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Determination of the Injectivity and Productivity Indices and Their Correlation with the Productive Evolution in Six Wells of the Las Pailas II Geothermal Field, Costa Rica (2019-2024)

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INTRODUCTION

The Las Pailas Geothermal Field lies in the southern flank of the Rincón de la Vieja Volcano (Figure 1). Currently, two production units are in operation:

- Las Pailas I: situated in the western zone, is a binary cycle plant with a capacity of 35 MWe, inaugurated in July 2011.
- Las Pailas II: situated in the eastern sector, is a condensation plant with a capacity of 55 MWe and has been operational since July 2019.

The study was based on the results obtained from completion tests conducted at the end of drilling and in the initial flow testing of six wells (Table 1). Data analysis allowed for the determination of:

- injectivity index (*II*)
- productivity index (*PI*)
- Also was analyzed the productive behavior of each well over five and a half years of field operation.

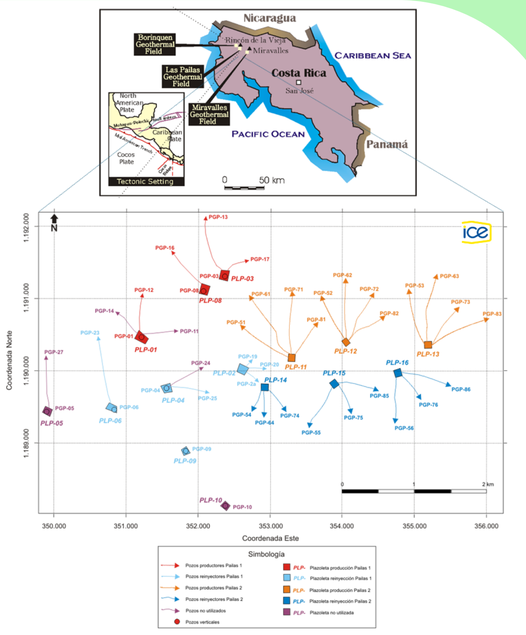


Figure 1: Location of the Guanacaste geothermal fields and well locations in Las Pailas.

Well	Elevation (m a.s.l.)	Bottom Hole (m)	Horiz. Displ. (m)	Main Feed Zones Elevation (m a.s.l.)			
PGP-71	736	-1397	919	-176 to -195	-288 to -339	-579	-1363
PGP-81	736	-421	631	-84	-221 to -404		
PGP-72	799	-1287	773	-96 to -123	-306 to -352	-352 to -529	-1100 to -1230
PGP-82	799	-990	615	-232 to -330	-764	-957 to -990	
PGP-63	784	-1295	1000	-112	-704 to -804	-1096 to -1261	
PGP-83	784	-1384	898	-959 to -1042			

Table 1: General characteristics of the Las Pailas II wells studied.

METHODS: INJECTIVITY AND PRODUCTIVITY INDICES DETERMINATION

Injectivity index (kg/s)/bar: determined at the end of the drilling process by measuring the pressure response above the main permeable zone of the well, while different flow rates were pumped from the surface (including fall-off period). The tests were analyzed using the Welltester software (V2.1.1, Marteinsson, K., 2016) developed by Iceland GeoSurvey (ÍSOR). Figure 2 shows data collected during the test carried out at PGP-83 on Feb-2017. This procedure was applied to obtain with Welltester the *II* values for the six wells analyzed in this study. (Table 2)

Productivity index (kg/s)/bar: following the beginning of commercial exploitation in July 2019, the six wells were incorporated into production. Initial evaluations were subsequently conducted to monitor the wells' production parameters. Using the obtained flow rates along with the temperature and pressure profiles carried out as an integral part of the output curves both static and flowing conditions (Figure 3), the *PI* was calculated for each well (Table 3) using the following formula:

$$PI = \frac{Qt}{Ps - Pf}$$

Where:

PI: Productive Index (kg/s/bar)
Qt: Total flowrate measure during flowing profile (kg/s)
Ps: Static pressure at select depth (bar)
Pf: Flowing pressure at select depth (bar)

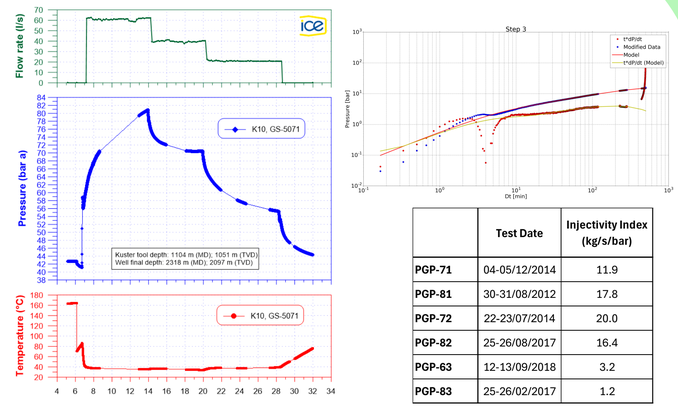


Figure 2: Injectivity test from well PGP-83 (25-26/02/2017) and model result obtained with Welltester.

	Test Date	Injectivity Index (kg/s/bar)
PGP-71	04-05/12/2014	11.9
PGP-81	30-31/08/2012	17.8
PGP-72	22-23/07/2014	20.0
PGP-82	25-26/08/2017	16.4
PGP-63	12-13/09/2018	3.2
PGP-83	25-26/02/2017	1.2

Table 2. Injectivity indices in Las Pailas II.

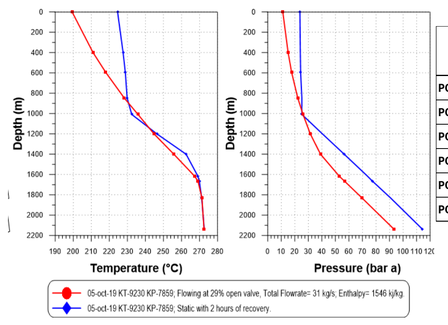


Figure 3: PGP-83 static and flowing profiles.

	Test Date	Productivity Index (kg/s/bar)
PGP-71	26-27/09/2019	2.7
PGP-81	28-29/09/2019	8.3
PGP-72	02-03/10/2019	20.0
PGP-82	02-03/10/2019	13.0
PGP-63	26-27/02/2020	1.1
PGP-83	05-06/10/2019	1.5

Table 3: Productivity indices in Las Pailas II.

RESULTS AND DISCUSSION

Comparison between Injectivity and productivity indices

To compare the data obtained for the *PI* and *II* indices, a graph was constructed including values from the six productive wells of Las Pailas II (Figure 4). It can be observed that the values of both indices are related to the geographic location of the wells. The graph also includes the line correlating the productivity and injectivity indices obtained for Las Pailas II. This relationship is defined by the following equation:

$$II = IP * 1.2$$

As part of the analysis two graphs were constructed. Each graph illustrates the correlation between the injectivity and productivity indices and the estimated maximum initial total flow rates for the analyzed wells. (Figures 5 and 6)

The graphs show significant variations between the values measured at the wells relative to the best-fit line. However, a general correlation is observed between the increase in both indices and the increase in total produced flow. The equations obtained to estimate produced flows from both indices are:

Qt= PI/0.104

Qt= II/0.141

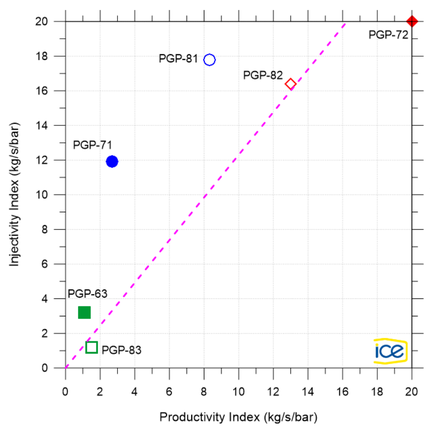


Figure 4: Correlation between injectivity and productivity indices at Las Pailas II.

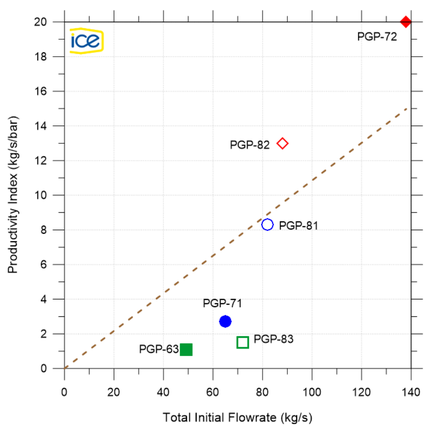


Figure 5: Correlation between productivity indices and maximum total flowrate at Las Pailas II.

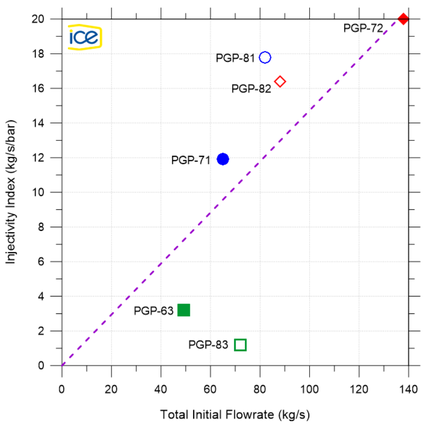


Figure 6: Correlation between injectivity indices and maximum total flowrate at Las Pailas II.

Evolution of productive parameters during operation period.

Figures 7a,b,c illustrates variable behavior in total flow rate, vapor flow rate, and enthalpy under maximum flow rate conditions over time for the six wells studied. The graphs reveal significant differences in the total flow rates produced by the wells according to topographic location. It is observed that the wells in the central sector have the highest flow rates, while the northwest and northeast wells exhibit lower but relatively similar magnitudes. After the output tests carried out in 2020, most wells maintained stable flow rates with variations no greater than 10 kg/s. Regarding to vapor flow rates, the initial conditions show considerable variation between wells; however, starting with the 2020 test, the flows tended to stabilize, except for well PGP-63, which continued to show an increasing trend. Finally, enthalpy exhibited highly variable behavior.

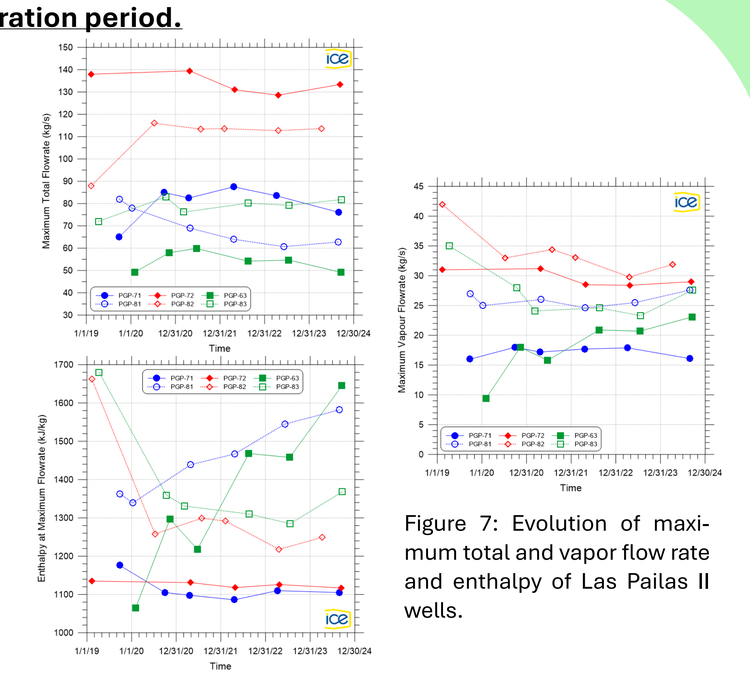


Figure 7: Evolution of maximum total and vapor flow rate and enthalpy of Las Pailas II wells.

Total mass produced by wells during operation period.

As part of the study, the total mass contribution of the six wells to the plant was analyzed. The field's exploitation strategy included using wells with varying opening rates of the valve throughout the period. Additionally, the time required to incorporate the wells into the system also varied. (Figures 8a,b,c,d,e,f,g,h)

Wells PGP-71, PGP-81, PGP-82, and PGP-83 have been incorporated to the system for more than 90% of the time, while PGP-72 and PGP-63 were integrated 16 and 24 months after the plant began operating. Regarding their mass contribution to the system, the largest amounts come from wells PGP-72 and PGP-82, each contributing 9 Mtn, closely followed by PGP-83 with 8 Mtn. Wells PGP-71 and PGP-81 contributed between 6 and 7 Mtn, and finally, PGP-63 contributed only 4.5 Mtn.

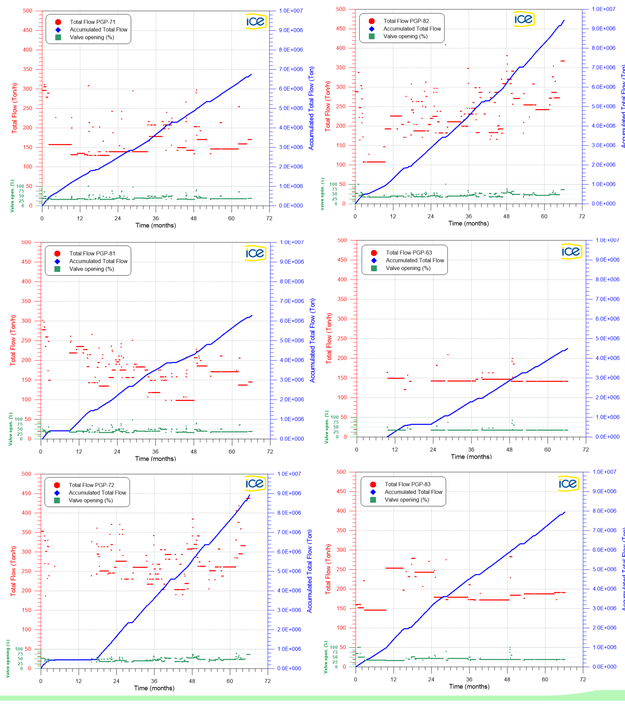


Figure 8: Average and cumulative flow rate produced by wells during exploitation period.

CONCLUSIONS

- The information analyzed in this study is considered statistically limited because data were available from only six of the twelve production wells. The wells not analyzed were excluded for various reasons, including a lack of testing during the drilling and/or initial production phases, a short duration since their incorporation into the production system, and, finally, one well experienced accelerated change, resulting in it producing only steam.
- The analysis conducted on the six Las Pailas II production wells established a first-order correlation between the injectivity and productivity indices, although considerable variability exists .
- Based on the information obtained from the correlation graphs between the total flow rates and the injectivity and productivity indices, were obtained two equations to estimate the flow rates produced by the Las Pailas II wells.
- During the productive period, it was observed that the central sector wells, PGP-82 and PGP-72, contributed the greatest mass to the system. Additionally, they registered the highest *II* and *PI* values. The western sector wells, PGP-71 and PGP-81, exhibited intermediate *II* and *PI* values and contributed intermediate masses to the system. Finally, the eastern sector wells, PGP-83 and PGP-63, showed the lowest *II* and *PI* values. However, from a productive standpoint, PGP-83 was anomalous, as it was the third highest contributor to the system, while PGP-63 maintained a good correlation with the defined indices by contributing the least mass to the plant.
- The previously discussed results from Las Pailas II confirm that analyzing the injectivity and productivity indices obtained during the pre- and post-exploitation stages provides valuable insights into well characteristics. Furthermore, data on production behavior during the initial years of exploitation allowed for the identification of variable conditions in the observed production trends compared to those initially defined. A key factor in the detected anomalies was the evolution of the enthalpy of the well fluid, as it directly influenced the produced flow rates. This is particularly important for condensation plants, as it determines the vapor flow rate produced by each well.

Acknowledgements

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