Experimental development of a novel thermoelectric generator without moving parts to harness shallow hot dry rock fields

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***Abstract*—Nowadays, geothermal energy in shallow hot dry rocks is not exploited enough due to the high economic and environmental impact as well as the lack of scalability of the existing technologies. Here, thermoelectricity has a great future potential due to its robustness, absence of moving parts and modularity. With this research, the feasibility of a novel and robust geothermal thermoelectric generator whose working principle is phase change has been experimentally demonstrated, as well as the importance of compactness to maximize its efficiency and thus, power generation.**

Keywords—Thermoelectric generator, Heat pipe, Thermosiphon, Fins dissipator, Thermoelectricity.

I. INTRODUCTION

Nowadays, the only existing technologies to convert geothermal energy into electricity are geothermal power plants, which are only profitable for elevated powers. Timanfaya National Park is the biggest hot dry rock field, where temperatures up to 400 ºC can be found at 1m deep inside the ground [1]. The existing method to harness this kind of fields is Enhanced Geothermal System, which requires fracturing the rock and may cause seismicities [2]. The elevated environmental and visual impact, as well as the lack of scalability make it impossible to implement this method in Timanfaya. Here, thermoelectricity has a great future potential. A geothermal thermoelectric generator is a solid-state device that directly transforms thermal energy from the superficial Earth's crust into usable electricity, it is very compact, without moving parts and it causes a low environmental impact. It contains three principal parts: The hot side heat exchanger (HHE), the thermoelectric module (TEM) and the cold side heat exchanger (CHE). The hot side heat exchanger transports the heat from a heat source (the geothermal source) to the hot side of the TEM.

The thermoelectric module is the most important part, which is responsible of transforming part of the heat into electricity thanks to the Seebeck effect. The heat that is not transformed into electric energy must be dissipated into the cold source, usually the environment, for which a CHE is used. The module's efficiency highly depends on the temperature difference between its hot and cold sides.

Different thermoelectric generators (TEG) for geothermal energy can be found in the literature. Most are computational studies and few experimental, and what is more, in order to apply thermoelectric generation to geothermal energy, all of them use moving parts to circulate a fluid [3], thus losing the intrinsic advantage of thermoelectricity: the absence of moving parts.

The only TEG proposed to take advantage of the high enthalpy geothermal anomalies in hot dry rock fields is the one designed, computationally studied by Catalan et al. [4]. It consists of biphasic thermosiphons with water as working fluid in both sides of the thermoelectric modules. As laboratory and field work should be done, this research deepens in the experimental operation of a geothermal thermoelectric generator based on biphasic passive heat exchangers, with the objective of obtaining the maximum power generation and optimizing the occupied space. Furthermore, the objective is to demonstrate the viability of this kind of devices to harness shallow hot dry rock fields.

In Section 2, the heat exchangers are experimentally studied to select the best option for both the hot and cold sides. In Section 3, the results of the GTEG's experimentation are collected and finally, Section 4 contains the conclusions of the work.

II. CHARACTERIZATION OF THE HEAT EXCHANGERS

A. Hot side heat exchanger

The hot side heat exchanger is a biphasic closed thermosiphon with water as working fluid, which was characterized by applying a heat flux through its lower part and determining the temperature drop from the bottom to the top. Its thermal resistance was also calculated according to (1), by measuring its surface temperature, the ambient temperature and the heat flux passing.

$$(1) \quad R_{th} = \frac{T_{surf} - T_{amb}}{\dot{Q}}$$

The maximum temperature drop was from 160 ºC to 145 ºC, with a thermal resistance of 0.07 K/W for a 160 W heat flux, which shows the good performance of this heat exchanger.

B. *Cold side heat exchanger*

The cold side heat exchanger consists of four 500 mm long sintered heat pipes with a diameter of 8 mm inserted horizontally and then inclined in a 70×90mm^2 fins dissipater with a base 14.5 mm thick and fifteen 40×1.5mm^2 corrugated fins.

It was characterized with the same method in order to select the most effective geometry, which permits more compactness so that the visual impact is minimum. The result of the characterization was a thermal resistance value of 0.4 K/W, constant with the heat flux.

III. GENERATION RESULTS

Once proved that both the hot and cold side heat exchangers have low thermal resistance values and are appropriate for the geothermal thermoelectric generator, the complete generator was built. It was decided to build two prototypes, one with 10 modules and other with 6, in order to compare if the addition of thermoelectric modules increases the output power.

The generator was experimented in laboratory during 10 days under different hot source temperature and external convection conditions. Temperatures and power generation were measured as shown in Figure 1. The total generated power was of 36 W (17 W by a prototype with 10 modules and 19 W by a prototype with 6 modules) for a temperature difference of 160ºC between the heat source and the environment. The efficiency diminished from 4.06% in the prototype with 6 modules to 3.72% in the one with 10, showing the importance of compactness in these generators.

IV. CONCLUSIONS

In conclusion, this research has demonstrated experimentally the feasibility of thermoelectricity to generate electricity from high enthalpy geothermal anomalies in shallow hot dry rock fields. The generator developed in this work is capable of generating 36 W in total with a temperature difference between the heat source and the environment of 160ºC, without auxiliary consumption. In short, a passive generator that demonstrates the viability of this technology to take advantage of the natural resources as high enthalpy geothermal anomalies present in shallow hot dry rock fields and to provide electricity in a renewable and environmentally friendly way.

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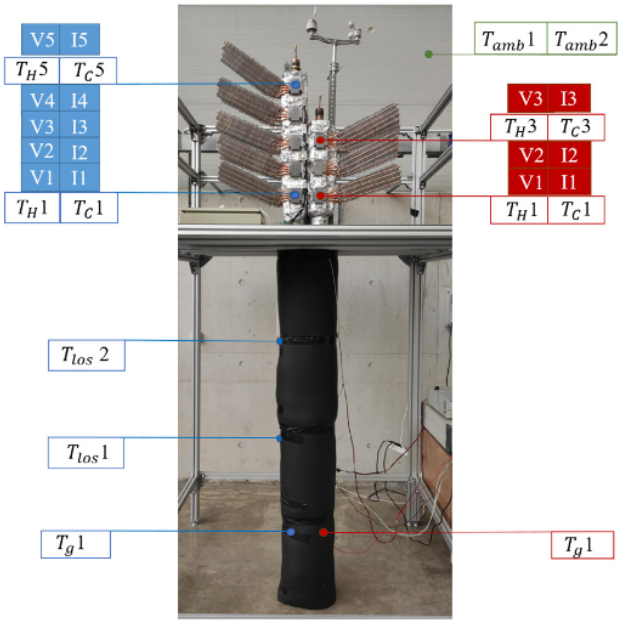

Figure 1. Complete prototype with measuring points in laboratory tests.

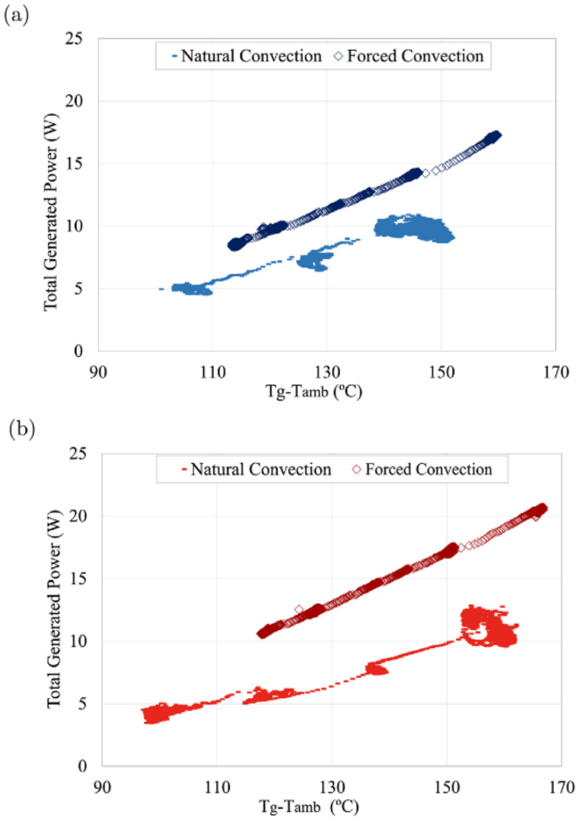

Figure 2. a) Total generated power by Prototype with 10 modules. b) Total generated power by Prototype with 6 modules.