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Reservoir Parameters Determination Using Well Tester Software in Las Pailas Geothermal Field, Costa Rica

Sergio Castro Zúñiga

scastroz@ice.go.cr

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ABSTRACT

Las Pailas Geothermal Field is located on the northwest part of Costa Rica and is the second field developed by the Costa Rican Electricity Institute (ICE). Las Pailas is located on the southwest flank of the Rincón de la Vieja volcano, has a two-phase liquid-dominated reservoir, with temperatures of 230-270 ºC. The first unit of Las Pailas has been producing electricity since 2011, and nowadays it is producing 35 MW in a binary cycle unit.

The drilling for development of the second unit started in 2012 and ended in 2018. It is projected that the 55 MW power plant of single flash will start operating during the second semester of 2019.

This report includes an analysis of data related to reservoir engineering studies, obtained in transient pressure tests carried out in 3 deviated wells. The data were obtained in injection tests during completion and include determination of the reservoir parameters using the computer software Well Tester (V2.1.1, Marteinsson, K.) developed by Iceland GeoSurvey (ÍSOR).

The estimated well parameters for the analyzed wells show variations indicating different conditions in the reservoir, in detail it was observed that transmissivity varies between 3.56 E-08 and 5.99 E-09 [m3 /(Pa*s)], storativity varies between 2.06 E-08 and 6.62 E-08 [m/Pa] and injectivity indices range is 1.2 - 4.3 [l/s/bar].

Considering that the geological environment of the study area is quite uniform and that the wells do not show skin effects, it is interpreted that structural conditions represent the most important factor for the behaviour of the parameters of the well.

The use of the Well Tester software will allow obtaining new information about the parameters of the reservoir. This information will later be included in the numerical model of the different geothermal fields that are developed in Costa Rica by ICE.

1. INTRODUCTION

Costa Rica is located in the southern part of Central America. Las Pailas -high temperature- the geothermal field is located on the south flank of the Rincon de la Vieja Volcano (Figure 1). The deep drilling in the area started in 2001, after 10 years, in 2011 the first unit -a binary cycle plant of 35 MWe- was inaugurated.

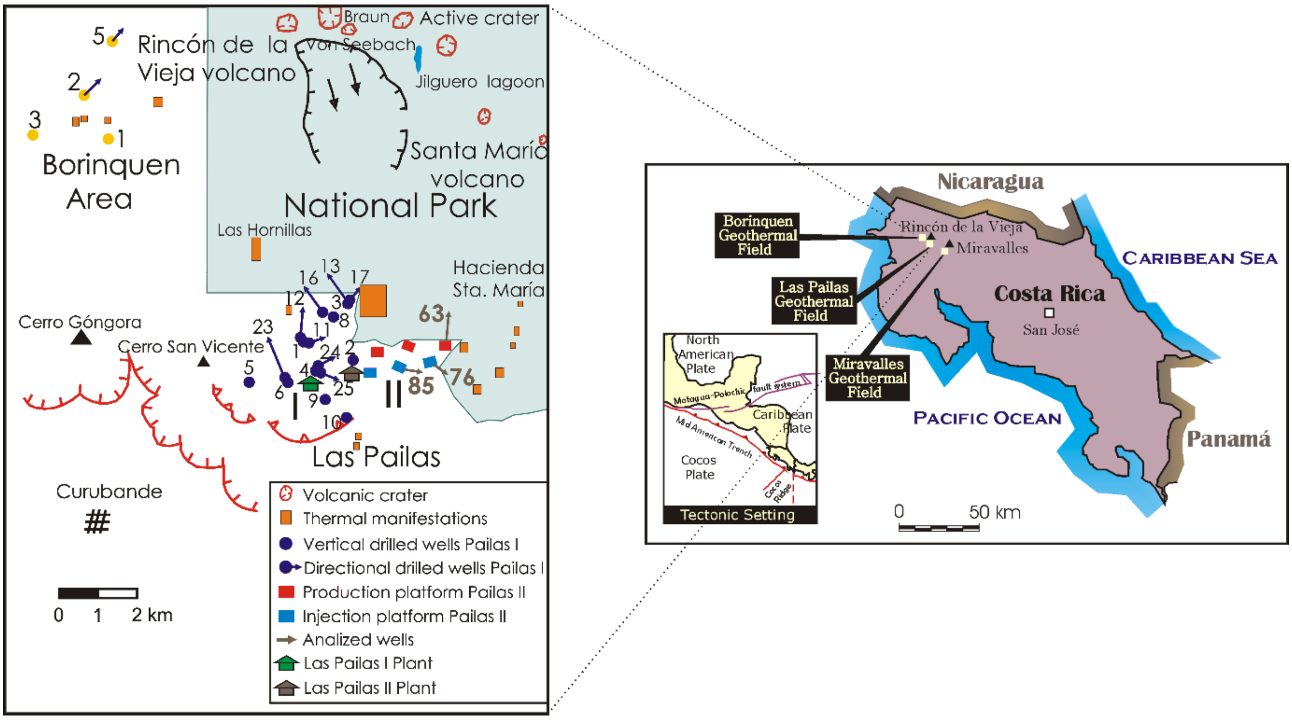

Figure 1: Tectonic setting, Costa Rica borders, location of the Guanacaste Geothermal Fields, and location of the studied wells.

Previous geoscientific studies carried out by ICE showed that in the east sector of Las Pailas I were conditions for the development of the second unit. Six platforms were built from which a total of 21 deviated wells were drilled, 12 for productive purposes and 9 that will be used for the reinjection of the residual brine. The drilling was carried out between 2011 and 2018, and the results obtained allowed to obtain steam for the construction of a single-flash power plant that will generate 55 MWe, from the second semester of 2019.

During the drilling, the reservoir engineering area conducted multiple campaigns to evaluate the well permeability conditions, which included temperature and pressure profiles to identify feed zones and injectivity tests. This report includes the description of the tests carried out in three wells selected from Las Pailas II, and the respective analysis for the determination of the reservoir parameters using the computer software Well Tester (V2.1.1, Marteinsson, K.) developed by Iceland GeoSurvey (ÍSOR).

These tests were made after the completion of the well and included the monitoring of the pressures and temperatures with electronic gauges during the injection of two or three flow rates for periods of 4 to 6 hours and the fall-off of 4 to 6 hours.

1.1 Well construction, geological conditions, and feed zones of the three wells studied.

The general characteristics of the three wells studied in Las Pailas II are mentioned in the following section.

1.1.1 PGP-63

This directional well is located at the northeast part of Las Pailas II, and it was drilled in 2017 to a measured depth (MD) of 2387 m (2079 m, vertical depth, VD). The permeability was located in three zones at 900 m, 1490-1590 m, and 1880-2050 m (Garrido 2017). Lithology can be described as intercalation of andesitic lavas and pyroclastic flows, with some thin intrusions (Mora and Acuña 2017). The main permeability can be associated with rocks of the Aguacate Group. (Figure 2).

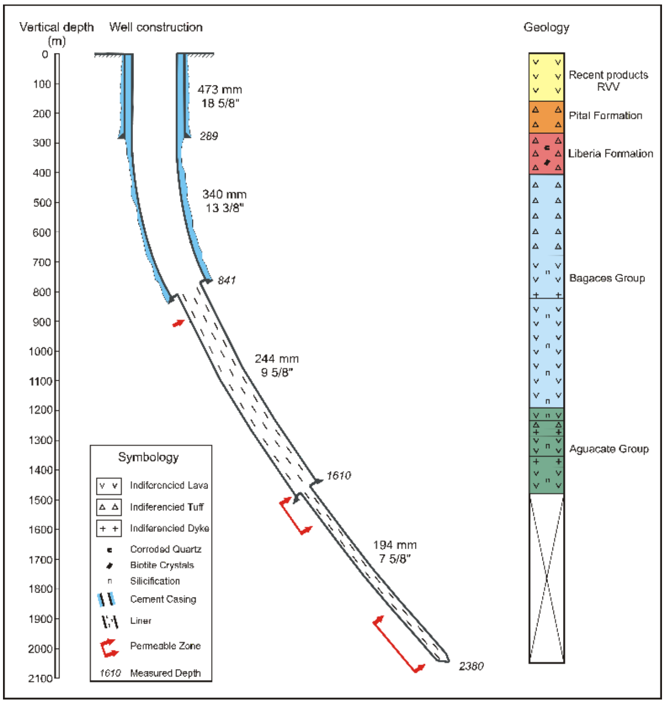

Figure 2: Well construction, geology, and permeable zones of PGP-63.

1.1.2 PGP-76

This directional well is located at the southeast part of Las Pailas II, it was drilled in 2015 to a maximum depth of 1912 m (1817 m VD). The permeability was located only in the interval 928-1017 m (Garrido 2015). Lithology can be described as intercalation of andesitic lavas and pyroclastic flows (Galvez and Ramírez 2015). The permeability can be associated with the rocks of the Bagaces Group and with a structure called FG28 that have NE-SW orientation (Ramírez, R. et al. 2017). (Figure 3).

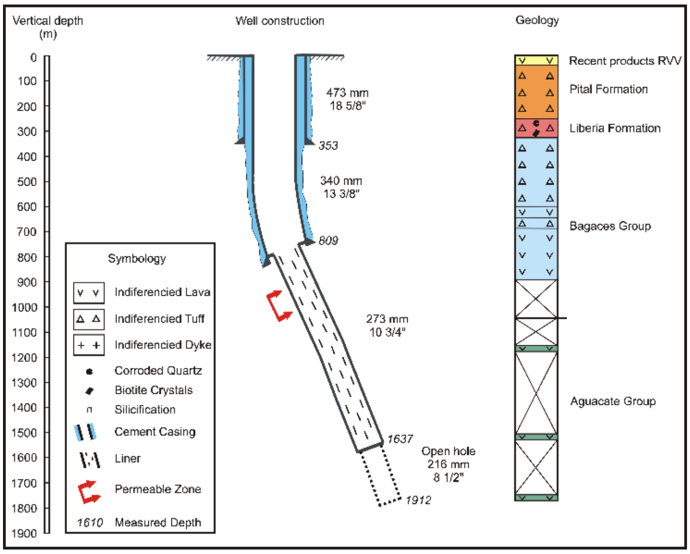

Figure 3: Well construction, geology, and permeable zones of PGP-76.

1.1.3 PGP-85

This directional well is located at the central-south part of Las Pailas II, was drilled in 2016 to a maximum depth of 1990 m (1862 m VD). The permeability was located in five zones at 924 m, 1163 m, 1280-1305 m, 1460-1505 m, and 1672 m (Garrido 2016). Lithology can be described as intercalation of andesitic lavas and pyroclastic flows, with some thin intrusions into the Bagaces Group (Acuña and Mora 2016). The permeability can be associated with the Bagaces and Aguacate Groups and with two structures called FG13 and FG22 that have NW-SE orientation (Ramírez, R. et al. 2017). (Figure 4).

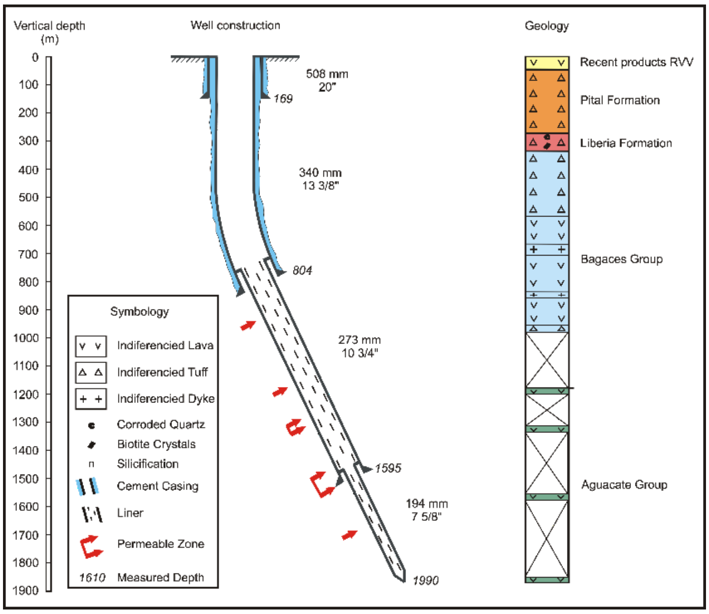

Figure 4: Well construction, geology, and permeable zones of PGP-85.

1.2 Lithostratigraphy of Las Pailas

The lithostratigraphic units described in the Las Pailas area are the following (Ramírez, R. et al. 2017):

1.2.1 Recent products of the Rincon de la Vieja Volcano

It consists of lahars with different degrees of consolidation, varied tobaceous materials and by levels of andesitic lava with a variable alteration.

1.2.2 Pital Formation

It is described as a sequence of interbedded pyroclastic materials with lacustrine sediments and epiclastic deposits, and lava flows of andesitic to basaltic-andesitic composition. This composition is related to the volcanism that occurred before and during the establishment of the Rincon de la Vieja-Santa María volcanic complex.

1.2.3 Liberia Formation

It is constituted by pyroclastic flows of white or pink tones, of rhyolitic composition, with plagioclase crystals, corroded quartz, biotite and sporadically hornblende as distinctive elements.

1.2.4 Bagaces Group

It was formed by a sequence of tuffs of varied composition, underlain by lavas of andesitic and dacitic composition.

1.2.5 Aguacate Group

It consists of highly altered andesitic lavas interspersed with thin levels of tuffs and presence of andesitic dykes.

1.3 Tectonic and structural location

The most important tectonic feature at the regional level is represented by the subduction zone of the Cocos plate below the Caribbean plate. The contact zone has a northwest-southeast orientation and is parallel to the Guanacaste volcanic mountain range, within which the Rincon de la Vieja volcano is located.

Locally, a series of structures are recognized that have orientations in the N-S, E-O, NO-SE, and NE-SO directions, which confirm the direct influence of the area of stress generated by the collision of the plates. In addition, based on the information obtained from the deep wells drilled, the importance of the local faulting for the permeability detected in the wells is confirmed.

2. INJECTION WELL TESTS

After the completion of the wells, the Reservoir Engineering Unit carried out injection tests to estimate different parameters of the well and the surrounding reservoir. The characteristics of each test analyzed in this study are described below.

2.1 PGP-63

This test consisted of the injection of two flow rates of 46 and 95 l/s, with the pressure gauge located at 960 m (Figure 5). The record of the final recovery (fall-off) could not be interpreted due to a problem with the measuring element. Data show that the injection time of each flow rate was different and that, in both cases, the pressure and temperature-stabilized correctly. Well Tester analysis was carried out on the behavior of the pressure between the 0 and 6 hours of the test. (step 1)

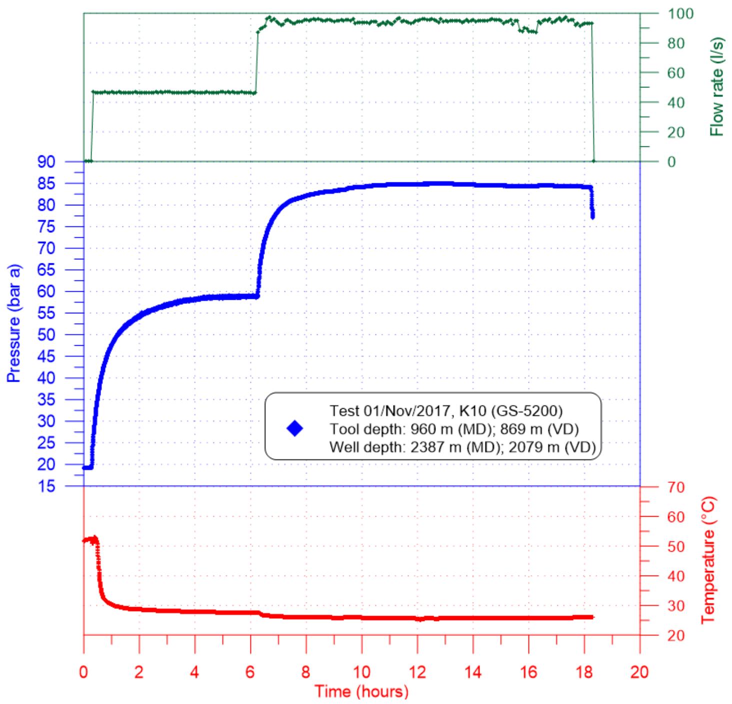

Figure 5: Injectivity test carried out in PGP-63 (01-Nov-2017).

2.2 PGP-76

Three descending flow rates of 53, 41, and 18 l/s were injected, with the pressure gauge located at 960 m (Figure 6). Data show that the injection time of each flow was similar, and in all cases, the pressure and temperature-stabilized correctly. Well Tester analysis was performed with data between 13 and 19 hours. (step 3)

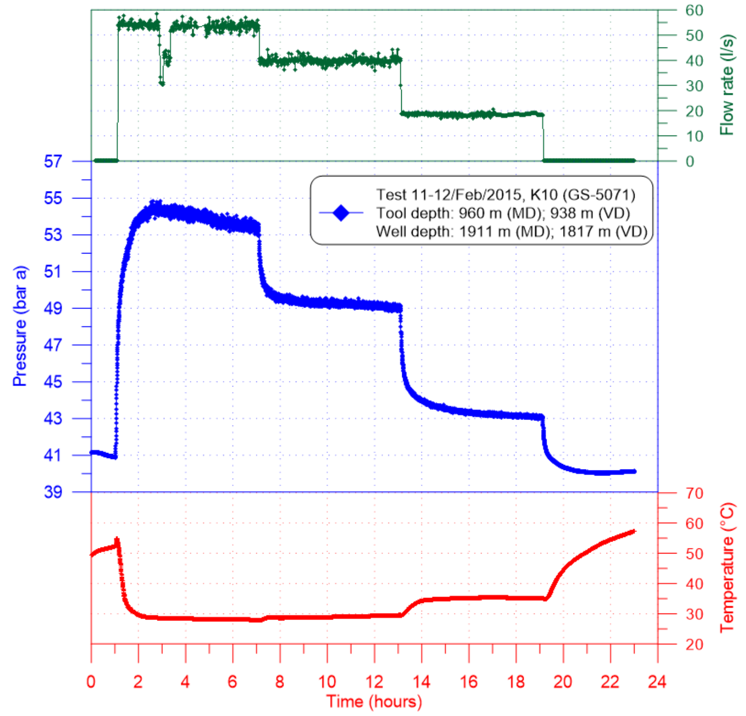

Figure 6: Injectivity test carried out in PGP-76 (11-Feb-2015).

2.3 PGP-85

Here were injected three ascending flow rates of 20, 39, and 59 l/s, with the pressure gauge located at 1600 m (Figure 7). The data show that injection time of first flow rate was longer than the others; also it is noticeable that each pressure record was non-continuous because these carried out a dynamic profile to analyze the presence and importance of the different permeable zones of the well. The pressure and temperature-stabilized correctly. A well Tester analysis was performed with the fall-off data between 21 and 25 hours. (step 4)

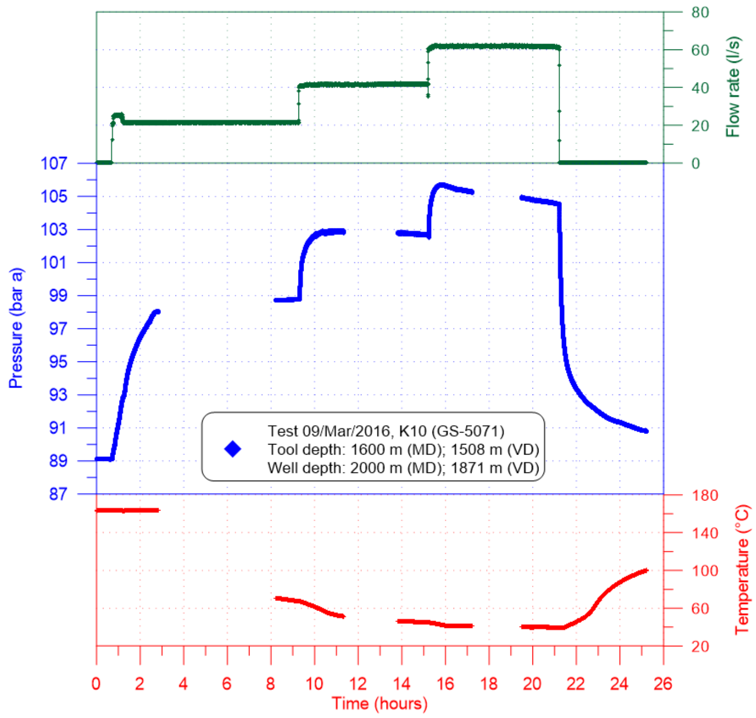

Figure 7: Injectivity test carried out in PGP-85 (09-Mar-2016).

3. DATA PROCESS AND ANALYSIS USING WELL TESTER

3.1 Discussion

The objective of the injection tests carried out in Las Pailas is to obtain the changes that occur in the reservoir by modifying the flow rates used during the test.

The theoretical analysis is based on the pressure diffusion equation that is derived from the Laws of Conservation of Mass, Darcy´s, and Compressibility of Fluids. The parameters that are obtained when modeling with Well Tester are transmissivity (permeability), storativity, wellbore skin, wellbore storage, initial pressure, and reservoir boundaries. (Wondwossen, K. 2013)

In this report, the data obtained in the three wells of Las Pailas were only analyzed using Well Tester. For the Well Tester run, it is previously required to have included the initial parameters of the wells and the reservoir model type. Later, during the second stage, calculations were made for the determination of the reservoir parameters.

Tables 1 and 2 show the initial parameters and the model selected for the analysis of the data with Well Tester. It should be mentioned that the dual-porosity deposit model was chosen because it is considered to be the one that best reflects the type of permeability that prevails in the Las Pailas wells.

Table 1: Initial parameters used in the well test analysis of PGP-63, PGP-76, and PGP-85

Parameters and units	PGP-63	PGP-76	PGP-85
Reservoir Temperature (°C)	255	245	240
Reservoir Pressure (bar a)	105	80	70
Wellbore Radius (m)	0.09	0.12	0.09
Reservoir Porosity (%)	10	10	10
Dynamic Viscosity of Reservoir Fluid (Pa*s)	1.06E-04	1.10E-04	1.12E-04
Compressibility of Fissured Rock (Pa-1)	2.65E-11	2.65E-11	2.65E-11
Compressibility of Reservoir Fluid (Pa-1)	1.43E-09	1.31E-09	1.25E-09
Total Compressibility (Pa-1)	1.67E-10	1.55E-10	1.49E-10

Table 2: Model selected for injection tests analysis in wells PGP-63, PGP-76 and PGP-85

Reservoir	Dual Porosity
Boundary	Constant Pressure
Well	Constant Skin
Wellbore	Constant Wellbore Storage

3.2 Results

Figures 8, 9 and 10 show the curves obtained after processing the data of the injection tests with Well Tester, which were plotted on a log-log scale and included the derivative (t*dp/dt) and the respective model calculated.

The selection criteria for each chosen step of the injection tests carried out in the wells. It considers the lower value of the variation coefficient (Marteinsson, K. 2016). Statistically, this represents a smaller dispersion data of the model with respect to the data measured in the test.

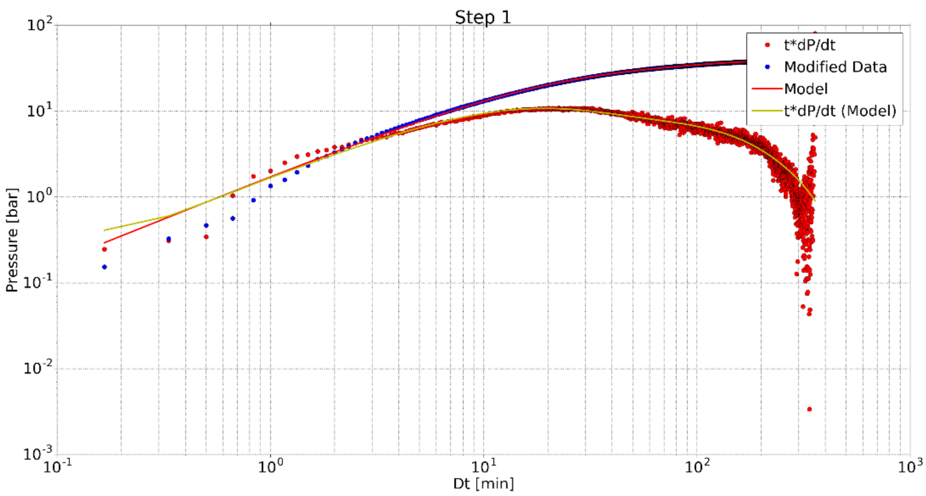

Figure 8: PGP-63 model results for step 1 using a log-log scale and including the derivative

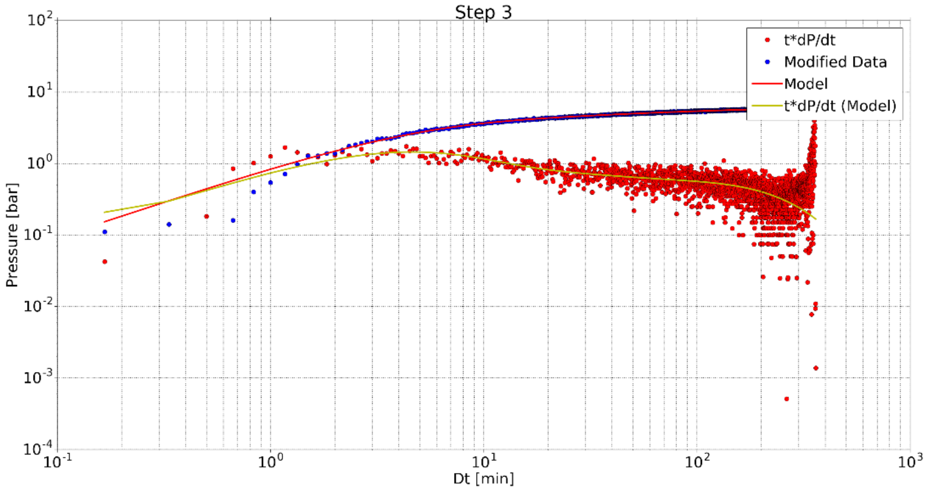

Figure 9: PGP-76 model results for step 3 using a log-log scale and including the derivative

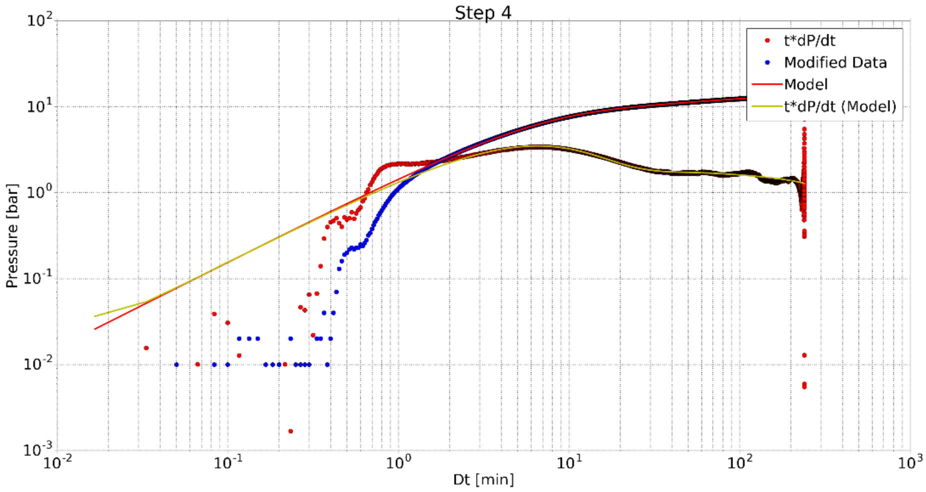

Figure 10: PGP-85 model results for step 4 using a log-log scale and including the derivative

The reservoir parameters determined by Well Tester were included in Table 3. It is observed that the values of the variation coefficient of the wells PGP-63 and PGP-76 are relatively higher than PGP-85.

Table 3: Estimated reservoir parameters of PGP-63, PGP-76, and PGP-85 from the best model and best step

Model Parameters	**PGP-63**	**CV %**	**PGP-76**	**CV %**	**PGP-85**	**CV %**
Transmissivity *[m³/(Pa*s)]*	5.99E-09	0.6	3.56E-08	0.3	3.36E-08	0.1
Storativity *[m/Pa]*	2.06E-08	0.8	2.19E-08	1.6	6.62E-08	0.1
Radius of Investigation *[m]*	71.3	0.8	239.3	1.0	166.6	2.0
Skin factor	-3.4		-1.8		-2.3	
Wellbore storage *[m³/Pa]*	1.56E-05	0.2	1.48E-05	0.5	2.28E-05	0.1
Transmissivity ratio	1.88E-05		2.47E-05		1.88E-05	
Storativity ratio	9.28E-04		2.08E-04		4.25E-05	
Reservoir Thickness *[m]*	123.0		141.5		444.5	
Injectivity Index *[(l/s)/bar]*	1.2		3.9		4.3	
Effective Permeability *[m²]*	5.15E-15		2.77E-14		8.47E-15	

3.3 Parameter values interpretation

Results show better transmissivities in PGP-85 and PGP-76 than in well PGP-63 and a relatively good storativity in all wells. The transmissivity values were on the order of E-8 [m3/(Pa*s)] in the first wells and E-9 [m3/(Pa*s)] for well PGP-63; the storativity values in all cases were in the order of E-8 [m3/(Pa*m2)]. The wells show a good ability to transmit fluid, and considering the thermal conditions, all wells can be classified as producers from a liquid-dominated geothermal reservoir.

The radius of investigation calculated by Well Tester shows values ranging from 71 to 239 m. This range qualitatively indicates the approximate distance at which the pressure generated by the injection test becomes undetectable in the surroundings of the well. Due to poor permeability, the well PGP-63 shows the lowest influence distance.

The skin factor shows values in the range of -1.8 to -3.4. This range indicates that all wells have higher permeability in its closest surroundings than farther away. Its effective radius is, therefore, larger than its real radius. Due to the drilling method used and the completion tests carried out by ICE, no negative effects on the initial permeability of the wells are observed.

The injectivity index is frequently used to estimate the connectivity of a well with the surrounding reservoir. It is important to mention that Well Tester uses pressure values from the modeled response, not the actual data collected. In the three wells analyzed, the injectivity indices show different values, wells PGP-76 and PGP-85 presented intermediate values of 3.9 and 4.3 l/s/bar respectively while well PGP-63 showed a, fairly low value around 1.2 l/s/bar.

The effective permeability is a measure of the ability of a rock to transmit a given fluid when the rock contains more than one type of fluid. Well Tester deduced this parameter by combining the initial parameter estimates and the well test results, as a consequence the results should only be viewed as a qualitative cross-check on the well test results (Marteinsson, K. 2016). The values obtained indicate that wells PGP-76 and PGP-85 have the highest values of 2.77E-14 and 8.47E-15 m2 respectively, while PGP-63 has the lowest value 5.15E-15 m2.

4. CONCLUSIONS

The main objective of this study was to analyze the permeability characteristics of three deviated wells drilled in the Las Pailas Geothermal Field (Unit II) using the Well Tester computer program developed by ISOR of Iceland. The analysis of the tests made allowed to determine the parameters of the reservoir that characterize the eastern sector of Las Pailas. Likewise, the obtained results confirm that the determined values can be correlated with the values reported in others geothermal reservoirs of liquid-dominated type.

The selected model for simulating the injection step tests in wells PGP-63, PGP-76 and PGP-85 assumed a dual-porosity reservoir, constant boundary pressure, constant skin, and constant wellbore storage. The detailed analysis of each parameter indicates:

- The transmissivity calculated values indicate that wells PGP-76 and PGP-85 had a better ability to transmit fluid in the reservoir than well PGP-63.
- The storativity of three wells is quite similar, with relatively good values from 2.06E-8 to 6.62E-8(m/Pa).
- Injectivity index (II) indicate that connectivity of the well with the surroundings was better for PGP-85 and PGP-76, while PGP-63 had the lowest value.
- The skin factor shows values in the range of -1.8 to -3.4, which indicates that the wells are stimulated and free of damage produced by the drilling fluid.
- The effective permeabilities show wells PGP-76 and PGP-85 have higher values than PGP-63. These results are in accordance with the values defined for the transmisivities reported previously.

The best permeability conditions found in the wells PGP-76 and PGP-85 with respect to PGP-63, may be a consequence of the presence of nearby structures, which were recognized prior to the drilling of the wells and which would have allowed a better connection to the reservoir.

According to the exploitation scheme of Las Pailas II, PGP-63 is a producer well, while PGP-76 and PGP-85 wells will be used as brine re-injectors. The information obtained indicates that the PGP-63 has low permeability, so a cold water injection test was carried out during a month that allowed to improve the permeability of the well. It is expected that the new conditions will improve the productive characteristics of the well.

The reservoir parameters obtained by Well Tester in this study were compared with the values obtained using other methods for the same tests, data indicate that parameters values maintain the same order of magnitude, confirming the convenience of using a computational method that reduces the errors of interpretation of the alternative methods.

During the last year, the injection tests carried out in the wells drilled by ICE are being analyzed by Well Tester, with the aim of including the values of the reservoir parameters in the numerical models of the geothermal fields that are developed in Costa Rica.

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