

Electric Generation with Low-Enthalpy Geothermal Sources for Self-Consumption in Hotel El Guayacán, Guanacaste, Costa Rica

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ABSTRACT

Through the Distributed Generation pilot project, promoted by the Costa Rican Institute of Electricity, there is the option to launch self-generation of electricity as an option to hotels and spas located near places with volcanic activity which at the same time are covered by the ICE's distribution networks. That is how the first local and regional pilot project dealing with the exploitation of low-enthalpy geothermal resources for self-consumption came to be. To start the project, some promising locations around the Miravalles and Rincón de la Vieja volcanoes were analyzed, all of them having the adequate range of temperature for electrical generation with this kind of geothermal resources. From there, the appropriate location was found: Hotel El Guayacán, situated inside the volcanic caldera of the Miravalles volcano, and which uses a hot spring (outflow) coming from the volcano. The heat source corresponds to a steam and gas escape from a place about $2\ 500\ m^2$, with a temperature of 95°C , a pH of 5.82, and high content of carbonates (HCO_3^-) and silicates (SiO_2), among others. Since the pH value does not eliminate the use of steel piping, an all-steel 'ad hoc' heat exchanger was used to proceed with the tests. Among the fundamental information needed to define the power plant capacity, the team obtained the hotel's electricity consumption. Deciding on this data the team found that it would be necessary to install a 5 kWe power plant to meet the hotel's needs and reduce the electric bill to almost nothing or even zero. Taking this into consideration and the temperature range mentioned before, an ORC power plant with an 8% performance was proposed. Preliminary estimations show that the total power output of the entire outcrop could reach 224 kWe.

1. INTRODUCTION

Geothermy in Costa Rica has been limited to the exploitation of steam for power generation and balneology, missing the opportunities for a wide spectrum of geothermal power uses. The project explained in this report is intended for small hotels and thermal spas that can use hot springs to generate their own electricity with micro Organic Rankine Cycle (ORC) power plants from 1 to 10 kWe.

On October 25, 2010, the Costa Rican Institute of Electricity (ICE in Spanish) started a pilot project called "Distributed Generation Pilot Project for Self-Consumption". Its objective is to promote small-scale power self-generation. The project was originally designed for alternative energy sources such as biomass, micro-hydroelectric power, wind, and solar. By December 2013, it had 138 interconnected clients, whose contribution to the national electric grid was 748.51 kW (Arias Alvarado, 2013).

In early 2012, the ICE Research and Development (R&D) Department started the task of visiting hotels and hot springs, with temperatures over 80°C , around the Miravalles and Rincón de la Vieja volcanoes. After visiting the sites, it was determined that three locations met that requirement, but only one hotel, Hotel El Guayacán, showed interest in this pilot project (Vindas, 2014).

Hotel El Guayacán is located within the Guayabo caldera (Figure 1). It uses a hot spring (outflow) from the main high-enthalpy geothermal reservoir of Costa Rica of the Miravalles Geothermal Project, used for power generation.

2. GEOLOGY

Costa Rica is located east of the Pacific Ring of Fire. It has nine active volcanoes and more than 200 inactive volcanoes. Its recent volcanic history began in the late Miocene with the clash between the Cocos and Caribbean plates.

The Miravalles volcano is located in northwestern Costa Rica. Its age is nearly 550 000 years old and is a resurgent volcano, partially surrounded by a huge volcanic caldera ($200\ km^2$) called Guayabo Caldera. It is formed by lava flows, flows, surges, pyroclastic falls, and volcanic mega landslides. According to Alvarado Induni (2009), the last event of importance was 10 275 years ago.

The outcrop studied is a flow of mud and rock (Figure 2). It is made of andesitic metric blocks embedded in a clay matrix, with a high degree of hydrothermal alteration, which is probably a lahar deposit. The study site is characterized by small fractures where steam and gases flow.

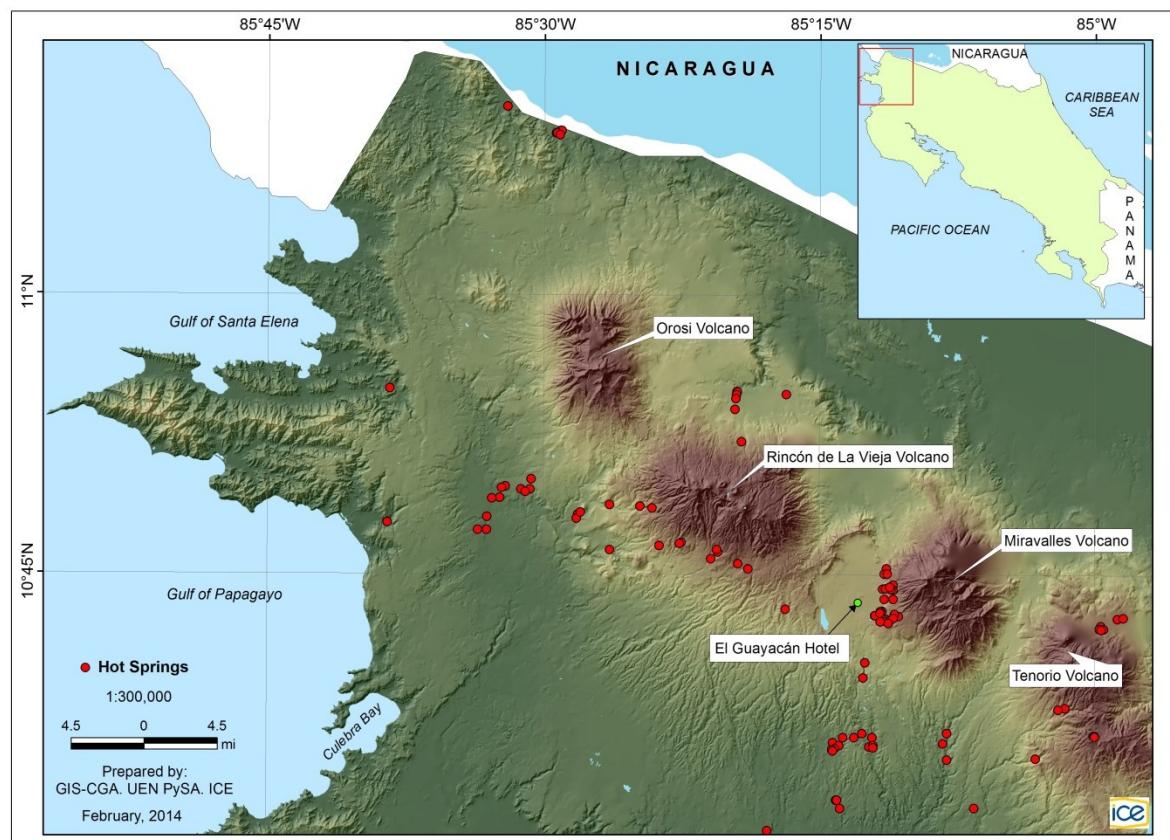


Figure 1: Location map.



Figure 2: Breccia outcrop with gas and steam vent.

3. GEOCHEMISTRY

The heat source in mind is a mixture of steam and gas at about 95°C that comes out from metric fractures oriented preferentially north-south, crossing the outcrop of approximately 2 500 m².

Table 1 shows the results obtained from a hot spring located near to the outcrop. It is assumed that the steam there is similar to the one intended to use for power generation.

Table 1: Chemical analysis of the hot spring.

pH Laboratory	5.82
Cond. (μS/cm) lab	171.5
Na ⁺ (ppm)	7.9
K ⁺ (ppm)	1.8
Ca ⁺⁺ (ppm)	11.5
Mg ⁺⁺ (ppm)	5.005
Fe Tot (ppm)	<0.07
Cl ⁻ (ppm)	7.2
SO ₄ ⁼ (ppm)	16.3
HCO ₃ ⁻ (ppm)	66.5
H ₂ S (ppm)	<1
NH ₃ (ppm)	< 0.50
SiO ₂ tot (ppm)	54
TDS (ppm)	118

As shown in the above table, the pH is not far from neutral pH values; however, the content of HCO₃⁻ presents values that should be considered when defining the type of materials to be used for the heat exchange. On the other hand, the values of Cl⁻ and SO₄⁼ are not so high as to cause corrosion, for example in a metal pipe. However, the content of SiO₂ could generate medium-term scaling problems in the heat exchange system.

Testing for six continuous months has been planned in order to observe any problems that could arise in the medium or long term. The objective is to foresee possible negative effects during the production stage in the final heat exchange system.

4. THERMODYNAMIC SYSTEM

The pattern of electrical consumption of the hotel is among the key information necessary to define the capacity of the plant. From this information, it was determined that a power plant with a capacity less than 5 kWe would be required to meet the hotel's electrical needs and to achieve a zero or close to zero electricity bill per year. For this purpose and under the conditions of the temperature described, it is proposed to install a micro ORC plant with an approximate efficiency of 8%.

5. PERFORMANCE TESTING

Several tests were performed in order to determine the energy potential of the outflow of steam and gases through the fractures found in this location. A pit of 60 cm depth and 4 m² in area was excavated in one of these fractures, following the natural inclination of the terrain in that point. In this test, an ad hoc heat exchanger¹, named J-1, was installed (Figure 3) and covered with several layers of material in the following way:

A layer of gravel was placed to generate turbulence of the fluid (gas and steam) and to help to simulate a permeable environment. Inside this layer, the J-1 was embedded to transfer heat from the outflow to the water running through the heat exchanger (Figure 4). This layer was covered with plastic and soil to waterproof the system, and to enhance the crossing of gases through the pit towards one of its corners, where the surplus of gas and steam could be released thanks to a pipe acting as a chimney.

¹ Heat exchanger material is made out of steel coated with a layer of galvanized steel. Its tube has an inner diameter of 24.2 mm.

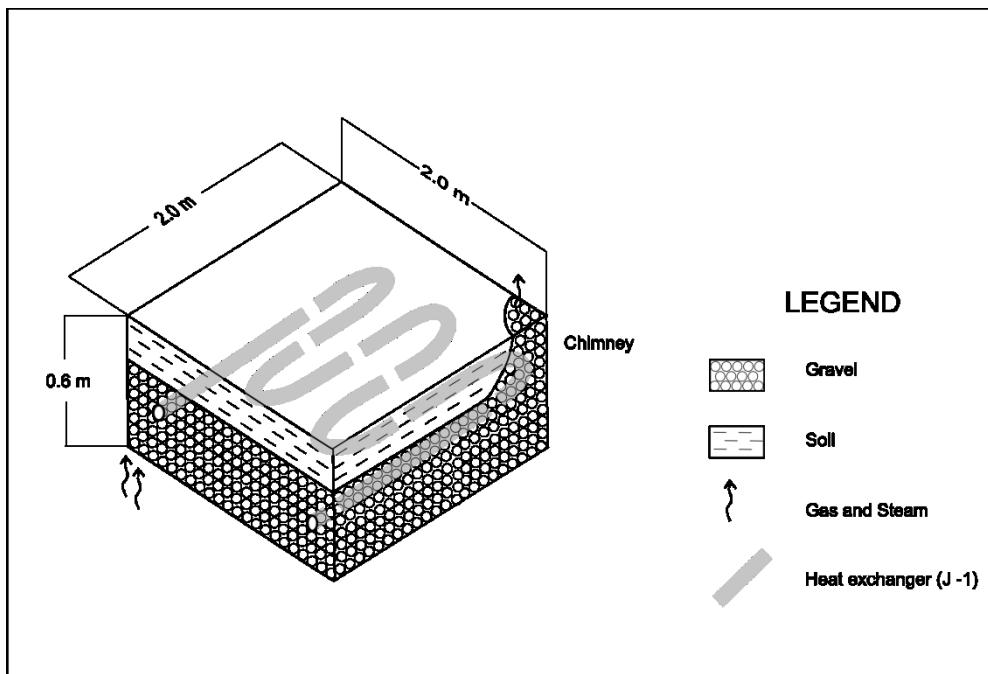


Figure 3: Layout of the J-1 heat exchanger.



Figure 4: Installation of the heat exchanger J-1 in a pit of 2 m x 2 m x 0.6 m.

Various tests were carried out after installing the heat exchanger. These tests consisted of injecting water at 26°C, taken from a small creek close to the outcrop, and circulating it through the J-1 during a defined period of time and continuously measuring the temperatures of input and output of the heat exchanger. Several flows were used: 1 l/min, 5 l/min, 11 l/min and 13 l/min.

Based on the previous tests, it was possible to define the trend line included in Figure 5, which shows the behavior of the temperature according to the variation of the flow rate. (Arias Molina et al., 2013)

It was determined that the best course of action was to use an approach similar to the one used by the Chena Hot Springs geothermal power plant, which uses water at a maximum produced temperature of 165°F (~74°C) to produce a total electrical power output of 400 kW (Holdmann, 2007). Even when the circumstances are different, it is reasonable to think that it could be technically and financially feasible to generate electricity from the El Guayacán outcrop if the outflow temperature of water could reach 80°C, taking the Chena project as an example. Using the data from the test, the flow of water necessary to obtain an outflow temperature of 80°C can be calculated as:

$$\dot{m} = \frac{C_p \Delta T}{Q} \quad (1)$$

Where Q, m, Cp, and ΔT are the thermal output, the mass flow of water, the specific heat, and the difference of temperature, respectively. Thus, it was determined that the optimal flow to obtain a constant outflow temperature of 80 °C is 1.21 l/min.

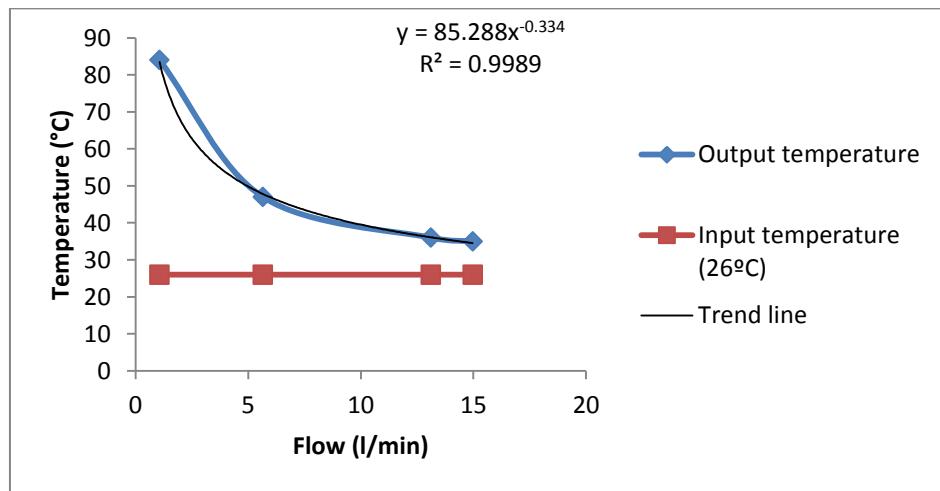


Figure 5: Trend line of the inlet temperature vs flow.

In order to estimate the total thermal output of the outcrop, it is assumed that the entire area of the outcrop has the same thermal output. Knowing that the test area is 4 m^2 , and the entire outcrop area is $\sim 2500 \text{ m}^2$, and using an estimate efficiency of thermal conversion of 8%, the total electric output of the outcrop can be estimated as 224 kWe. Of course, there are plenty of practical considerations to make in order to get a better estimate, so this figure will be considered as a maximum, as the real electric output will surely be less than that.

6. CONCLUSIONS

A projection was made based on the performance tests conducted at the site. Results indicate that the likely power of the whole outcrop is around 224 kWe.

Based on the tests performed, the heat found in the area would generate electricity to meet and exceed the energy consumption needs at Hotel El Guayacán.

With the heat surplus obtained from this site, a 200 kWe power plant could be installed to deliver electricity directly into the ICE electrical grid.

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