Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Increasing Permeability in Deep Geothermal Wells Through Water Injection for The Las Pailas and Borinquen Geothermal Fields, Costa Rica

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Keywords: Well stimulation, Las Pailas and Borinquen Geothermal Fields, Costa Rica.

ABSTRACT

The permeable conditions found in some wells of the Las Pailas and Borinquen Geothermal Fields has been very limited, so ICE`s decided to use an easy and cheaper method of stimulation, to try to improve the permeability conditions of the wells.

The PGB-01 was the first vertical deep well drilled in the Borinquen area to begin the pre-feasibility studies. The temperatures measured in the well were very high (275°C), nevertheless, the tests carried out during drilling defined an injectivity index of 1.4 l/s/bar. It was considered that these conditions could be partly responsible for the low productive characteristics obtained during the output tests carried out in the well. By the other hand, the PGP-08 was a vertical well drilled in the heater area of Las Pailas, with the objective of finding mass to use in the binary plant located in this field. However, despite showing good temperature conditions (240 ºC), the permeability was low with an injectivity index of 1.9 l/s/bar. Because of these characteristics, several output tests showed low conditions of mass produced and wellhead pressure.

With the objective to improve the permeability in both wells, ICE conducted several water injection tests for extended periods in each well. The main factors to consider for the possible increase of the wells permeability, are forced cleaning of the permeable zones, thermal impact caused by the temperature difference between the injected water and the bottom of the well, and the pressure increase generated for the water column in deeper permeable zones.

Injection tests led to a significant increase in permeability and further improved production conditions, in mass produced and operating pressures. Due to the positive results obtained in the two wells tested, it was decided to carry out similar tests in others wells drilled in Miravalles, Las Pailas and Borinquen, in order to increase the permeability of the wells.

1. INTRODUCTION

Costa Rica is located in the southern part of the Central American Isthmus. The Borinquen and Las Pailas geothermal fields are 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. The last one was inaugurated in July 2011, and today is producing 35 MWe from a binary power plant.

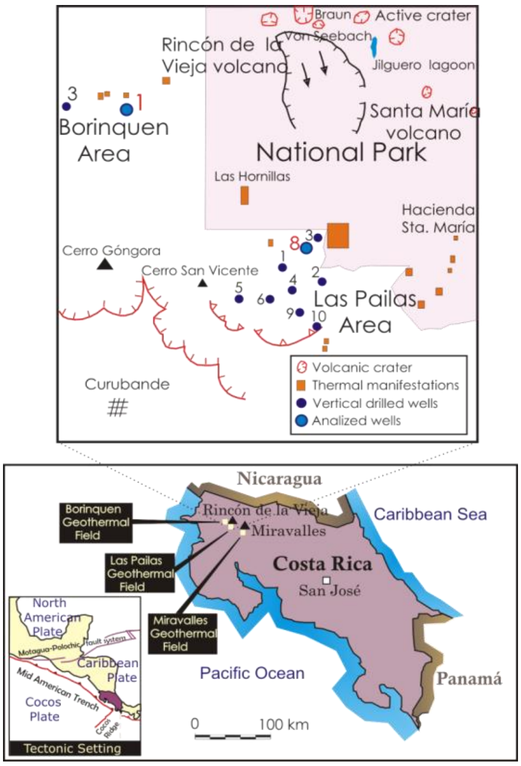

Figure 1: Tectonic setting, Costa Rica borders, location of the Guanacaste Geothermal Fields and location of the wells studied (modified from Chavarría, 2003)

1.1 PGB-01

The PGB-01 is located in the most important hydrothermal activity zone in Borinquen; the well was drilled in 2004 to a maximum depth of 2594 m. The main permeability was located in the zone 1850-2050 m, and other smaller zones were located at 900, 1000 and 2150 m. (Castro, 2006). Geologically the formation can be described as several intercalations of andesitic lavas and pyroclastic flows. Permeability cannot be associated with a particular lithology. (Figure 2).

The static temperature measurement in the PGB-01 is the greatest in Costa Rica, reaching 275°C. (Figure 3) Nevertheless, the permeability of the well is very low and with a bad connection to the reservoir. The production tests carried out in the well confirmed the existence of a deep geothermal reservoir of the 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.

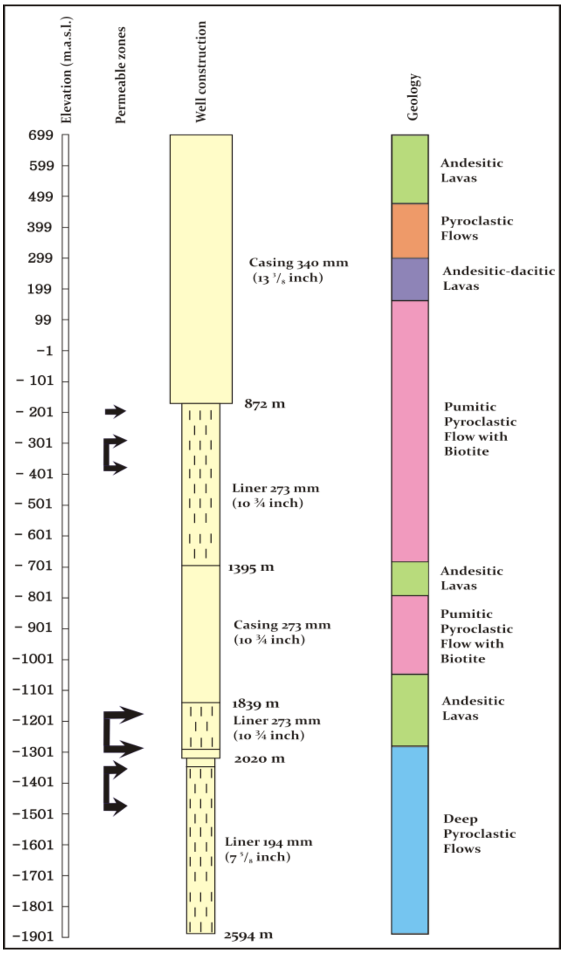

Figure 2: Well completion and geology of the PGB-01

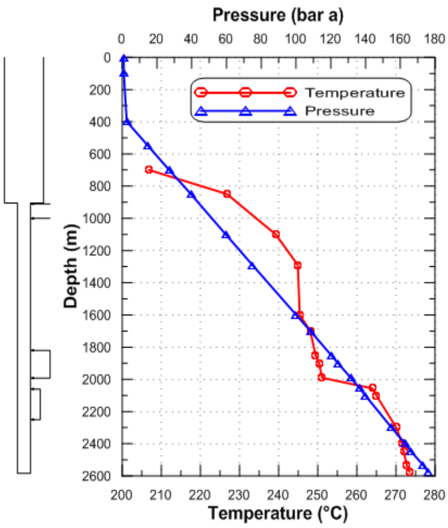

Figure 3: Static temperature and pressure measure in the PGB-01 (02-06-07)

1.2 PGP-08

The PGP-08 is located in the north part of the Las Pailas field, near to the boundary of the Rincón de la Vieja National Park. The well was drilled in 2008 to a maximum depth of 1712 m, and the permeable zones were located at 795, 1042-1065, 1190, 1286, 1602-1692 m. (González, 2010). Geologically the formation can be described as an intercalation of andesitic lavas and pyroclastic flows. Similarly than PGB-01, the permeability cannot be associated with a particular type of rocks. (Figure 4).

Static temperature and pressure profiles consider almost stabilized in the PGP-08 are shown in Figure 5. The maximum temperature was 243°C and the last point shows a lower temperature due to the effect of the water injected during drilling. Well permeability is very low and with a bad connection to the reservoir. The production tests carried out in the well confirmed the existence of a deep geothermal reservoir of the two-phase type, predominantly liquid phase, similar to found in other wells of Las Pailas. The geothermal fluid is neutral, sodium-chloride type, with a conductivity of 19500 uS/cm and 12500 ppm of dissolved total solids (González, 2011).

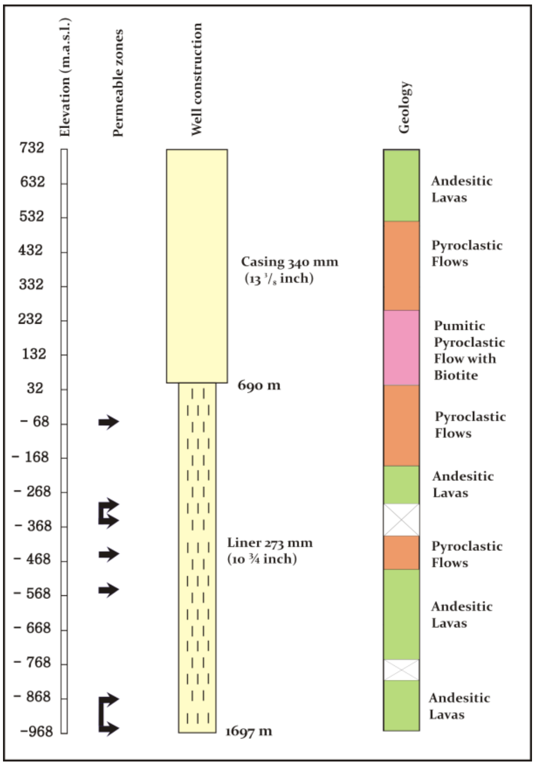

Figure 4: Well completion and geology of the PGP-08

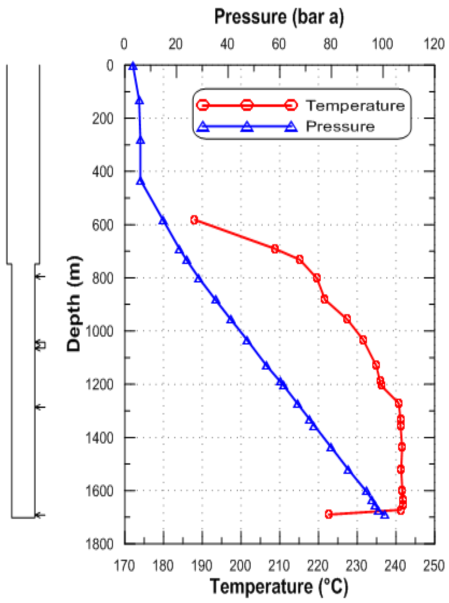

Figure 5: Static temperature and pressure measure in the PGP-08 (18-06-09)

Injection tests as proposed in wells PGB-01 and PGP-08, have been carried out in other geothermal fields developed in volcanic zones, with the objective of increasing the permeability (Wojnarowski and Rewis, 2003; Bjornsson, 2004)

The tests were led by the personnel of the Centro de Servicios de Recursos Geotérmicos, of the Instituto Costarricense de Electricidad (I.C.E.). The water injected was carried from two sources located approximately to 1.5 km away through several pipes of 10.16 cm (4 inches). The injection was carried out by gravity and lines discharged the fluid in a storage tank and posteriorly by the use of different valves the volume injected in each well was controlled to maintain a constant rate.

2. RESULTS

2.1 PGB-01

After drilling completion several tests of production and injection were carried out in this well, to evaluate the conditions before and after each injection test. (Figure 6)

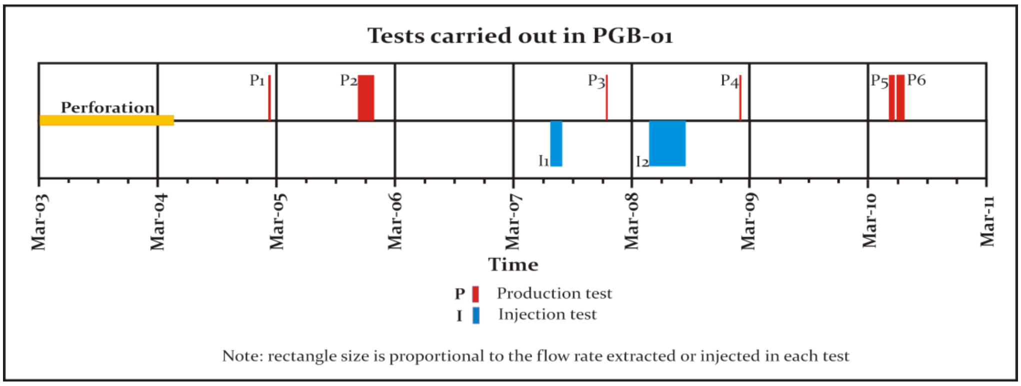

Figure 6: Different tests carried out in PGB-01

2.1.1 Injection Tests

Two injection tests were carried out in the well, first one comprehend from July 17, 2007 to July 31, 2007, and the average flow rate was 35 l/s by 336 hours, and 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 45734 m^3 of water, equivalent to a mass of 44 911 Ton (at 20°C). The second test starts on May 01, 2008 and finish on June 04, 2008, injecting an average flow rate of 50 l/s by 831 hours. Later, a similar injectivity test was performed to evaluate the response of the well to injection. The total volume injected during the second test was 148 662 m^3 of water, equivalent to a mass of 145 986 Ton (at 20°C).

2.1.2 Determination of the Well Permeability

Injectivity tests carried out in 2007 and 2008, had the same design of the test carried out when finished the well drilling in 2004, with the objective to establish a valid criterion of comparison among different tests. Figure 7 includes data obtained in 2004 and 2008, before and after the injection tests to evaluate the well permeability. The tests 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 fall-off was measured for 8 hours. It is observed that the magnitude of the change of pressure among the volumes of each test, confirms that the well permeability change after the injection tests, indicating a considerably improve between the tests.

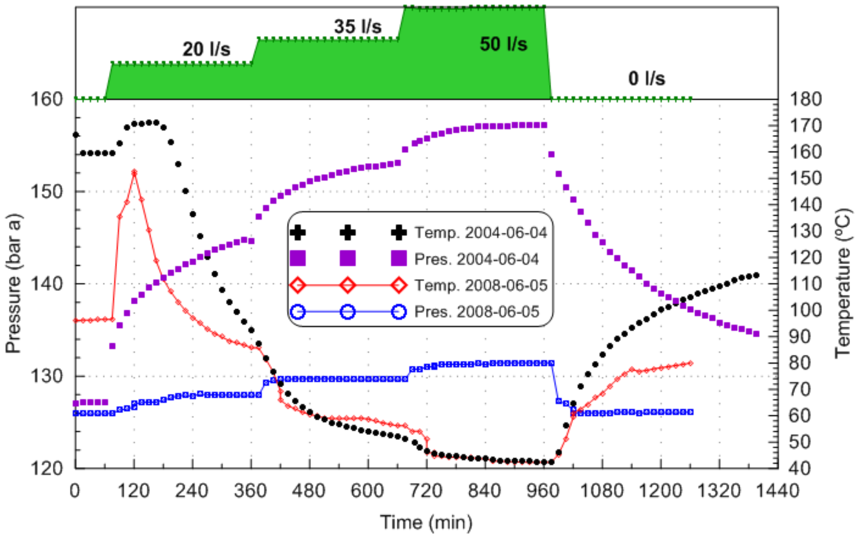

Figure 7: Injectivity tests carried out in the PGB-01

Figure 8 shows 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 (dP 2004) the experimental data and the correlation have irregular behavior, indicating that the well was still affected by the drilling process. After the second injection test, the data represented by dP 2008 are completely lined and besides the projection of the straight line crosses the axes in the originating point, confirming that the current permeability probably represents the original condition of the well. In general terms, the permeability was four times greater than the measured value of the first test.

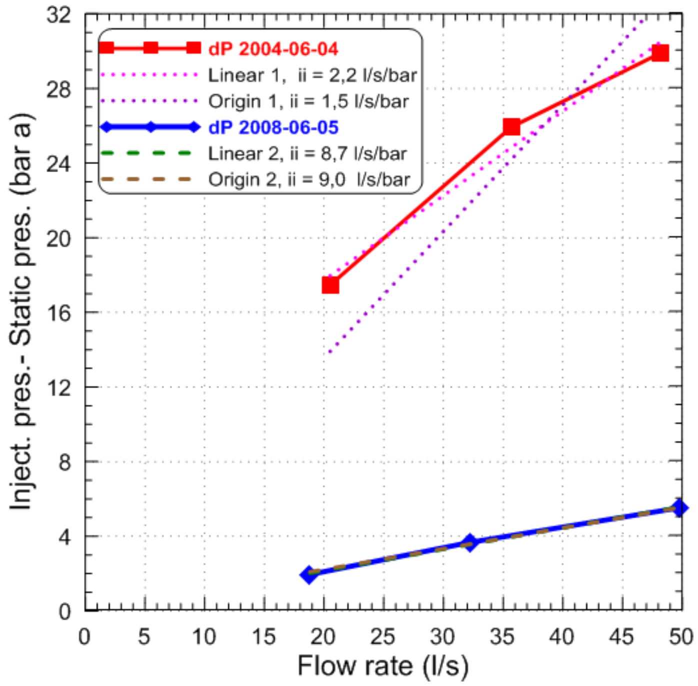

Figure 8: Injectivity index determination using the slopes method in two injectivity tests carried out in the PGB-01

Another way to analyze the permeability of the well is through the type-curve method. In this case, we use the data of the final segment of the pressure recovery (fall-off). Figure 9, shows data of both tests previously studied, it can be confirmed that for the most recent assessment is an increase of the parameter *kh*, growing from 0.6 Dm to a very high value, as indicated by the horizontal form of the blue line.

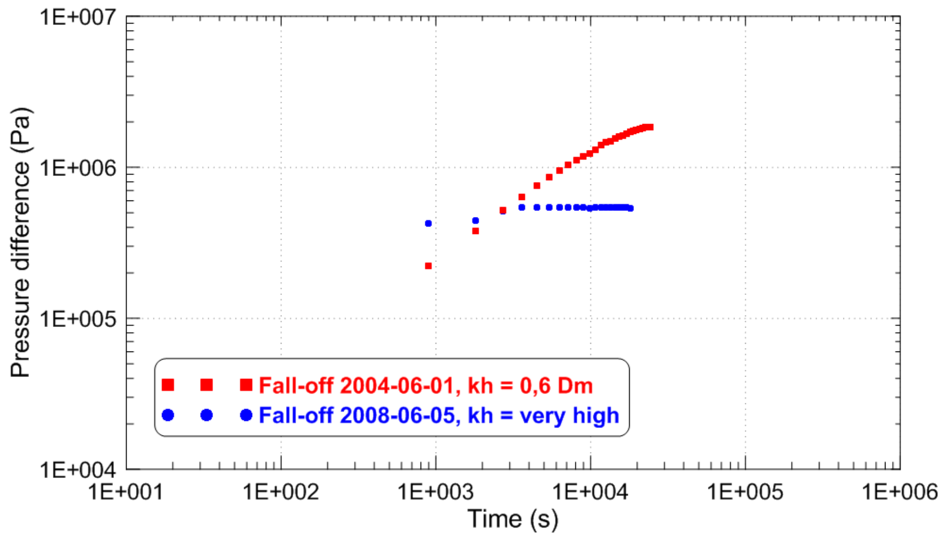

Figure 9: kh determination using the type-curve method for the fall-off section of the injectivity tests carried out in the PGB-01

2.1.3 Production Tests

Figure 10 presents the production parameters of the six output curves carried out in the well. First two tests were performed in February and November 2005, before the injection tests, the third was carried out on December 2007, after the first injection test and the last three were carried out after the second injection tests. It is seen that all the parameters obtained in the recent tests were markedly greater than in the tests of 2005, confirming the improvement in the well characteristics. Nevertheless, due to the 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. The objective was to evaluate if the increase in permeability was correlated with a real improvement in the productive parameters of the well.

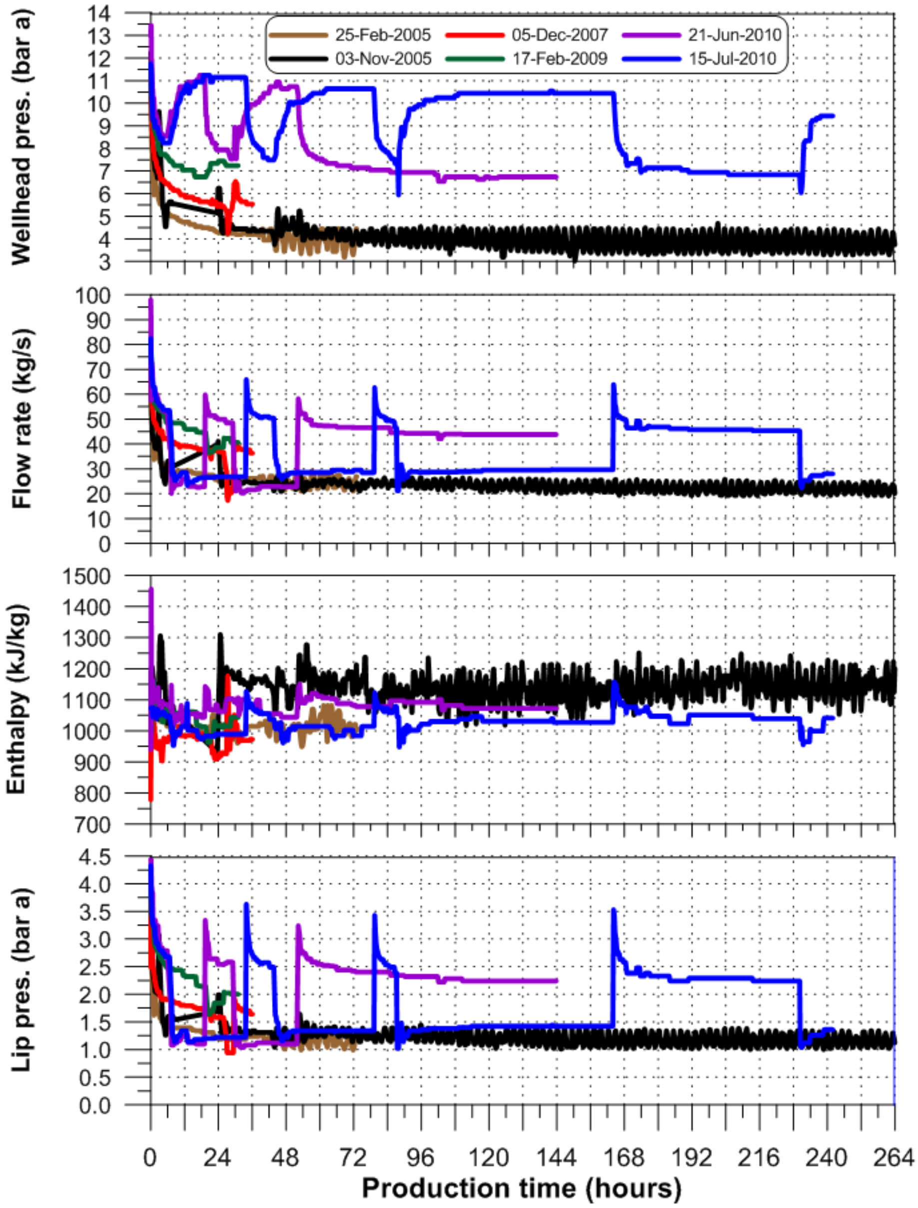

Figure 10: Output parameters obtained in different tests in the well PGB-01

2.2 PGP-08

In this case, after the drilling completion, several output tests were performed in order to evaluate the productive well characteristics. However, data obtained confirm bad conditions in the total flow rate and in the wellhead pressure; then considering the good results obtained in PGB-01, was defined to make an injection test similar to carried out in that well.

2.2.1 Injection Test

The injection test was carried out from April 09, 2010 to June 02, 2010. The flow rate was very variable, changing between 30 and 50 l/s by 1337 hours. Later, on June 03, 2010 an injectivity test was carried out with three different flow rates and with a fall-off of 8 hours. The total volume injected during the test was 184 345 m^3 of water, equivalent to a mass of 184 014 Ton (at 20°C).

2.2.2 Determination of the Well Permeability

The two injectivity tests shows in Figure 11 had the same arrangement to establish a valid criterion of comparison among both tests. The figure includes data obtained in 2008 and 2010, before and after the injection test. Both tests consists in the injection of three increasing rates of 20, 35 and 50 l/s for 5 hours each and once the injection was stopped, the pressure fall-off was measured for 8 hours. It is observed that pressure change with respect the volumes of each test, indicate an increase of well permeability as consequence of injection.

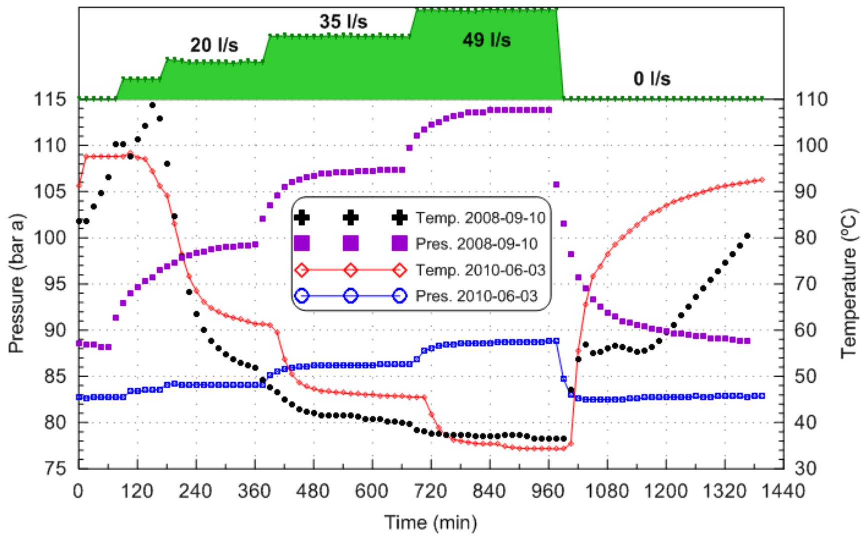

Figure 11: Injectivity tests carried out in the PGP-08

The Figure 12 includes the data analysis of both injectivity tests, using the slope method for each one. As part of the analysis are included the lineal and by origin correlations, to estimate the injectivity index of the well. It is observed that for the first test (dP 2008) the experimental data and the other curves have a similar slope and a good correlation, indicating that the well has a poor permeability. After the injection test, the data represented by dP 2010 and the curves related had been similar slope and a good correlation but the current permeability was four times greater than the measured value of the 2008 test.

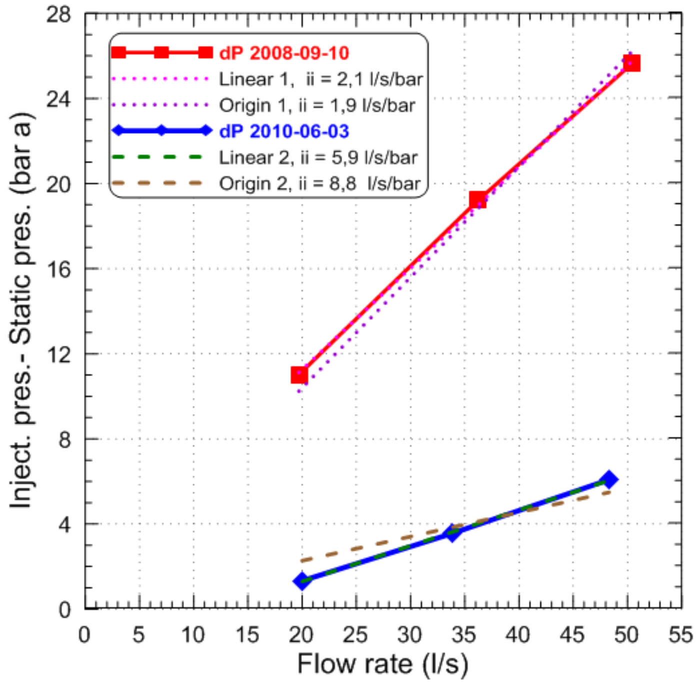

Figure 12: Injectivity index determination using the slopes method in two injectivity tests carried out in the PGP-08

The analysis of data obtained in the fall-off segment of the injectivity test is shown in Figure 13. The data confirm that in the most recent test, conducted after the injection of cold water, occurred a change of the parameter kh, which is increased of 0.7 Dm to a very high value, which is evident by the horizontal tendency of the blue curve compared with the growing trend of the red curve.

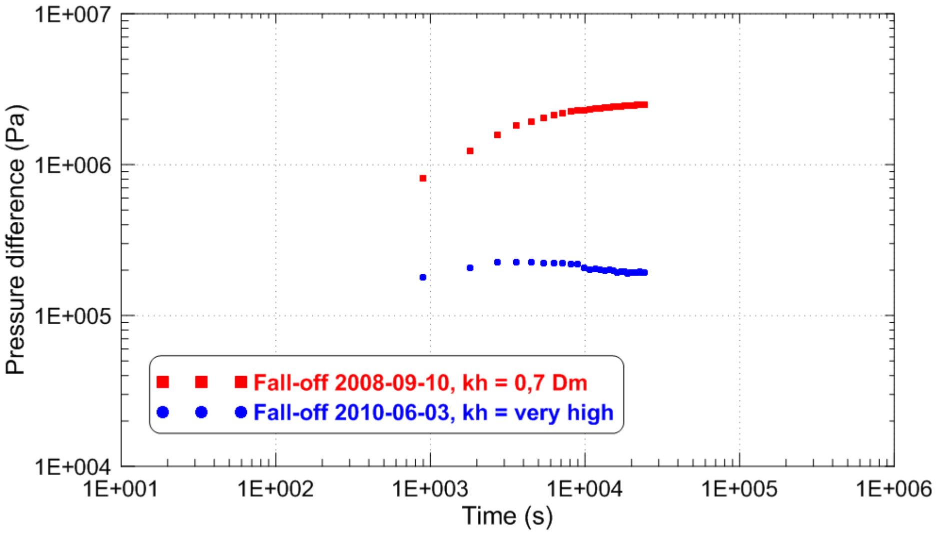

Figure 13: kh determination using the type-curve method for the fall-off section of the injectivity tests carried out in the PGP-08

2.2.3 Production Tests

Figure 14 presents the parameters obtained in the two production tests conducted before and after the injection of cold water in the well. It is noted that the first test has a duration of 14 days, in which after a good start, the parameters tended to fall rapidly to a value of head pressure near to 4 bar a. and with a total mass of 37 kg/s. The second test was extended for 9 days, in this case the parameters showed higher values, with a head pressure of 6 bar a. and a total mass of 70 kg/s. These results indicate that the injection produces a significant change in the surrounding areas of the well.

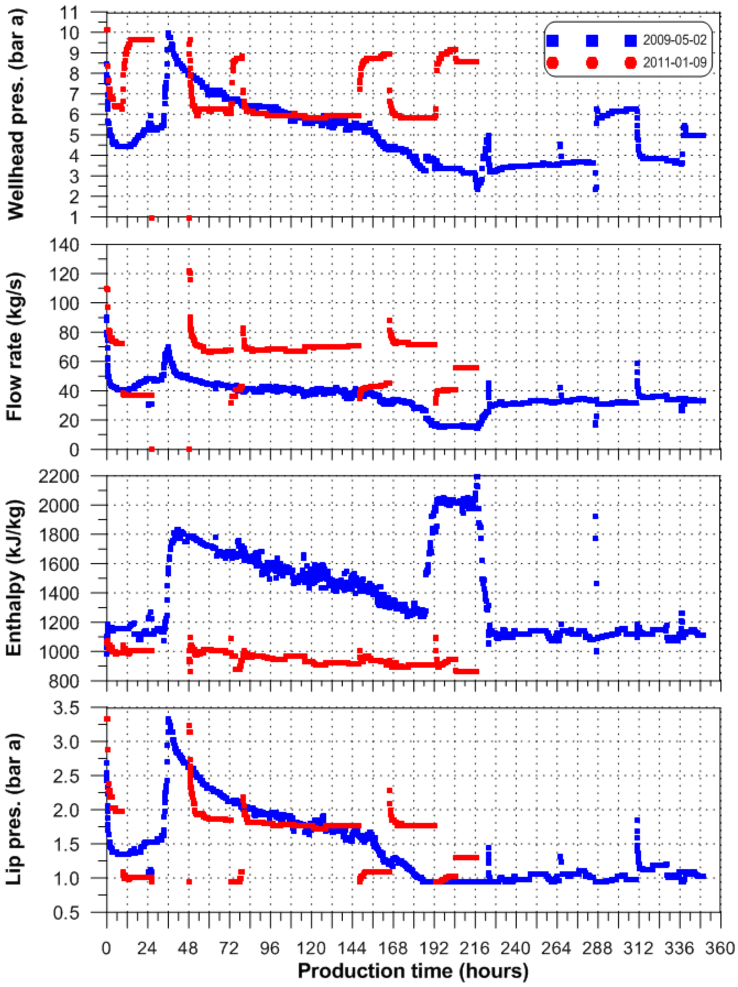

Figure 14: Output parameters obtained in two different tests in the well PGP-08

2.2.4 Production History

The PGP-08 was incorporated into the Las Pailas power plant during the period between July 2011 and October 2013. The total mass produced by the well was around 2,500,000 tons, with a wellhead pressure ranging between 6 and 10 bars (absolute). The well was taken out of the system in October 2013 because it was replaced by the PGP-16, which is more massive and led to improved quantities extracted from the different areas of the reservoir. Figure 15 shows the mass partially removed during the well operation. (until March 2013)

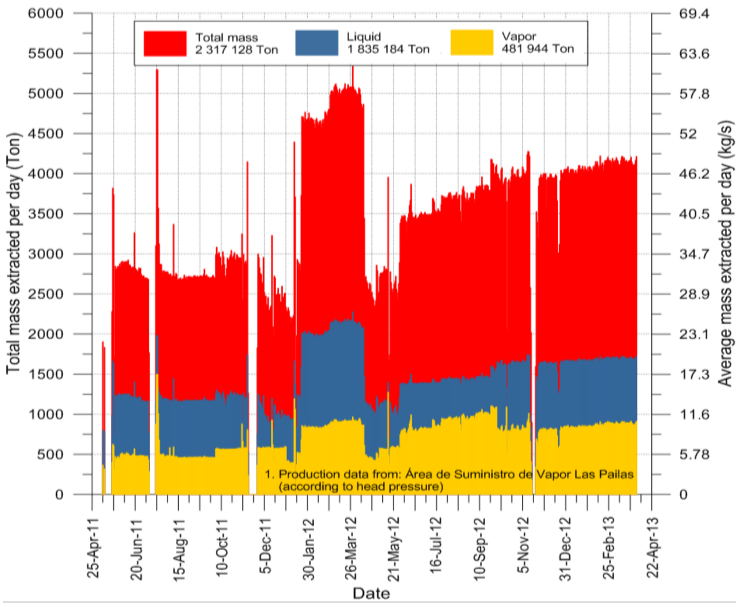

Figure 15: Production data from the PGP-08. (From 07-May-2011 to 31-March-2013)

3. CONCLUSIONS

The results obtained in the two wells tested in this study, indicate that the cold water injection produces an increase of the injectivity index and after the recovery period, produce an important improvement in the total mass obtained during the output curves carried out in each well.

The injection in both wells produced a fourfold increase in the assessed value of the injectivity index, also produced an increase in the parameter kh happened to a value below one to a very high value could not be determined by the type of test performed.

Both tests consisted of injecting a maximum flow rate of 50 l/s water at 20 ° C in a period of 32 days in the PGB-01 and 52 days in the PGP-08. Observed changes in the characteristics of the two wells can relate to the effect of increased pressure in lower permeable zones, combined with the thermal effect produced by the difference between the temperature of injected water and formation. These factors may result in hydraulic fracturing in the vicinity of the two wells.

An additional factor that may have improved the permeability of the wells was the injection of large volumes of liquid cleaning caused permeable zones, both rock cuttings as drilling waste.

The success of the procedure as the PGP-08 to enhance the well permeability, was confirmed by its incorporation into the productive system in the period 2011-2013. During this period, the well contributed approximately 5% of the power produced in the Las Pailas plant.

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