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INCREASING PERMEABILITY IN GEOTHERMAL WELLS THROUGH HYDRO-FRACTURING FOR THE LAS PAILAS AND BORINQUEN GEOTHERMAL FIELDS, COSTA RICA

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ABSTRACT

The permeable conditions found in some wells of the Las Pailas and Borinquen Geothermal Fields have been very limited, so ICE has 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 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, 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 and Torres, 2006). On the other hand, 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 (II= 1.9 l/s/bar). (González, 2010). Because of these characteristics, several output tests showed low conditions of mass produced and wellhead pressure, making it impossible to accommodate the well to the production system. With the objective to improve the permeability in both wells, ICE conducted two water injection tests for an extended period in each well. The two factors considered to increase the permeability of the wells are the temperature difference between the water injected and the reservoir, and/or the increase of pressure generate in the deeper permeable levels. Theoretical reasons to expect an improvement in the wells permeability are the secondary fracturing of the rock (Castro, 2007) and the mechanical cleaning of the permeable well zones. After both tests were completed, data analysis indicated that the injectivity index of PGB-01 was increased four times with regard to the last test carried out during drilling, increasing from 1.4 l/s/bar to 7.1 l/s/bar. In the case of PGP-08 the injectivity index rose from 1.9 to 5.9 l/s/bar. But the most important fact was that both wells showed good conditions in post-production tests that allowed them to be incorporated into a productive system. Due to the results obtained in these wells, 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 south-western 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.

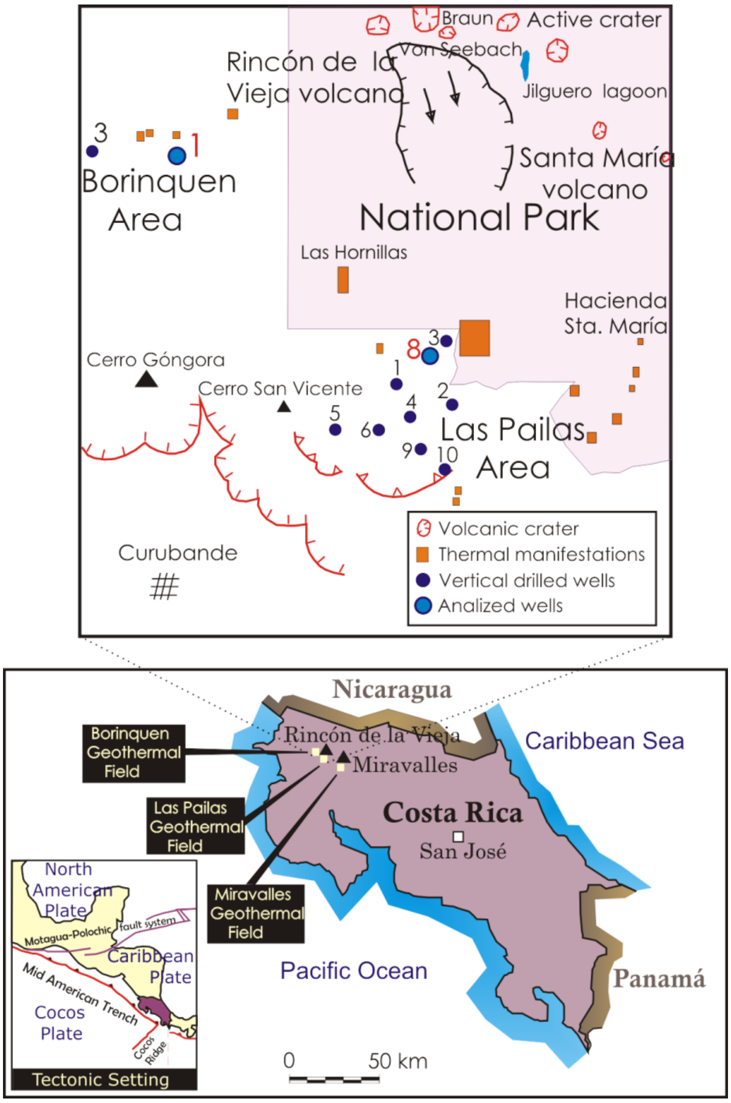

FIGURE 1: Tectonic setting, Costa Rica borders, location of the Guanacaste Geothermal Fields and location of the wells studied (modified from Chavarría, 2003)

1.1 PGB-01

The PGB-01 well 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 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 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 very little 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 (I.C.E, 2006).

1.2 PGP-08

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. Geologically the formation can be described as several intercalations of andesitic lavas and pyroclastic flows. Similarly to PGB-01, the permeability cannot be associated with a particular type of rocks (Figure 4).

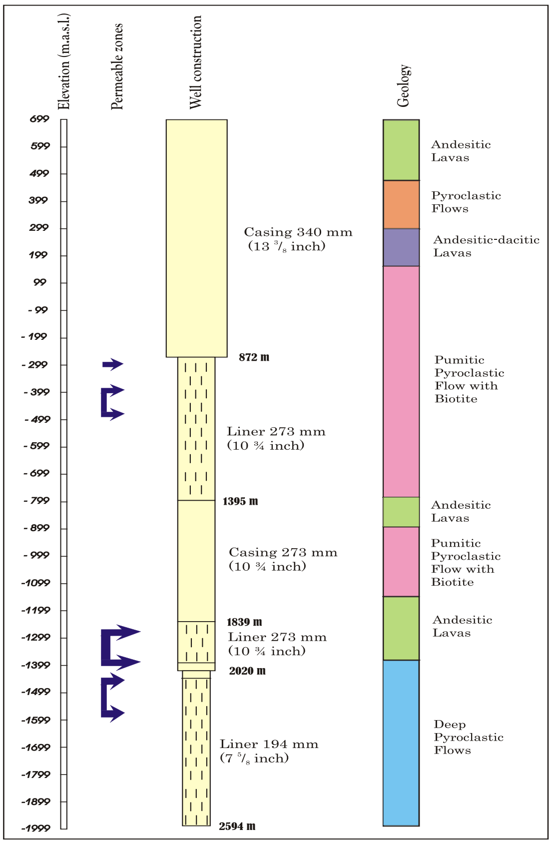

FIGURE 2: Well completion and geology of PGB-01

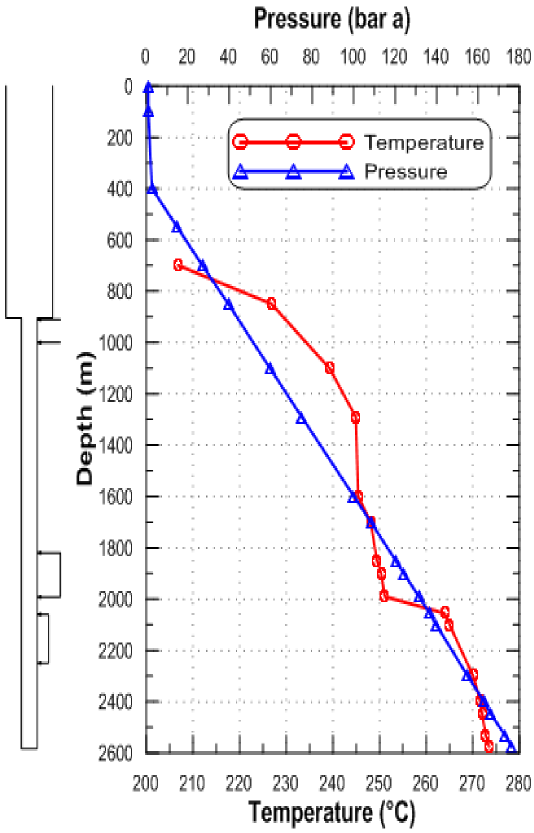

FIGURE 3: Static temperature and pressure measure in PGB-01 (02-06-07)

Static temperature and pressure profiles in PGP-08 that are considered to be almost stabilized 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. The permeability of the well is low and with a bad connection to the reservoir. The production tests carried out in the well confirmed the existence of a deep geothermal two-phase reservoir, predominantly liquid phase, similar to those 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 (I.C.E, 2006).

In other geothermal fields developed in volcanic zones, similar tests have been carried out with the purpose of increasing the permeability of the wells, and have obtained positive results (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.) 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 1.5 km away through several 10.16 cm (4 inches) pipes. 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.

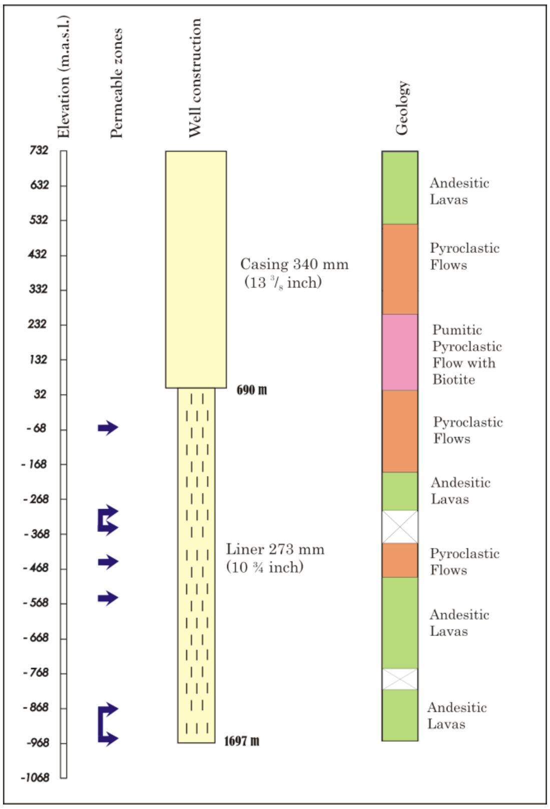

FIGURE 4: Well completion and geology of PGP-08

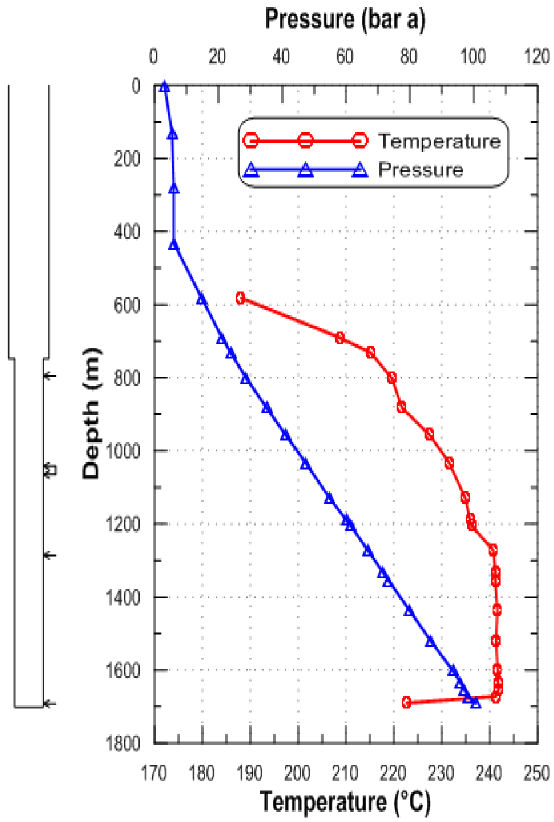

FIGURE 5: Static temperature and pressure measure in PGP-08 (18-06-09)

2. RESULTS

2.1 PGB-01

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

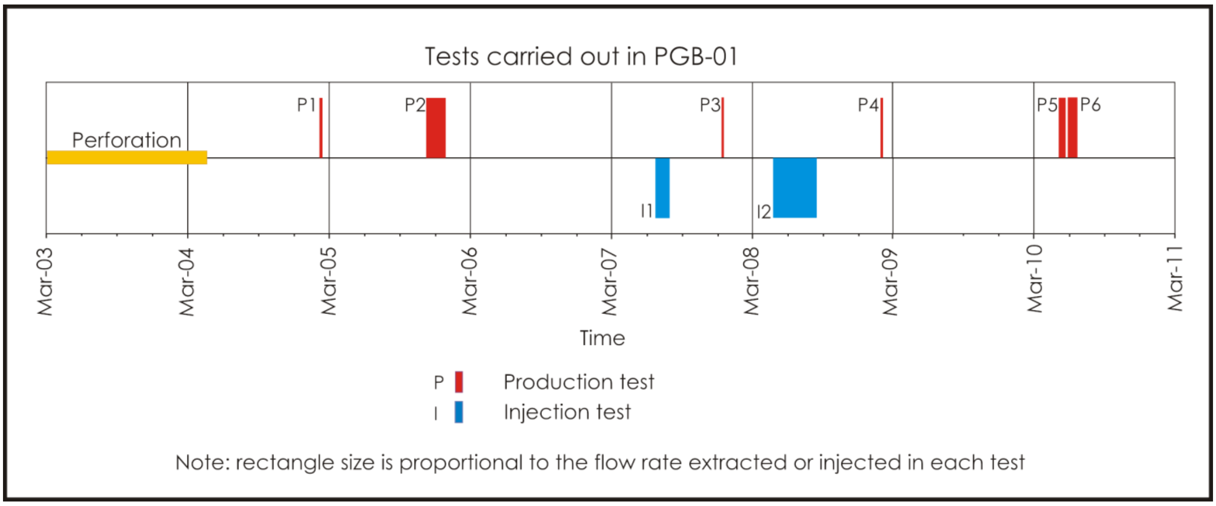

FIGURE 6: Different tests carried out in PGB-01

2.2 Injection tests

Two injection tests were carried out in the well, first one conducted from July 17, 2007 to July 31, 2007. 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 45,734 m^3 of water, equivalent to a mass of 44,911 tons (at 20°C). The second test started on May 01, 2008 and finished 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 tons (at 20°C).

2.3 Determination of the well permeability

The injectivity tests had the same design as the test carried out when the well drilling finished. The objective was to establish a valid criterion of comparison for both tests. Figure 7 includes data obtained in 2004 and 2008, before and after the injection tests to evaluate the permeability of the wells. 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 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.

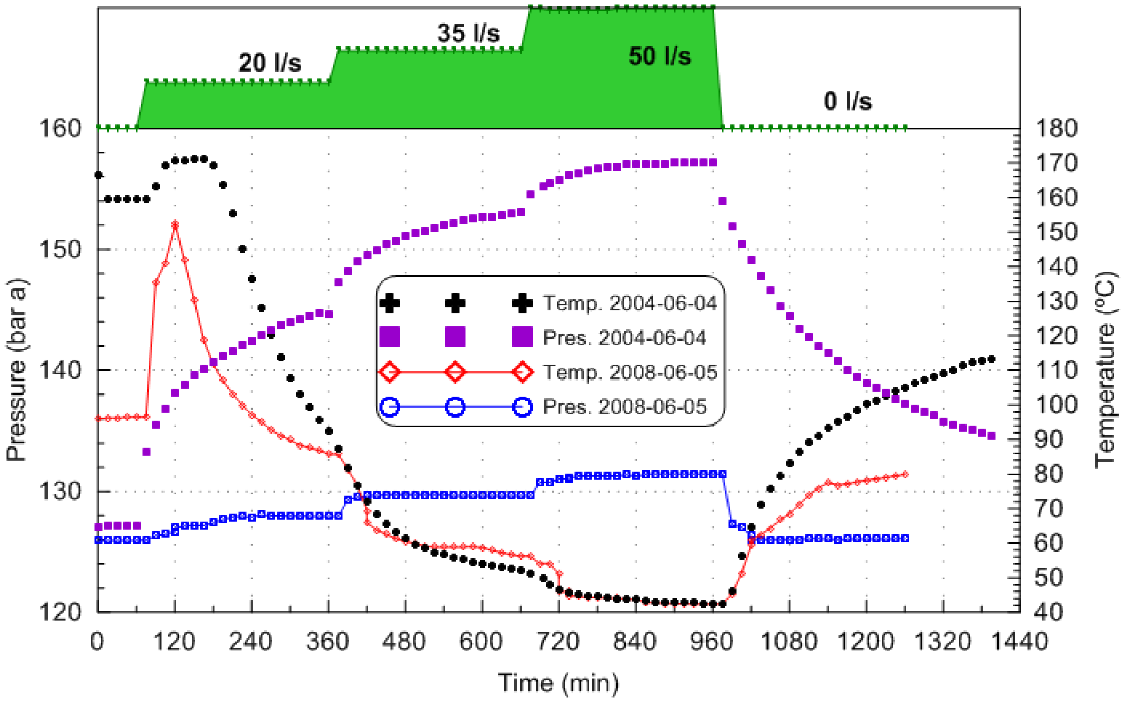

FIGURE 7: Injectivity tests carried out in PGB-01

Figure 8 shows the data analysis of both tests, using the slope method for each one. Also included are the lineal and by origin correlations. It is observed that for the first test (dP 2004) the experimental data and the correlation have irregular behaviour, 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.

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.

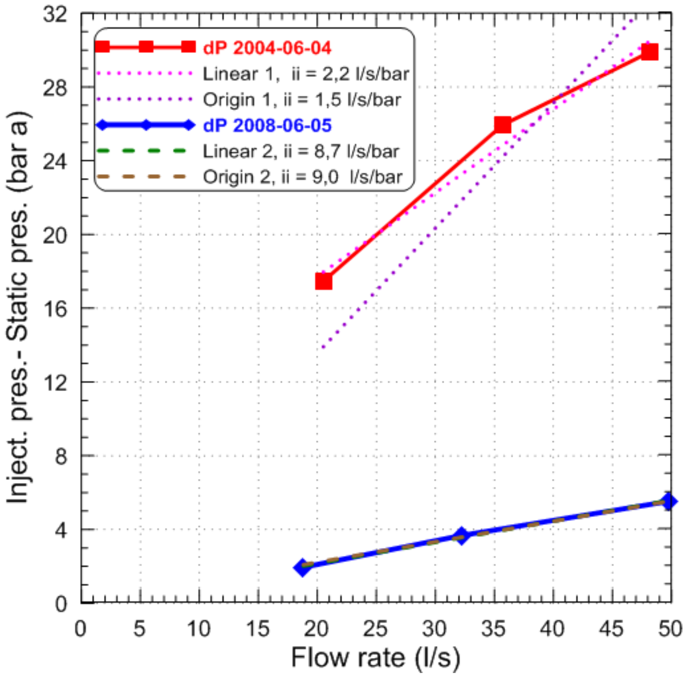

FIGURE 8: Injectivity index determination using the slopes method in two injectivity tests carried out in PGB-01

2.4 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 can be 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.

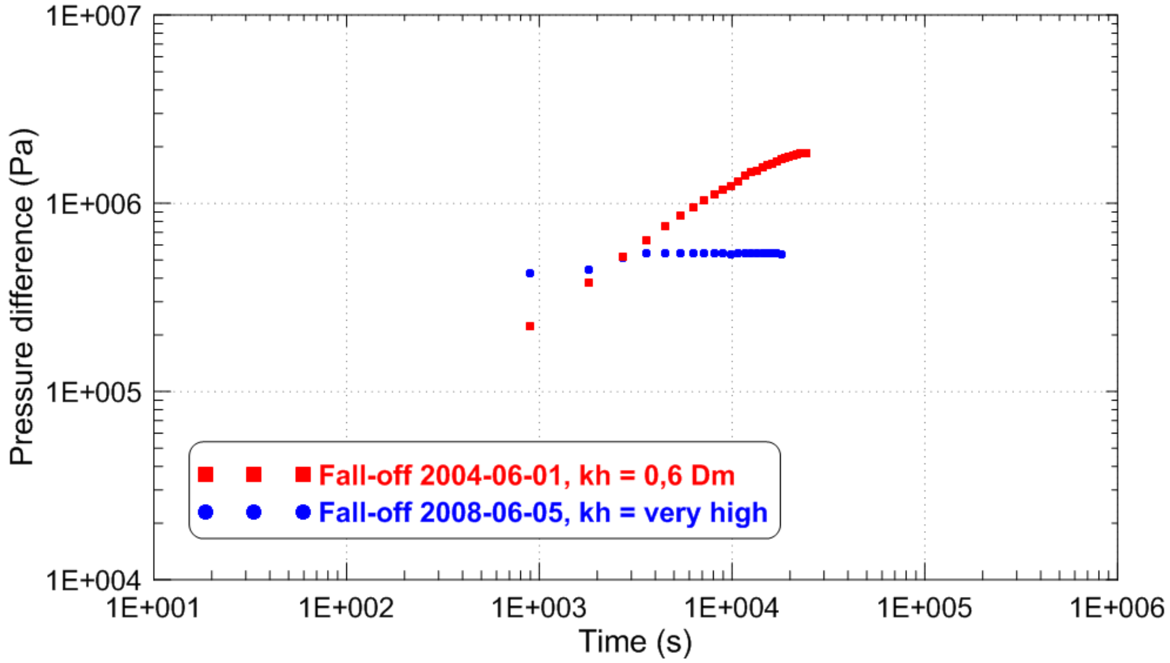

FIGURE 9: kh determination using the type-curve method for the fall-off section of the injectivity tests carried out in PGB-01

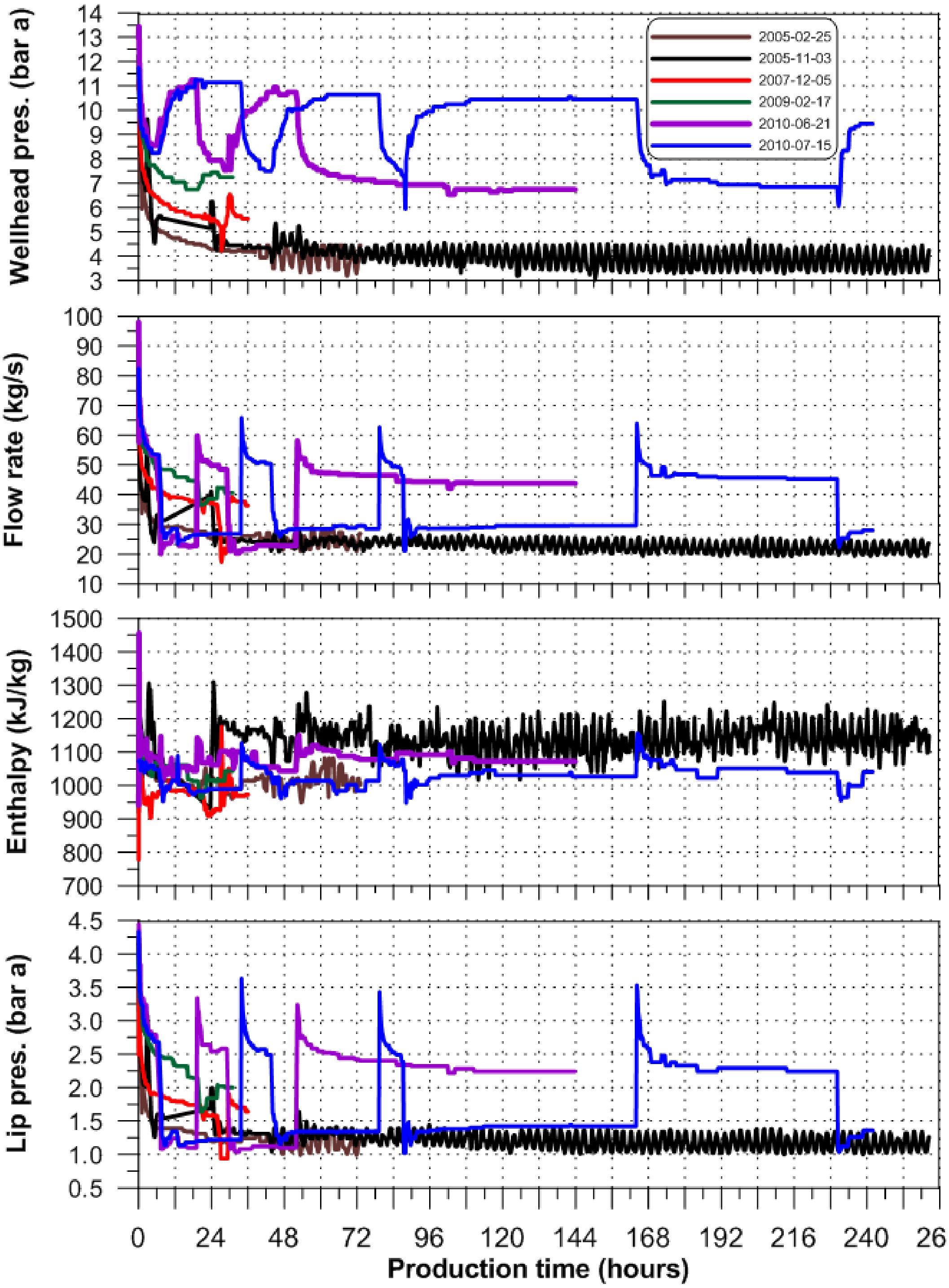

FIGURE 10: Output parameters obtained in different tests in the well PGB-01

2.5 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 confirmed bad conditions in the total flow rate and in the wellhead pressure; then considering the good results obtained in PGB-01, it was defined to make an injection test similar to the one carried out in that well.

2.6 Injection test

The injection test was carried out in the well 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 tons (at 20°C).

2.7 Determination of the well permeability

The two injectivity tests shown 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 mentioned above. 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 stopped, the pressure was measured for 8 hours. It is observed that the change of pressure with respect the volumes of each test, indicate that the well permeability had a positive change after the injection, showing a considerable improvement between the tests.

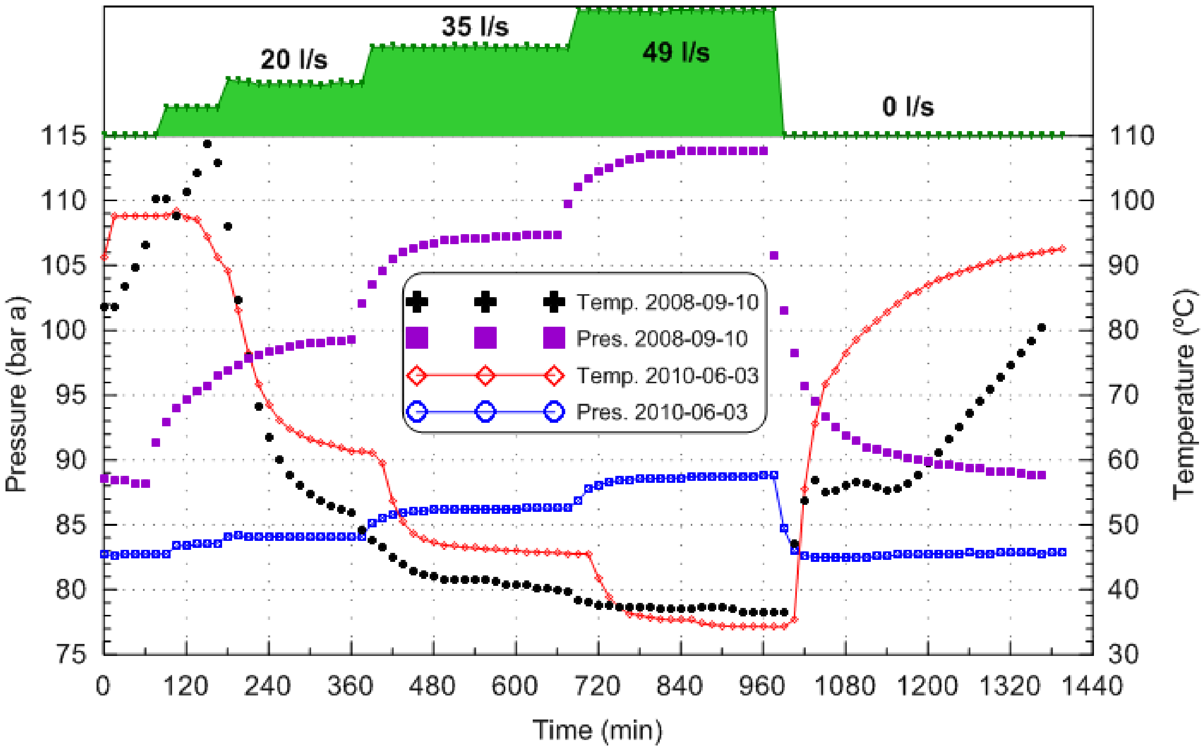

FIGURE 11: Injectivity tests carried out in PGP-08

The Figure 12 includes the data analysis of both injectivity tests, using the slope method for each one. As part of the analysis the lineal and by origin correlations are included, 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 had a similar slope and a good correlation but the current permeability was four times greater than the measured value of the 2008 test.

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, there occurred a change of the kh parameter, which increased by 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.

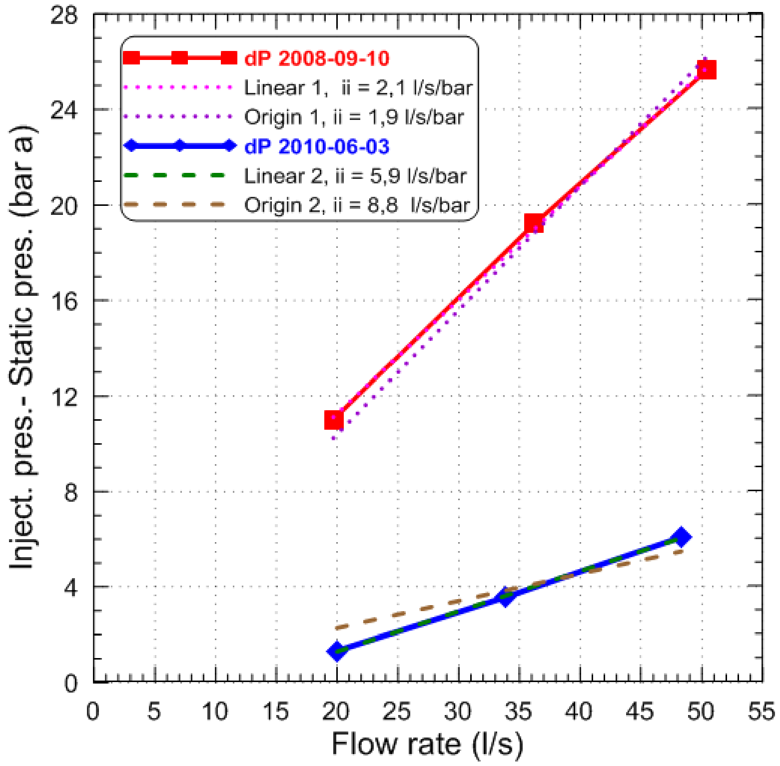

FIGURE 12: Injectivity index determination using the slopes method in two injectivity tests carried out in PGP-08

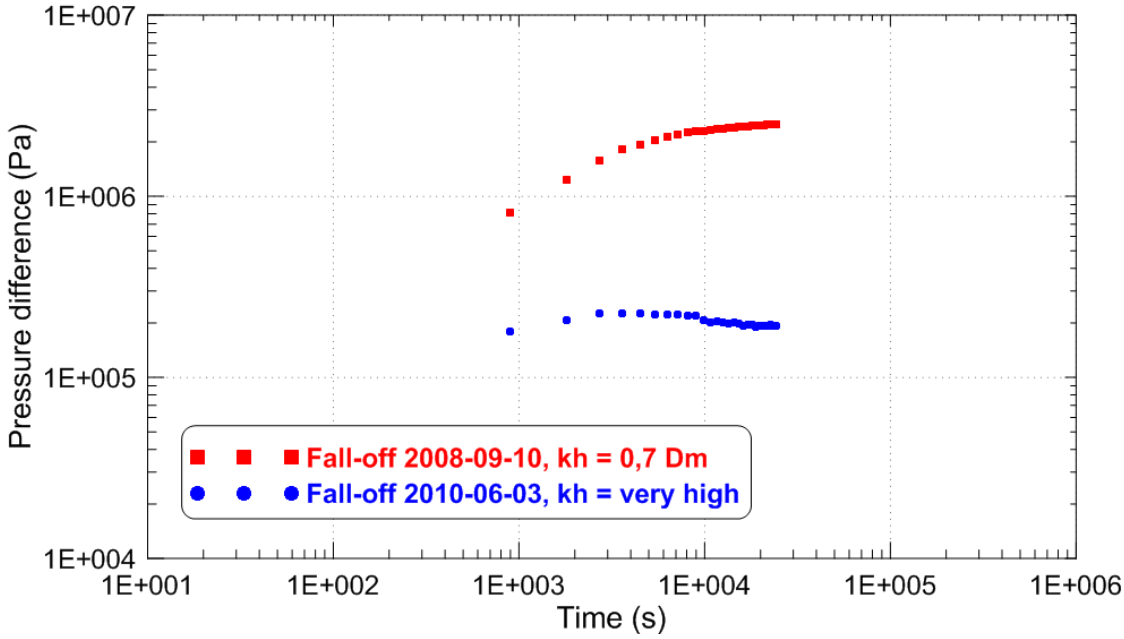

FIGURE 13: kh determination using the type-curve method for the fall-off section of the injectivity tests carried out in PGP-08

2.8 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 areas surrounding the well that helped to improve the connection with the reservoir.

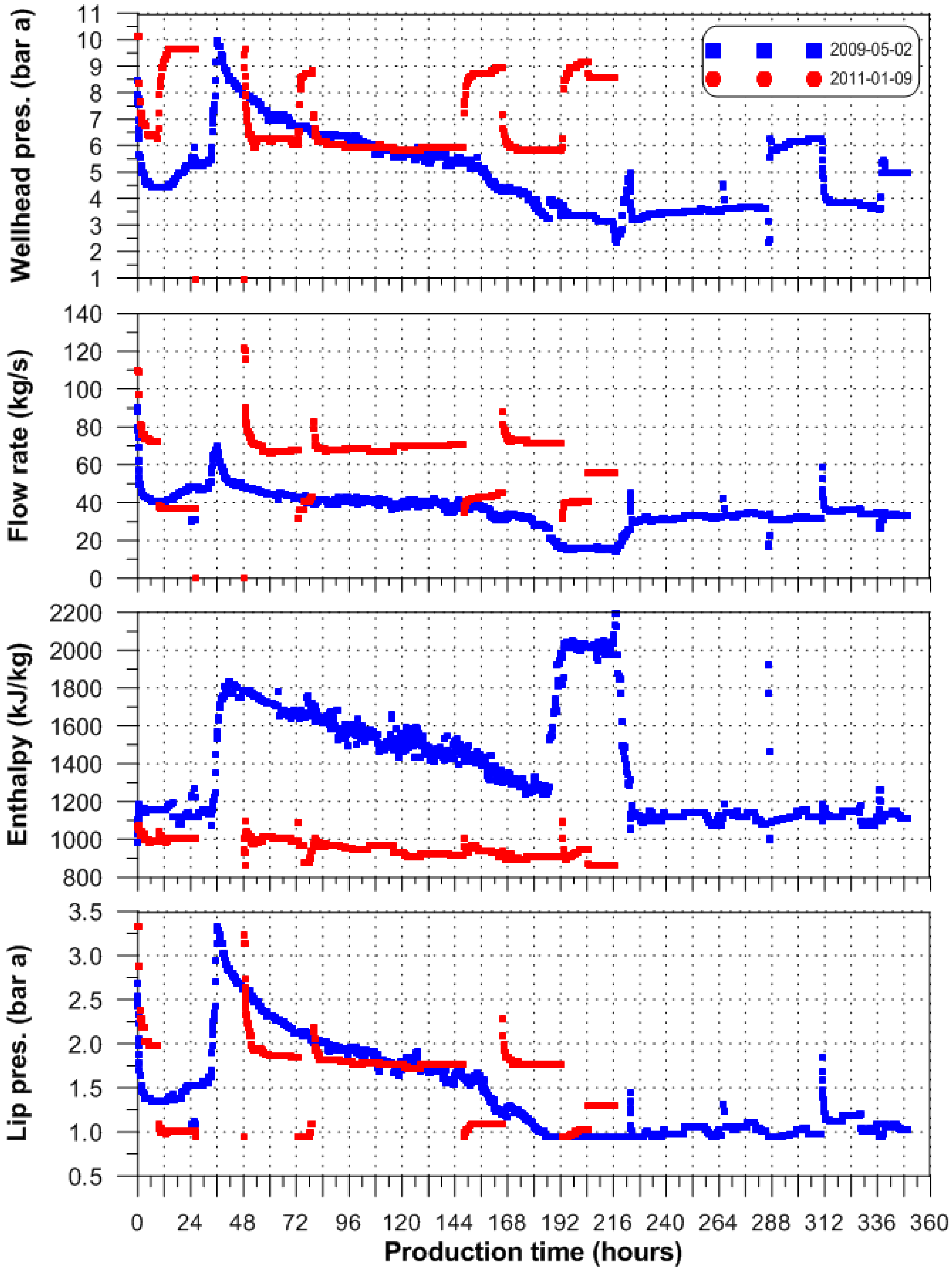

FIGURE 14: Output parameters obtained in two different tests in the well PGP-08

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. It also produced an increase in the kh parameter 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 PGB-01 and 52 days in 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 conditions of permeability of the wells was the injection of large volumes of fluid that provoked cleaning the permeable zones, both cut from rock like of waste from drilling.

The seismic stations placed in the areas around both wells showed an increase in seismic activity in the first 3000 meters of depth after injection testing carried out, for this reason it is considered that there is a hydraulic fracturing component related to the tests.

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