Heat Sink Analysis and Effect of Different Cooling Systems on the Power Generated by a Thermoelectric Module

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This research studies the open circuit voltage produced by a thermoelectric generator module, under different heat sink coolers. Fins with natural convection as well as forced convection, and a water cooler were analyzed. Results showed that the higher voltage, 0.81 V, was produced by the water cooler configuration with 17 °C of temperature difference across the module, and 10.4 W of heat generated by a heater located under the thermoelectric. Future works in this research will be to calculate the efficiency of the energy conversion as well as the power generated by the thermoelectric module using solar radiation as a heat source, with the different heat sink configurations explored in this work.

I. Introduction

In the recent years the development of the thermoelectric (TE) materials has been of great interest due to their multiples applications [1], [2]. A TE is a solid state device that converts a temperature difference into voltage or vice versa. One of its applications is to generate power (TEG) by using a heat source like solar radiation [3], human body or heat wasted from car exhaust systems, furnaces, etc. Also, thermoelectrics can be used for cooling systems like: water and wine coolers, computers chips, lasers, etc. [4].

The main objective of this research is to simulate and measure the power generated by a TEG using a heater to simulate solar energy. In this work, the measurement system is assembled and the heat sink configuration is analyzed under three different cooler techniques. Also, a Polyimide Film heater is used as heat source with low power and low temperature difference across the TEG.

II. Experimental setup

The TEG module used in this work was a TG12-8L3411, which was placed between the heater and the cooler as is shown in Fig. 1. In order to decrease the heat losses, foam tape and an acrylic plate were used as insulators at the sides and bottom of the system. A thin layer of silicon thermal grease was applied at the top and bottom of the module to decrease the contact thermal resistance. Two 75 μm in diameter thermocouples type E were used to measure the hot side, T_h, and cold side, T_c, temperatures (see Fig. 1).

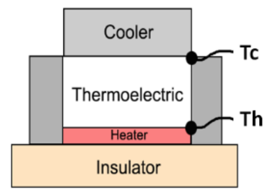

Fig. 1 Simplified experimental setup\

Three different heat sink cooler configurations were tested: 1) Fins with Natural Convection Configuration (FNCC), 2) the same Fins with Forced Convection Configuration (FFCC), with an air velocity of 45 cm/s; 3) Water Cooler Configuration (WCC).

A LabView code was developed to automatically apply the current, I, to the heater and measure the temperatures, voltage drop across the heater, V_{HE}, and voltage produced by the TEG, V_{TE}, until the steady state condition was reached. The current supplied to the heater was changed and tested for different values: 0.1, 0.3 and 0.5 A. The values of T_c, T_h, V_{HE} and V_{TE} were measured every 2.2 seconds during approximately 20 minutes to ensure the steady state condition. Then, the steady state values were used in the data reduction, as presented in the next section. In order to ensure the stability of the measurements, each experiment was performed twice and the differences in the measurements were evaluated.

The temperature difference, ΔT, was calculated as follows:

$$\Delta T = T_h - T_c. \quad (1)$$

The power of the heater, P_{HE}, was calculated as:

$$P_{HE} = V_{HE} \times I \quad (2)$$

III. Results and discussion

Fig. 2 shows the FFCC temperatures, T_h and T_c, during 20 minutes and a current of 0.5 A for the two repetitions. Initially both temperatures are equal to the ambient temperature. Then, after the heater is turned on, T_h increases faster than T_c due to the diffusion of the heat into the module. Finally, after approximately 600 seconds both temperatures reach the steady state condition. The graph shows the temperatures for the two repetitions under the same conditions. There was a great similarity between the values of T_h and T_c obtained in the two repetitions. Similar behavior appears in all the configurations and currents analyzed in this research, demonstrating the repeatability of the experiments.

Fig. 3 shows ΔT for a period of 20 minutes, for the three cooling configurations (FNCC, FFCC and WCC) and for a current of 0.5 A. Similar to Fig. 2, the temperature difference in Fig. 3 has a tendency to steady state conditions. The graph of the WCC has the highest slope demonstrating that water has better cooling performance than the air convection in the other two configurations. The FNCC shows a more irregular curve due to the changes in the ambient conditions caused by the air conditioner unit in the room. The ambient conditions affect the convection heat transfer coefficient, changing in this way the cooling performance of the FNCC.

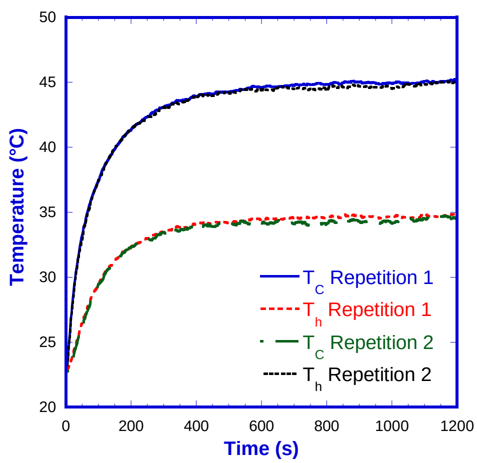

Fig. 2 Temperatures T_h and T_c, for the fins with forced convection configuration, a current of 0.5 A and for the two repetition tested.

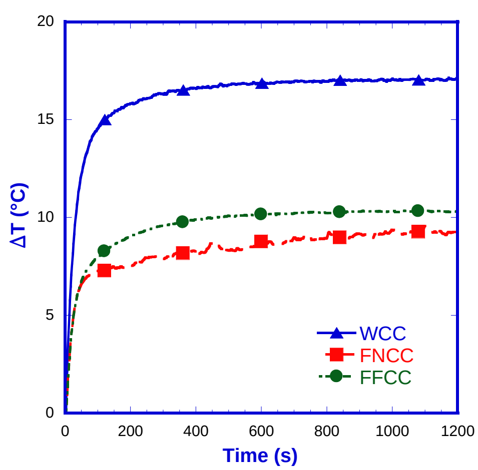

Fig. 3 Temperature difference for the three cooling configurations and for a current of 0.5 A.

Fig. 4 shows the TEG open circuit voltage, V_{TE}, against the heater power for the three cooling configurations. The graphs show that V_{TE} increases linearly with power. This is due to the linear correlation between ΔT and the power applied to the heater. The results show that the best cooling configuration is the water cooler, as expected, followed by the forced convection.

Finally, the maximum voltage produced by the water cooler configuration was 0.81 V for 17 °C of temperature difference, produced under a 10.4 W of power in the heater. It's important to mention that the power consumed by the pump was 10 W. This means that for power generation this device has a low efficiency. In a future work the optimum pump power, the power produced by the TE under an electrical load, and additional improvements will be explored.

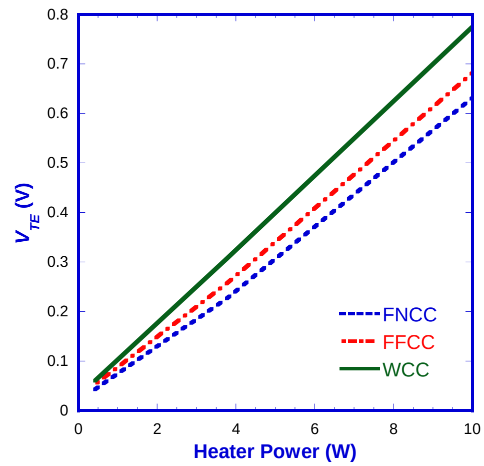

Fig. 4 Open circuit voltage vs heater power for the three cooling configurations and a current of 0.5 A.

IV. Conclusions

The open circuit voltage produced by a TE power generator was explored under different heat sink configurations. Water cooler configuration was found to be the best cooler mechanism, but the power consumed by it results in a very low energy conversion efficiency of the device. Future works will explore the power produced against the power consumed by the device. Also, higher temperature differences with the same power consumed will be evaluated.

References

[1] L. E. Bell, "Cooling, heating, generating power, and recovering waste heat with thermoelectric systems," *Sci.*, vol. 321, no. 5895, pp. 1457–1461, Sep. 2008.

[2] G. Chen, "Nanoscale heat transfer and nanostructured," *IEEE Trans. Compon. Packag. Technol.*, vol. 29, no. 2, pp. 238–246, 2006.

[3] R. Amatya and R. J. Ram, "Solar thermoelectric generator for micropower applications," *J. Electron. Mater.*, vol. 39, no. 9, pp. 1735–1740, 2010.

[4] H. Xi, L. Luo, and G. Fraisse, "Development and applications of solar-based thermoelectric technologies," *Renew. Sustain. Energy Rev.*, vol. 11, no. 5, pp. 923–936, Jun. 2007.