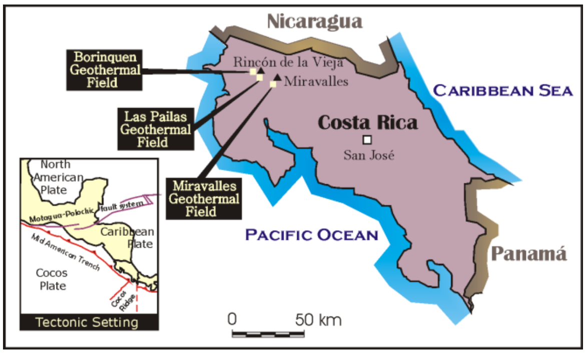

Figure 1: Tectonic setting, Costa Rica borders and location of the Guanacaste Geothermal Fields (modified from Chavarría, 2003).

The PGB-01 is located in the most important hydrothermal activity zone in Borinquen (Figure 2);

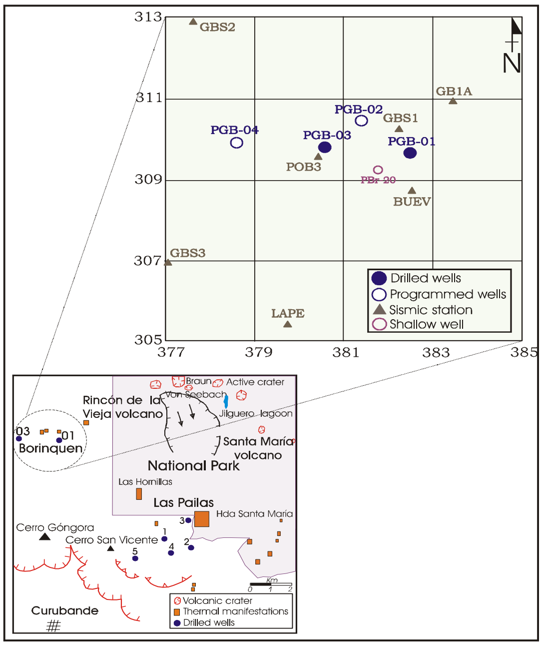

Figure 2: Location of wells in Las Pailas and Borinquen geothermal fields.

The well was drilled in 2004 to a maximum depth of 2594 m. The greater permeability was located in the zone 1850-

2050 m, and other smaller zones were located at 900, 1000 and 2150 m. Geologically the formation can be described as several intercalations of andesitic lavas and pyroclastic flows. Permeability can not be associated with a particular lithology. (Figure 3).

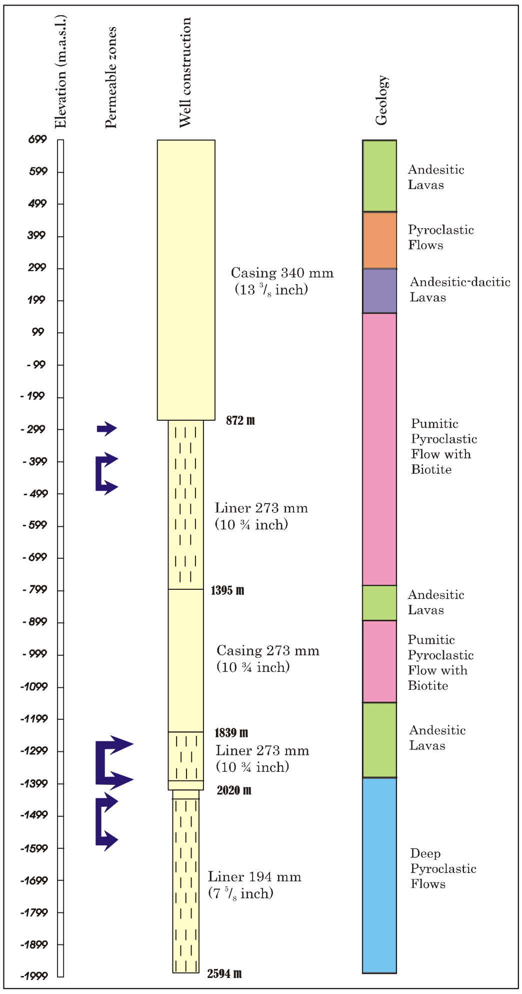

Figure 3: Well completion and geology of the PGB-01.

The static temperature measurement in the PGB-01 is the greatest in Costa Rica, reaching 275°C. Nevertheless, the permeability of the well is very low and with very little connection with the reservoir. The production tests carried out in the well confirmed the existence of a deep geothermal reservoir of two-phase type, predominantly liquid phase. The geothermal fluid is neutral, sodium-chloride type, with a conductivity of 18600 uS/cm and 11770 ppm of dissolved total solids (I.C.E, 2006).

In other geothermal fields similar tests have been carried out with the purpose of increasing the permeability of the wells, and have obtained positive results (Wojnarowski, P. and Rewis, A., 2003; Bjornsson, G., 2004)

The test was led by the personnel of the Centro de Servicios de Recursos Geotérmicos, of the Instituto Costarricense de Electricidad (I.C.E.) and included the participation of the Oficina de Auscultación Sísmica, which installed several seismological stations in the zone. The water injected was carried from two sources located approximately to 1.5 km away through three pipes of 10.16 cm (4 inches). The injection was carried out by gravity and lines discharged the fluid in a storage tank and to the well. Using different valves the volume injected in the well was controlled to maintain a constant rate.

2. RESULTS

2.1 Temperature and Static Pressure

After completing the production test in December 2005, the well was left inactive. It is considered that conditions of temperature and pressure measure in June of 2007, are very close to the stabilized of the well. Figure 4 shows that temperature is growing until 2000 m, where it is stabilized at 250°C, but then increases until reaching the 275°C in the well bottom. On the other hand the profile of pressure indicates that the hydraulic level is located at 400 m and in the main permeable zone the pressure is 125 bars.

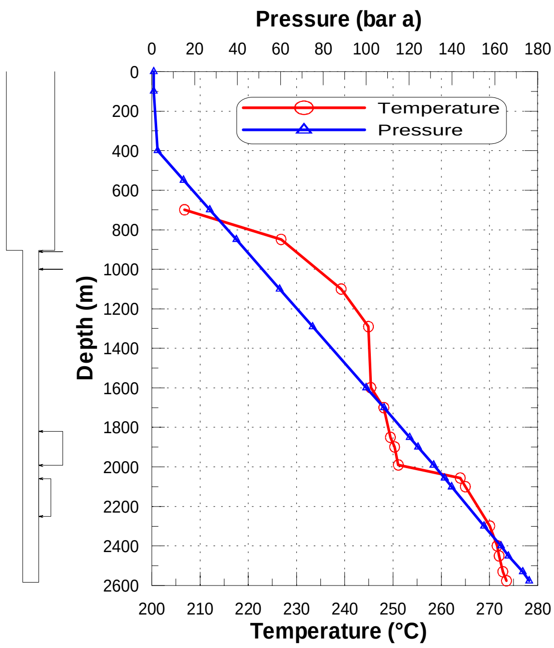

Figure 4: Static temperature and pressure measure in the PGB-01 (02-06-07).

2.2 First Injection Test

Test design planned the injection of 50 l/s at a constant rate. Nevertheless, once the test was initiated July 17, 2007 at 8:30 am, it was observed that the maximum volume available was 35 l/s. This flow was maintained for 336 hours until July 31, 2007 8:28 am. Later, the flow rate was increased to 60 l/s for 7 hours. Finally, after one day, on August 02, 2007 an injectivity test was carried out with three different flow rates for 5 hours each. The total volume injected during the test was 43850 m^3 of water, equivalent to a mass of 43 770 000 Kg (at 20°C).

2.3 Determination of the Well Permeability.

The injectivity test had the same design of as the test carried out when finished the well drilling. The objective was to establish a criterion of comparison among both tests.

The evaluation included the injection at three increasing rates of 20, 35 and 50 l/s for 5 hours each and once the injection was finished, pressure was measured for 8 hours. Figure 5 shows the flow injected, pressure and temperature, obtained during the tests carried out the 01 and June 02, 2004 (temperature and pressure 1) and the test carried out on 02 and August 03, 2007 (temperature and pressure 2). It is observed that the general form of the curves is very similar in both cases. Nevertheless, the magnitude of the change of pressure among the volumes of each test, confirms that the well permeability characteristics change considerably after the injection test.

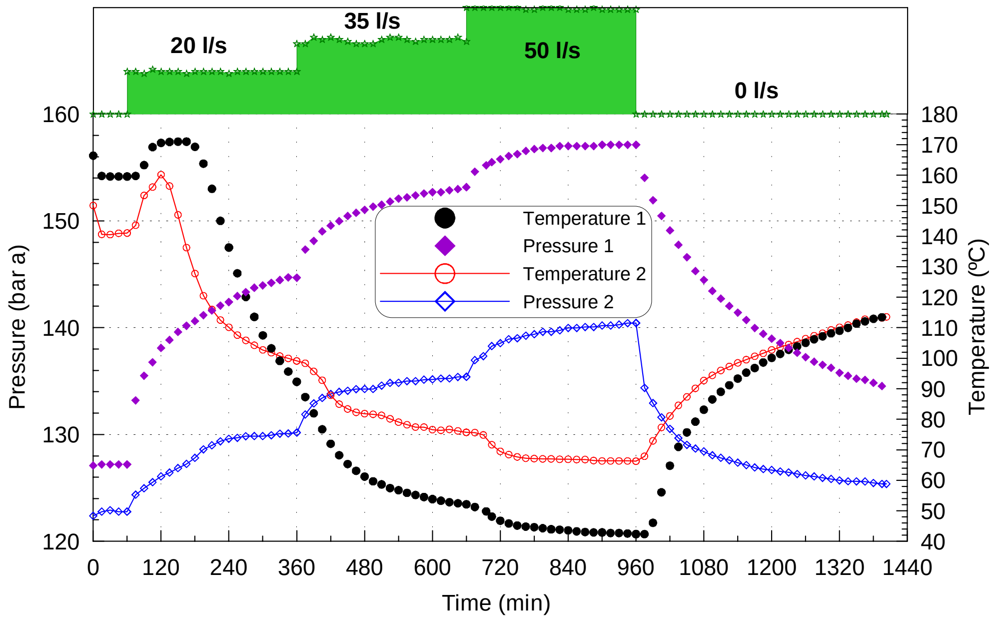

Figure 5: Injectivity test carried out in the PGB-01.

Figure 6 presents the data analysis of both tests, using the slope method for each one. Also are included the lineal and by origin correlations. It is observed that for the first test (dP1) the experimental data and the correlation have irregular behaviour, indicating that the well was still affected by the drilling process. After the injection test, the data represented by dP2 are completely lineal and besides the projection of the straight line crosses the axes in the origin point, confirming that the current permeability probably represents the original condition of the well. In general terms, the permeability was duplicated with regard to the value of the first test.

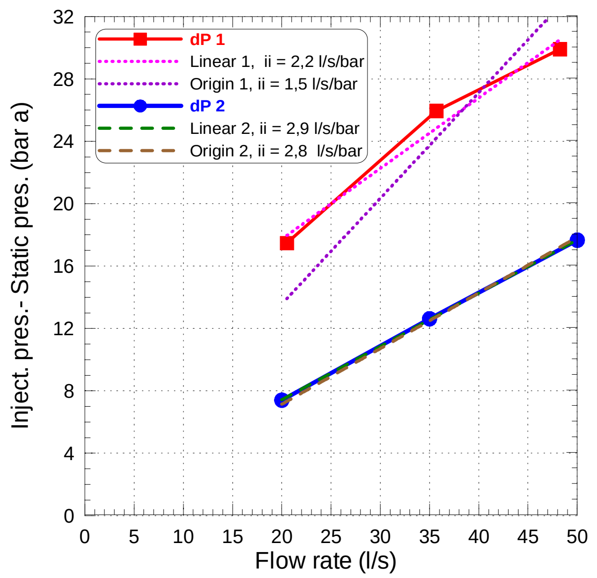

Figure 6: Injectivity index determination using the slopes method in two injectivity tests carried out in the PGB-01.

Also data were analyzed through the type curve method. For each test, the final segment was analyzed (fall-off). In figure 7, data of both tests are included, can be confirmed that for the most recent evaluation has an positive change, with the parameter *kh*, increasing from 0.6 to 1.6 Dm, confirming the increment of the permeability of the well.

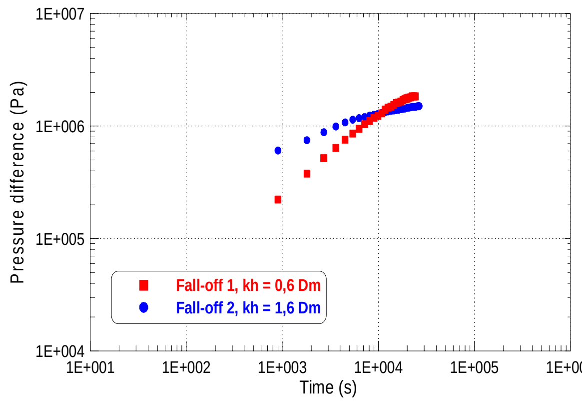

Figure 7: kh determination using the type-curve method for the fall-off section of the injectivity tests carried out in the PGB-01.

2.4 Production Test

The production test was carried out four months after finalized the injection when all necessary infrastructure had been placed at the well site and the static temperature had reached 230ºC. The objective was to evaluate if the increase in permeability was correlated with an improvement in the productive parameters of the well. Figure 8 presents productive parameters from the first 36 hours, in the three longer tests carried out in the well. First tests were performed in February and December, 2005, while the most recent was carried out on December, 05 and 06, 2007. It is seen that all the parameters obtained in the most recent test were markedly greater than in the tests of 2005, confirming the improvement in the well characteristics. Nevertheless, due to the short duration of the test and the great volume of water that was injected previously, a longer output test should be carried out to confirm the current productive characteristics of the well.

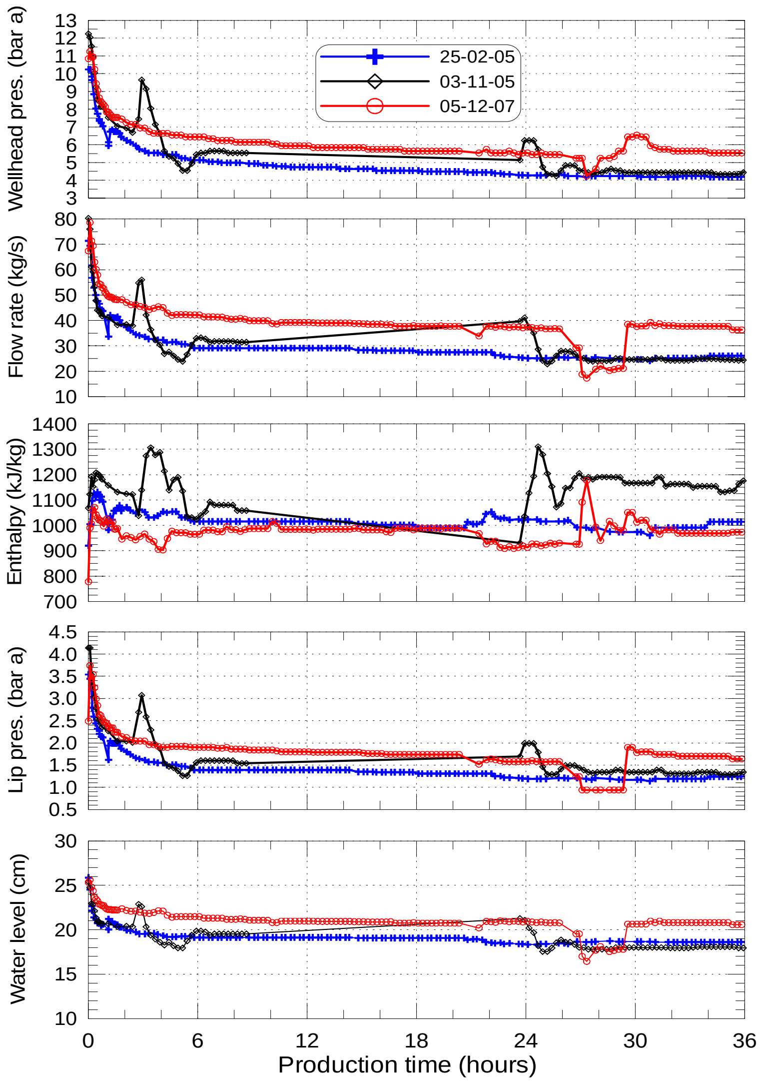

Figure 8: Output parameters obtained in different tests in the well PGB-01.

3. CONCLUSIONS

Initially it was planned to use a flow rate of at least 50 l/s. However the tubs allowed a flow rate 35 l/s. This factor should have limited the intended stimulation of the well, with a greater increase of the pressure in the lower permeable zones. The hydraulic levels obtained during the test confirm that the well accepted the flow rate injected in a gradual way.

The second variable expected to cause hydraulic fracturing was the thermal effect. In this case the effect of the temperature difference between the main permeable zone (250°C) and the water injected (20°C) was kept constant during the test, since in the zone of 1900 m, the fluid injected had a temperature close to the 40-50°C.

The results obtained from the transient tests carried out during the 15 days of tests suggest that increase in the permeability of the well occurred after the first 24 hours of injection and possibly at the end of the injection of 60 l/s flow rate because the values of the injectivity index and the product *kh*, were doubled. This hypothesis supposes that the initial impact of the injection of the 35 l/s was not significant, while the constant injection during the 15 days of the test, as well, the change of 35 to 60 l/s at the end of the test, produced the permeability increase in the well.

Permeability change was evaluated by two different methods. The first one measured an increase of the injectivity index from 1.4 l/s/bar to 2.8 l/s/bar, while the *kh* (permeability-thickness) factor grew from 0.6 Dm to 1.6 Dm.

The seismic stations placed in the nearest zone to the PGB-01, did not register any type of seismic activity. For this reason the permeability increase, cannot be associated with a hydraulic fracturing caused by the injection, but more likely is related to the cleaning of the fracture zones of the well. The cleaning occurred mainly in the permeable zone located between the 1850 and 2050 m of depth.

Output test indicated that during 36 hours the well productive parameters increased with respect to previous evaluations, probably as consequence of the permeability increase. Nevertheless, a more extensive test should be carried out to evaluate if the parameters are maintained with time.

Results indicate that it would be worthwhile to evaluate the procedure carried out in the PGB-01 in other wells to see if the injection of water over extended periods is able to clean the permeable zones of other drilled wells, increasing their permeability. Finally, it is necessary to evaluate if other wells also increase their output parameters.

REFERENCES

Automate for Windows, User´s Guide. Petroway Inc. 1984-97. Pag. (3)-146.

Bjornsson, G.: Reservoir conditions at 3-6 km depth in the Hellisheidi geothermal field, SW Iceland, estimated by deep drilling, cold water injection and seismic monitoring. Proceedings: Twenty-ninth workshop on Geothermal Reservoir Engineering, Stanford University, 2004.

Castro, S.: Informe final del PGB-01. Junio de 2006. Informe interno CSRG.

Castro, S.: Prueba de fracturamiento PGB-01 Julio 2007. Informe interno CSRG.

Castro, S. y Torres, Y.: Informe de las pruebas de producción del PGB-01, realizadas en febrero y noviembre de 2005. Octubre 2006. Informe interno CSRG.

Chavarría, L.: Miravalles Geothermal Field, Costa Rica – Evidence of thermal evolution and a comparison of the mineralogy of an acid well and a neutral well. Report 6 in: *Geothermal Training in Iceland 2003*. UNU-GTP, Iceland, 115-142.

Laboratorio de Registros termo-hidraúlicos: Bitácora de control de la prueba de inyección en el PGB-01 e informes de las pruebas realizadas. Julio-Agosto, 2007.

Wojnarowski, P. and Rewis, A.: Impact of injection pressure during cold water reinjection on the state of stress in geothermal reservoirs. International Geothermal Conference, Reykjavík, Sept. 2003.