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PERFORMANCE ANALYSIS OF PELTIER PELLETS IN DIFFERENT OUTPUT

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Abstract. *In this work, analysis of the data are provided for a Peltier module, built with a heatsink, in a polystyrene box of 11x19x14 cm in size. An estimation for the COP and the heat loss in the thermoelectric cooling device are also presented for different configurations. The temperatures were measured using digital sensors which are presented in different configurations by the use of a variable power supply. Furthermore, the serial and individual configurations with two Peltier were tested for comparison.*

Keywords: *Peltier Effect, heat transfer, experimental analysis, thermoelectric cooling*

1. INTRODUCTION

Peltier pellets are thermoelectric circuits that when applied to a voltage generates a current and causes a temperature gradient. The pellet is named after the Peltier Effect, discovered by the German physicist Jean Charles Peltier using the Seebeck effect of Thomas Johann Seebeck. The Seebeck effect constitutes a voltage differential by the joining of two different materials and temperatures. This difference of induced voltages causes a current and electrical power to be produced, consequently, a temperature gradient along the material. This phenomenon gives rise to the Peltier effect, when one side generate and the other absorbs heat by the surface of this semiconductor material. Thus, the heat absorption is positive when the current travels from n-type semiconductor to p-type. The Peltier modules have been employed in various cooling applications of small size device and portable equipment. Furthermore, the Peltier Effect have been study because it can convert waste electricity into useful cooling or heating system (Incropera, 2014).

The Peltier's modules it shows interesting for many applications, however, with low coefficient of performance (COP) around 0.3, its projects become limited. But we could find many situations the Peltier's pellets stand out. Caroff et al. (2015) quote solutions to refrigerate chips from helicopters controllers. Systems that only a heatsink, by the air convection, are not enough to ensure the right chip's temperature. In another hand, we could associate a few Peltier's pellets in serial, as Dizaji et al. (2019) research, they analyze the gain in the air-cooling system with association between some modules and shows that the COP for the associated systems are improve so that can be competitive with a compressor-based air-coolers.

Gao Min and Rowe (2006) studied how to improve a thermoelectric refrigerator. They observed an increase in the COP with the improvement in the contact resistance, thermal interface and the effectiveness of heat exchangers. Also, it is important to consider the hot surface refrigeration. That side can't be too hot, because the of ΔT between hot and cold surfaces can't extrapolate 75 °C, which, otherwise, could compromise the performance and lifetime of the pellet. This is also clear in the research of Roj and Katenbrink (2015) and Mirmanto et al. (2018), with their study using a thermoelectric air-cooling system with different heat dissipation apparatuses. They showed a great influence of the heat dissipation in the COP. Mirmanto et al. (2019) study the position of thermoelectric in the performance of the cooling system. I accordance with the results, the best position for the thermoelectric was in the wall.

Also, Jugsujinda et al (2010) in analysis with various power input, describes that COP varies according from input power in thermoelectric (TE). The component, in lower power, gets better COP, but the temperature difference gets higher between hot and cold surfaces. Exists an optimal power input that the Heat absorbed are higher.

In a mathematical model, Yu and Wang (2008), simulated maximum coefficient of performance of thermoelectric cooling modules using cascaded method. The results are that multiple peltier modules are better than a single TE, but for each TE, higher is the cost. For two Peltier modules, COP is 25.2% higher than a single and for three are 35.8%.

The main purpose of this study is to investigate the performance of thermoelectric cooling system with different settings input power and different associations of Peltier modules to observe the capability to draw heat from a reservoir. For this, a series of experiments were carried out in a cooling air system into a small box.

2. METHODOLOGY

The experimental setup is described in Fig. 1. It consists of a polystyrene box with 11x19x14 cm, a Peltier module with two heat exchangers on each side, a power supply and four temperature sensors. Two digital temperature sensors DS18B20 with a ± 0.05 error are used for the hot and cold surface of the Peltier module. One K-type thermocouple with a ± 1.0 error for the temperature inside de box. The ambient temperature outside the box, was obtained from a portable temperature meter using K-type thermocouple with ± 1.0 error. For the data acquisition was used an Arduino interface and a Matlab software.

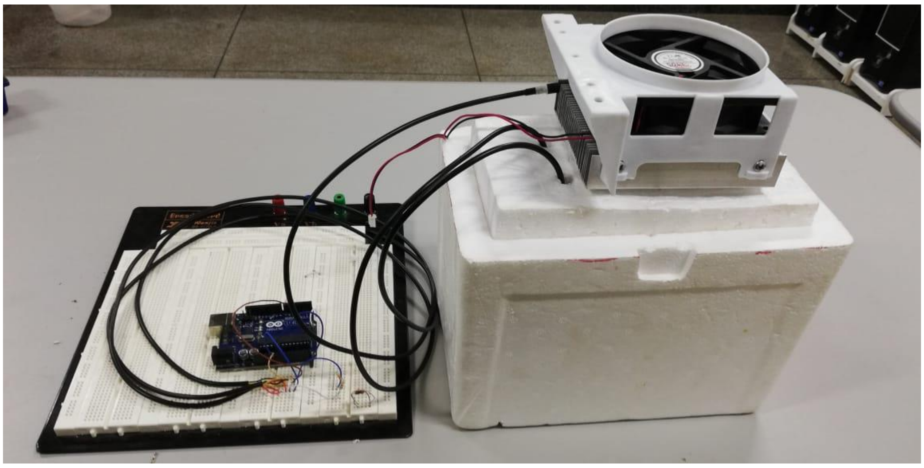

Figure 1. Data acquisition and the refrigeration system mounted.

The study consists of using the Peltier module for cooling a volume of air inside the insulated box. In the experimental setup, was used three different input to remove heat from the air inside the system, varying the amount of power to thermoelectric pellets,70 Watts (14 V, 5A), 49.2 Watts (12 V, 4.10 A) and 36 Watts (10 V, 3.6 A), and attached more than one Peltier module with different electrical arrangement, serial and connected individually. For the hot side and the cold side was used a heat transfer system formed by a heatsink and fan, Fig. 2 and Fig. 3.

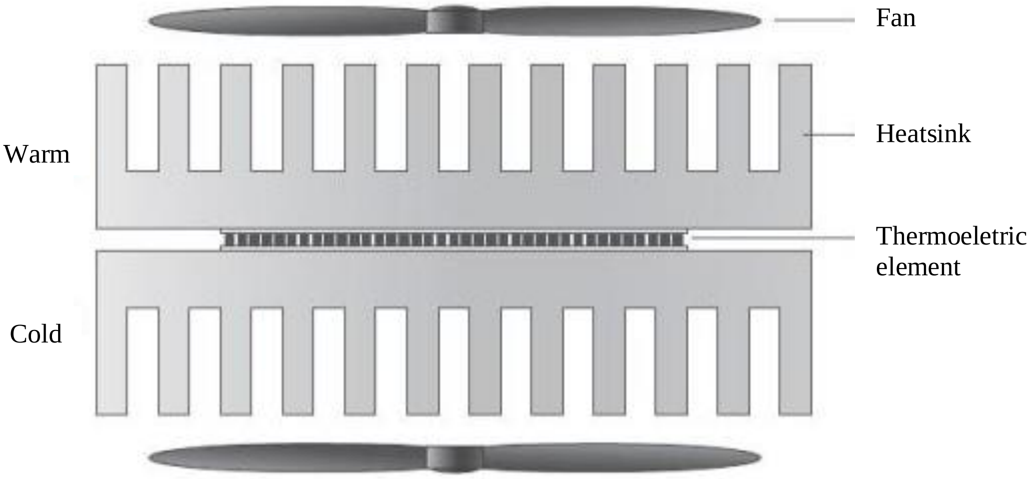

Figure 2. System illustration with one Peltier module.
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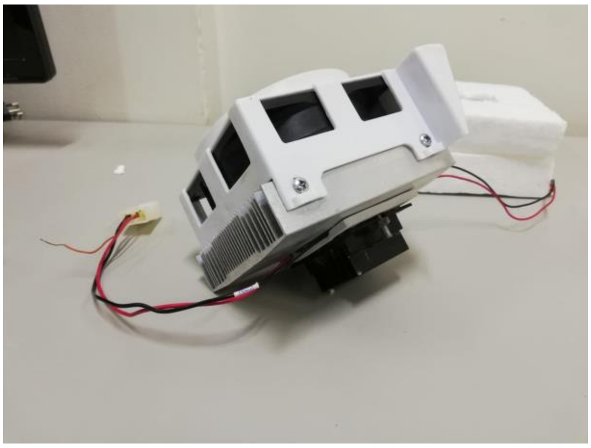

Figure 3. Peltier with heatsink system.

The association are made physically by putting one Peltier module in contact to another, the cold surface refrigerating the internal hot surface of another module, and electrically, the serial association is made connecting the positive terminal of the first module to a negative terminal of second module and, the positive and negative left over are connect on the source, and, for individually association, both modules are connected individually at the source.

With all the temperatures in balance, the system is started using the variable DC power supply, and the data is acquired for 30 minutes, till the steady state. Data acquisition would be repeat about three times each power input. We will test que cooling capacity of the system to a several configurations of voltage and current with a single peltier module.

Decided the best value of input power for one module, the test will be running with the two Peltier module attached one over another and electrically arranged at serial and individually connected.

To determinate the best solution, we will measure the temperature inside the box over the time and calculate the coefficient of performance (COP) that can be calculated from Eq. (1).

$$COP = \frac{Q}{P} = \frac{Q}{V \cdot I} \tag{1}$$

Where *COP* is coefficient of performance, *Q* is the amount of heat absorbed, *P* the potency, *V* the voltage and *I* current.

Based on the first thermodynamic law, we could determine the amount of heat absorbed by the pellet. Considering one substance with constant composition, with a single phase of state, and a constant pressure. The amount of heat can be calculated from Eq. (2).

$$Q = m \cdot cp \cdot \Delta T \tag{2}$$

Where *m* is mass, *cp* is specific heat at constant pressure and *T* is temperature.

Other parameter that can be measure is the amount of heat loss. For this we compare all heat that was necessary to achieve the temperature inside the box with a hypothetic situation in which the temperature inside is the same temperature of the cold side surface.

3. RESULTS

The Figures 4, 5 and 6 show the temperatures of the hot and cold side of the Peltier module and the air inside the box over time. These results are for the case study with one Peltier cell with 36 W, 49.2 W and 70W. With 36 W, we got 27.28 ºC for hot heatsink, 8.43 ºC inside the box and 3.37 ºC on cold heatsink, with 21.9 ºC of room temperature, resulting in 13.46 ºC of ΔT. With 49.2 W, we got 34.6 ºC for hot heatsink, 14.52 ºC inside the box and 5.52 ºC on cold heatsink, with the room temperature around 26.3 ºC, resulting in 11.77 ºC of ΔT. And for 70 W, with 21.87 ºC of room temperature, 33 ºC for hot heatsink, 9.06 ºC for air inside and 2.85 ºC for cold heatsink's temperature, resulting in 12.81 ºC of ΔT.

Figure 7 shows all the COP for three input powers over the time, the COP for 36 W experiment is higher duo to your low temperature allied with low power consumption.

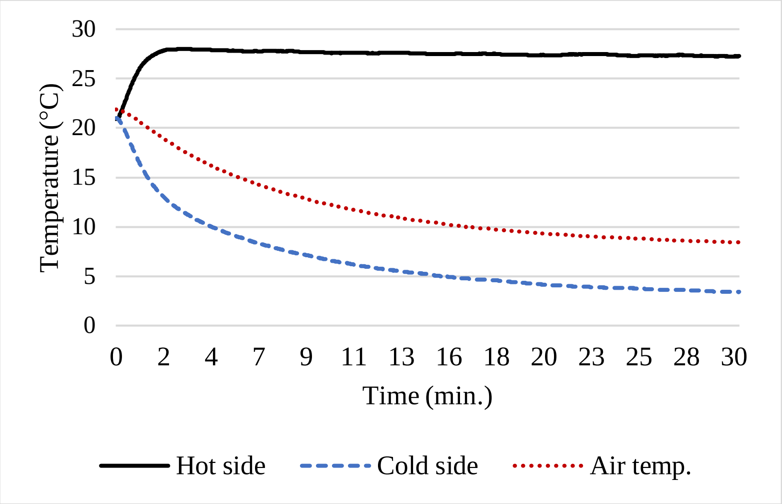

Figure 4. Results of the characteristic curve for the first method from 36 W.

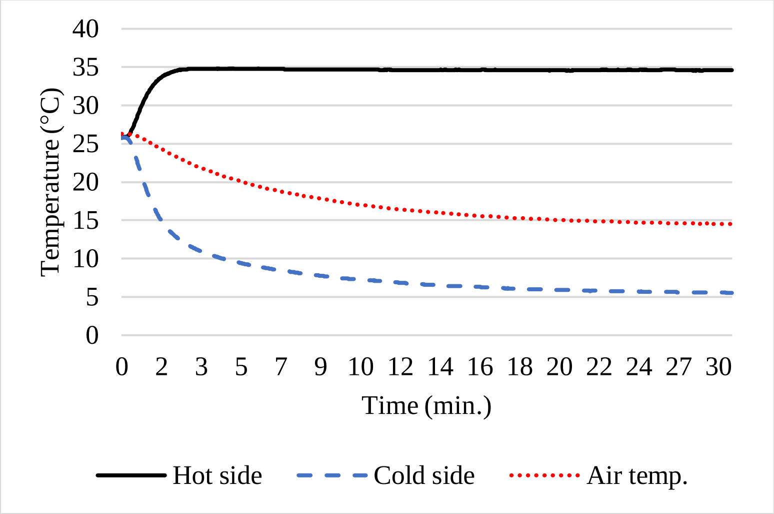

Figure 5. Results of the characteristic curve for the first method from 49.2 W.

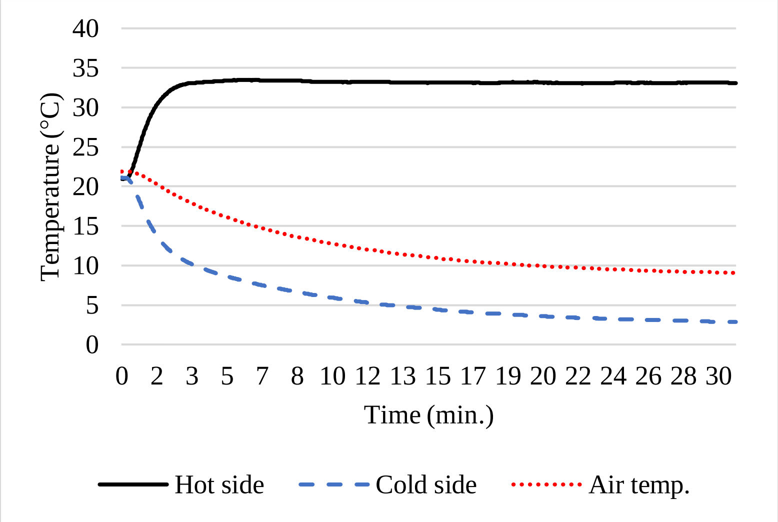

Figure 6. Results of the characteristic curve for the first method from 70 W.

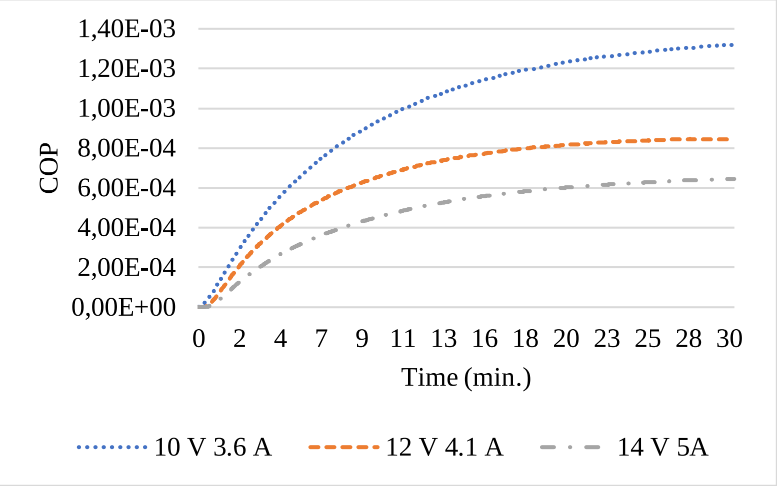

Figure 7. COP for each input power.

As we can see, the best option becomes use the modules with 10 V and 3.6 A to refrigerate the air. We got lower temperatures with lower electrical power, which cause better coefficient of performance. For the next experiments we determinate use, for modules associations, 10V.

For serial association, the internal resistances are summed and therefore setting the voltage, the amount of power consumed are lower than a single module, 3.6A to 2A.

Figures 8 and 9 shows the characteristic curve for serial association and individually connected. On serial arrangement, we got 21.66 ºC for hot heatsink, 4.85 ºC inside the box and -3.04 ºC on cold heatsink, with the room temperature around 19 ºC, resulting in 14.2 ºC of ΔT. Connected individually, with 17.49 ºC of room temperature, the result is 30.83 ºC for hot heatsink, the air inside is 7.47 ºC and 0.75 ºC for cold heatsink's temperature, resulting in 9.98 ºC of ΔT.

Compared to a serial arrangement, the air reached lower rates on individual arrangement. Even compared to a single module, serial association got lower air temperatures and higher ΔT. However, individually we got higher air temperature, thus ΔT lower. Even with higher electrical power, the individual arrangement got lower cooling performance.

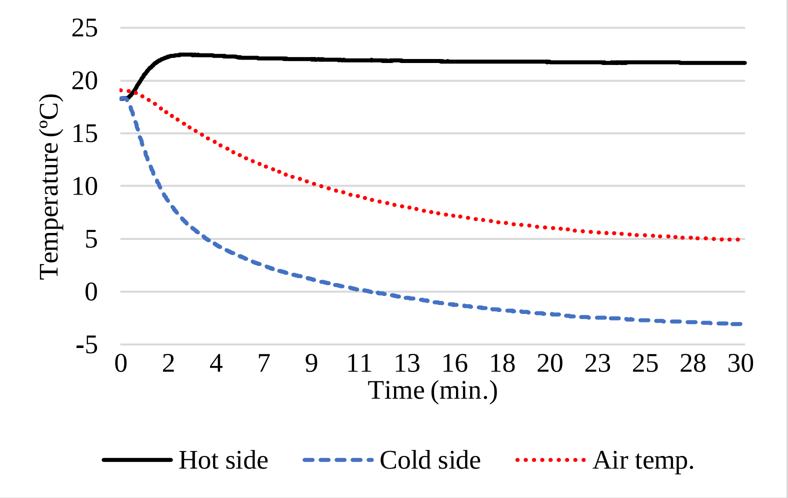

Figure 8. Results of the characteristic curve for the first method from serial association.

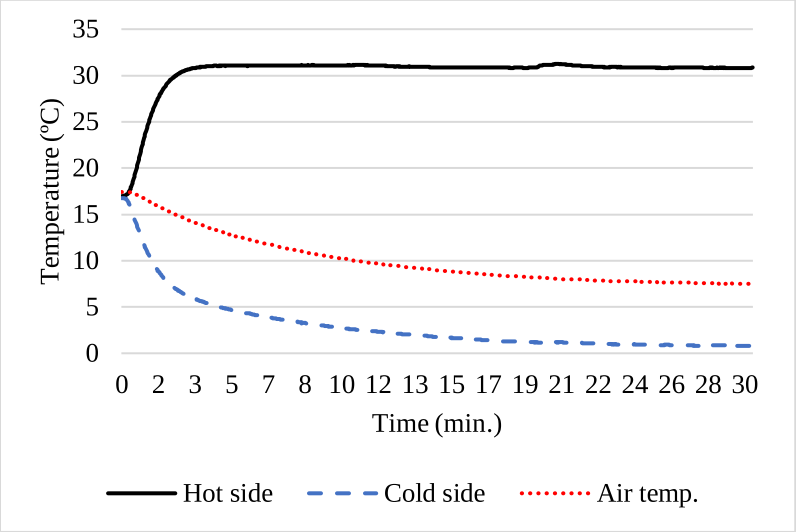

Figure 9. Results of the characteristic curve for the first method from individual association.

We can analyze the last result compared to those with only one module from Fig. 10 with all COP and observe that the serial arrangement is clearly the most efficient choice.

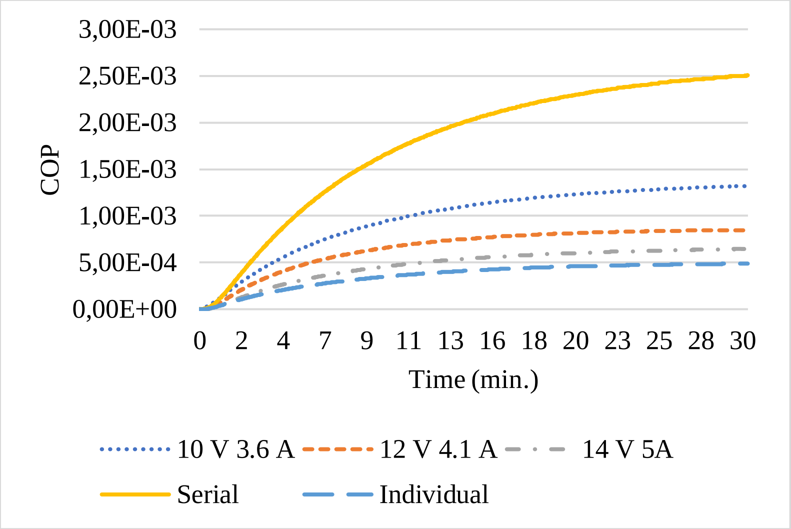

Figure 10. COP for all input powers.

For ideal situation, the temperature inside de box should be same of the Peltier's cold surface but the setup has heat losses between the box's wall material, fittings and grooves between the cover insert interfaces, that decrease inside's temperatures. Using Eq. 2 and Energy balance we calculate heat loss amount. The Tab. 1 shows the input power of the experiments, heat absorbed along this time and the quantity of heat loss, calculated with Eq. 2.

Table 1. Quantity of heat.

Input	Quantity of heat absorbed (kj)	Quantity of heat loss (kj)
10 V 3.6 A (36 W)	-0,04747	-0,01784
12 V 4.1 A (49.2 W)	-0,04149	-0,03172
14 V 5 A (70 W)	-0,04515	-0,02188
Serially connected	-0,05008	-0,02798
Individually connected	-0,03518	-0,02364

Thus, with a single Peltier module, not necessarily higher input power will represent lower inside temperatures, ΔT nor higher COP. With 36W we got better results over 49.2 W and 70 W consuming less electrical power. Still, the serial setup shows better results than the other arrangements, with lower air temperatures and lower consumption.

4. CONCLUSION

In this paper, was determinated the optimal method to extract the major quantity of heat for the system. Between those three experiments, with one module at time, the best result was achieved with 36 W, consuming less electrical power. Applying the same voltage for two modules at same time and we observe that for serial setup it shows better results than the other arrangements, again, consuming less and higher cooling capacity, however, for two modules individually connected at the source, it is important to note that even consuming much more power, it's has poor performance compared to 14 V and 5 A, which becomes unproductive to use this arrangement to refrigerate any substance.

5. ACKNOWLEDGEMENTS

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