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ANALYSIS OF THE THERMOELECTRIC POTENCIAL OF A HOMEMADE PELTIER REFRIGERATION SYSTEM UNDER DIFFERENT ELECTRICAL OPERATING CONDITIONS

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Abstract. *Peltier Effect cells and tablets represent a modern application of semiconductors. These thermoelectric components, when traversed by an electric current, transfer heat from one of their faces, dissipating it on the opposite face and promoting a thermal gradient widely explored in compact cooling systems, combined with ventilation and heat dissipation devices. Such refrigeration systems have a good service life and do not require the use of conventional refrigerants. A compact homemade thermoelectric cooling system was developed to analyze the influence of different voltages (9 V, 12 V and 15 V) on three models of commercial Peltier tablets (TEC1-12708, TEC1-12710 and TEC1-12715). Designing thermoelectric systems requires considering, in addition to the heat transfer phenomena involved, the cooling power provided which, in turn, is associated with the electric current and potential difference applied. The tests carried out expose the suitability of system as a refrigerator, operating, in the best test, with a temperature reduction of 11.7°C over 25 minutes, with the TEC1-12708 combination, 12 V and 3.45 A. Others results, negatively affected by the technical unreliability of the tablets and individual incompatibility of ventilation and thermal dissipation system, present significant resolutions, although with inferior results.*

Keywords: *Peltier Effect, electric current, heat transfer, refrigerator, experimental tests.*

1. INTRODUCTION

The technological development motivated by the industrial revolutions culminated in the advancement of thermodynamic sciences and, consequently, in the improvement of refrigeration techniques and discovery of new systems capable of removing heat from surfaces for temperature reduction or thermal control (Menna, 2008).

Conventional steam refrigeration thermal systems are equipped to carry out this process through the evaporation of a refrigerant fluid with particular thermal properties (Martinho, 2013).

Within this area, and with a bias towards thermoelectricity, Peltier tablets exploit one of the thermoelectric effects to provide temperature differences in compact refrigeration systems (Silva, 2010). Peltier tablets are devices that use semiconductor technology to transfer heat and their efficiency in thermal systems of this nature is influenced by the available electrical and thermal load of refrigeration compartment (Rufino, 2016).

Although the thermal efficiency of Peltier tablets does not surpass other cooling methods, this device has been widely used in portable and small systems (Moura, 2010), such as small refrigerators, wine cellars, laboratory equipment in health area and microprocessor cooling, for example (Silva, 2017).

In short, the versatility of Peltier tablets, as a thermoelectric device for controlled cooling, made them an attractive option in different scenarios, resulting in this research, which proposes to relate and evaluate the influence of three different electrical voltages permissible for operation, applied to three models of tablets commercially offered and installed in a house manufactured thermal enclosure. The objective is to obtain a comparison between the tests, in relation to the decay and thermal potential generated under the same initial conditions of analysis, as well as to select the combination of tablet and electrical voltage most appropriate for the technical and thermodynamic parameters of the thermal compartment manufactured.

2. THERMOELECTRIC EFFECTS AND REFRIGERATION

Thermoelectric effects are characterized by the conversion between thermal and electrical energy, according to Moraes and Guilherme (2020). The most notable effects will be described below.

The Seebeck Effect, applied in thermocouples (Gomes, 2008) and discovered by Thomas Seebeck in 1821, is basically the generation of electrical voltage at the junction of semiconductors exposed to different temperatures (Silva, 2017). The Peltier Effect, prestigious in this project, presents an inverse phenomenon to this one (Moura, 2010). The Thomson Effect (1851), in turn, verifies the relationship between the Seebeck and Peltier Effects and the absolute temperature, generalizing the fact that in a given metallic junction, the direction of the applied current can cause different thermoelectric effects (Gomes, 2008).

The advancement of semiconductor technologies in the 20th century allowed the thermoelectric effects discovered to be introduced into relevant applications in society, especially in refrigeration with Peltier Effect tablets, according to Gomes (2008).

2.1. Peltier Effect

Peltier tablets are based on the effect discovered in 1834 by Jean Charles Peltier (Fernandes, 2012). In the Peltier Effect, a temperature gradient is generated at the junction between two semiconductor materials when an electric current flows through them (Almeida, 2015). Heat transfer is due to the movement of electrons, and occurs from the cold side to the hot side (Rufino, 2016).

In the tablets, the heat Q_π , in joules (J), pumped in the junction of semiconductors A (represented in red color) and B (represented in blue color), as shown in Figure 1, when subjected to the passage of electric current I , in amperes (A), is defined by Eq. (1) (Júnior, 2019).

$$Q_\pi = \pi_{AB} \cdot I \cdot t \tag{1}$$

Where π_{AB} , the *Peltier coefficient* measured in volts (V), is positive when joint 1 is heated and joint 2 is cooled down, and t is the time the system remains on, measured in seconds (s).

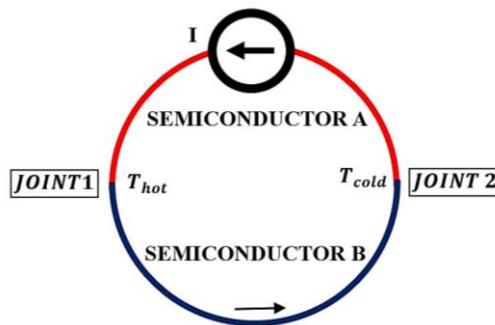


Figure 1. Scheme of Peltier Effect.

3. TABLETS AND PELTIER MODULE

Peltier tablets are devices composed of semiconductor materials with thermoelectric properties, such as bismuth telluride (Bi_2Te_3) doped with Selenium in the N-type and Antimony in the P-type (Fernandes, 2012), which are connected electrically in series and thermally in parallel (Moraes and Guilherme, 2020).

This thermoelectric device has two ceramic sides, or faces, which are the junctions of semiconductors. Through the passage of electric current, the movement of electrons from N-type elements to P-type elements occurs, causing heat transfer through the absorption of heat from the cold face and dissipation on the hot face, as shown in Figure 2 (Rufino, 2016).

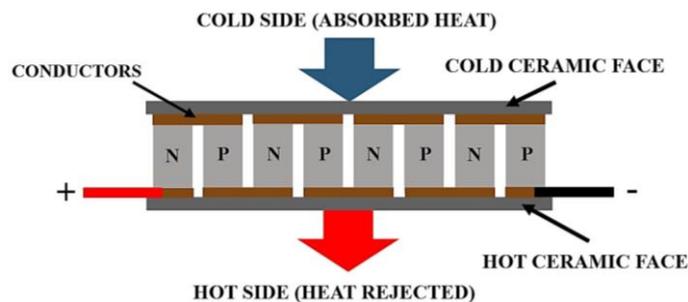


Figure 2. Scheme of how a Peltier tablet works.

During operation, Peltier tablets dissipate high rates of heat on the hot side (Júnior, 2019), which implies the design of additional thermal dissipation systems, mounted on a module and with the aim of preventing the device from overheating (Gomes, 2008).

Some equipment is conventionally used for thermal dissipation and guaranteeing safe operating limits, such as heat sinks (Silva, 2021), computer fans (Silva, 2017) and thermal paste (Fernandes et al., 2010).

Heat sinks are usually made of high thermal conductivity materials and dissipate heat to the environment due to the increased heat transfer area in their finned extensions (Silva, 2021). The fans, in turn, operate together with the heat sinks, directing an air flow in this direction and increasing the thermal exchange (Júnior, 2019). At the interfaces between these components, the application of thermal paste fills contact irregularities and improves heat conduction between their surfaces (Fernandes, 2012). Moura (2010) reiterates that a good performance of cooling systems of this nature must contain a ventilation and dissipation system capable of maintaining the temperature of the hot sink between 10 and 20°C above the ambient temperature.

In this way, conventionally, the Peltier module can be built with a larger heatsink and a powerful and continuous ventilation system for the hot face of tablet (Júnior, 2019) and a smaller heatsink (preferably of same dimensions as the tablet) with ventilation, for the cold side, which faces the interior of the thermal compartment (Fernandes et al., 2010).

4. EFFICIENCY IN PELTIER THERMOELECTRIC SYSTEMS

The *coefficient of performance* (COP) is an important dimensionless parameter of efficiency in refrigeration systems (Halliday et al., 2012), as it relates the heat transferred Q , in joules (J), with the energy consumed in the refrigeration process W , in joules (J), according to Eq. (2) (Silva, 2019).

$$COP = \frac{Q}{W} \quad (2)$$

In thermoelectric systems, such as this one that uses the Peltier Effect tablet, the analysis of results will be obtained with the compartment empty, that is, for the calculations, it was thought that the heat transferred by the system Q is proportional to the variation in the sensible heat of internal air during the process Q_{air} (in joules (J)) and depends on the observed temperature difference ΔT (in Celsius (°C)), the air mass \bar{m}_{air} (in kilograms (kg)) and the specific heat of internal air \bar{c}_{air} (in J/(kg·°C)), both at average temperature, according to Eq. (3) (Borgnakke and Sonntag, 2013).

$$Q_{air} = \bar{m}_{air} \cdot \bar{c}_{air} \cdot \Delta T = Q \quad (3)$$

The air mass is obtained through its specific mass $\bar{\rho}_{air}$ (measured in kg/m³) at average temperature and ambient pressure; and of the volume V_{air} that it occupies in the thermally controlled container, measured in m³, according to Eq. (4) (Borgnakke and Sonntag, 2013).

$$\bar{m}_{air} = \bar{\rho}_{air} \cdot V_{air} \quad (4)$$

The energy consumed in refrigeration with Peltier tablets is the electrical power used by the tablet in the process E (in joules (J)), related to the applied voltage U (in volts (V)), the electrical current i (in amperes (A)) and the time required t (in seconds (s)), neglecting the portion of fans that is tiny and following the Eq. (5) (Halliday et al., 2016).

$$E = U \cdot i \cdot t = W \quad (5)$$

The calculation of *Carnot Efficiency* η_{Carnot} is also fundamental to identify the maximum efficiency of a thermal system, and the Eq. (6) relates it to the final temperature of refrigerated compartment (internal) T_f and the initial temperature (external environment) T_i , both measured in Kelvin (K) (Halliday et al., 2012).

$$\eta_{Carnot} = 1 - \frac{T_f}{T_i} \quad (6)$$

5. MATERIAL AND METHODS

The methodology applied in the domestic construction of refrigerator compartment, although not included in the scope of research, guides the means used to obtain the best and most intelligible results in the analysis of the thermoelectric potential of models of tested Peltier tablets.

The refrigerator was made with an expanded polystyrene (EPS) box with a volumetric capacity of 5 liters (0.005 m³), machined superiorly for the module, in which a front cover of same material, contoured with foam and laterally

articulated, was installed. The set as a whole was coated and thermally insulated with layers of EVA (Ethylene Vinyl Acetate), of different thicknesses, and sheets of aluminum foil, as shown in Figure 3, to prevent heat transfer by conduction and thermal radiation, respectively (Moraes and Guilherme, 2020). The insulation layers were united with specific glues to guarantee the most perfect adhesion with the adjacent layer.



Figure 3. Coating and thermal insulation of box and front cover made of expanded polystyrene (EPS).

The ventilation system consists of computer fans of the model 60 mm x 60 mm x 25 mm, powered by 12 V, rotation of 523.6 rad/s and air flow of 0.011 m³/s. As for dissipation, are used heat sinks: the hot side receives a sufficiently large one and made of aluminum and copper, equipped with two computer fans; and the cold side, a heat sink made of aluminum, the same dimensions as the Peltier tablet, high enough to penetrate the layers of insulation on the upper wall, and equipped with a computer fan. The ventilation and thermal dissipation system devices are shown in Figure 4.



Figure 4. Elements of dissipation and ventilation system used.

The Peltier module in Figure 5 is assembled with an MDF (Medium-density fireboard) structure, dyed white and that compresses the Peltier tablet against the heat sinks. On both sides of tablet, thermal paste is applied for contact with the respective heatsink.

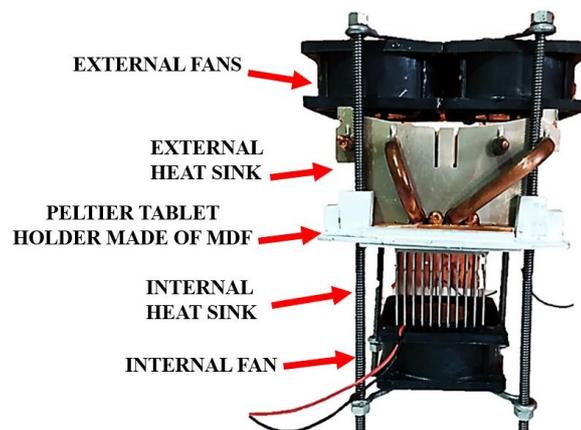


Figure 5. Manufactured Peltier module.

The Peltier module is seated and fixed to the upper part of the box, in order to favor the circulation of convection currents generated by the ventilation inside. Externally, the location of Peltier module is contoured with reflective tapes, in order to mitigate unwanted transfers of heat by radiation coming from the hot sink and directed to the thermal insulation of refrigerator compartment.

The thermal measurement is measured by a digital thermometer with an LCD screen (Liquid Crystal Display), shown in Figure 6, installed in an external capsule, and with a reading probe facing the lower internal environment.

Additionally, a front cover locking system is inserted to completely seal the compartment and an internal grid is used to reduce measurement interference in the thermometer.



Figure 6. Thermometer with LCD display and remote sensor used.

The finalization of assembly of the project is shown in Figure 7, already in the laboratory environment of the University.



Figure 7. Refrigerator already assembled in the laboratory environment.

Obtaining the thermal analysis of compartment was carried out in the laboratory environment of the University of Western São Paulo - UNOESTE, more specifically in the Instrumentation and Electro-electronics Laboratory (IEE), located at Campus 2. The tests were carried out with the Peltier tablets TEC1-12708, TEC1-12710 and TEC1-12715, shown in Figure 8, and which operate with up to 15.4 V of voltage, and 8 A, 10 A and 15 A of electric current, respectively. Its overall dimensions are 40 mm x 40 mm and 3.5 mm thick.

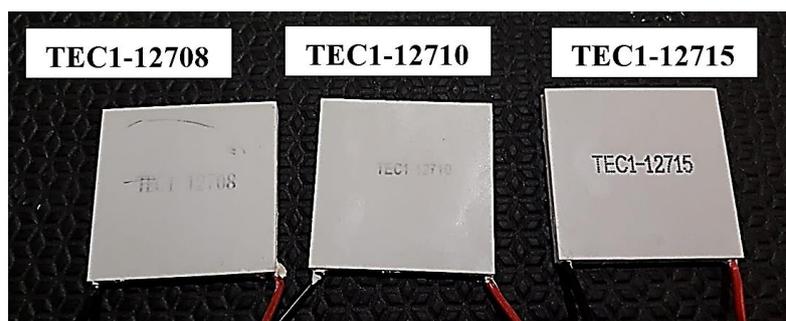


Figure 8. Peltier tablets models purchased for use in the analysis.

The ventilation system was powered, in all cases, with a dual voltage source of 12 V and 10 A, with the fans connected in parallel. In the case of tablets, they were replaced in the Peltier module manufactured to check the different voltages of 9 V, 12 V and 15 V.

The replacement of tablet, shown in Figure 9, obeyed the predetermined parameters of module compression and cleaning and reapplication of thermal paste on both contacts with the heat sinks.

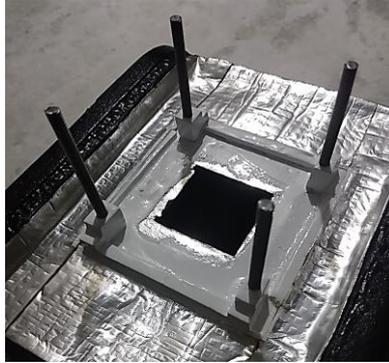


Figure 9. Peltier module cleaning for tablet replacement.

A 30 V - 3 A bench regulating source was responsible for feeding the tablets in the project during the nine tests, carried out in a time interval of 25 minutes each, as shown in Figure 10.

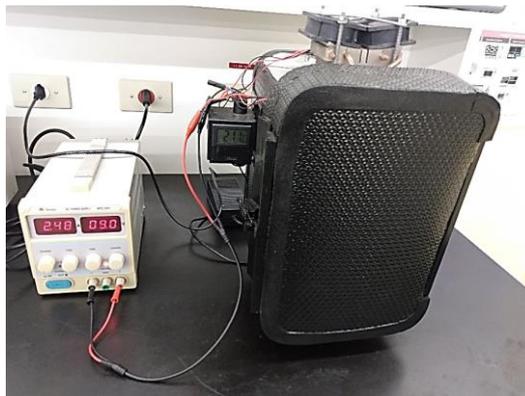


Figure 10. First test of TEC1-12708 with a 9 V power source.

It is noteworthy that the source display informed the operating current of Peltier system in the test and that, when the electrical current flowing through the tablet was greater than that provided by the source, a parallel connection between two sources was performed, as exemplified in Figure 11. In this case, the electrical operating current is the sum of those presented in the displays of bench regulating sources.

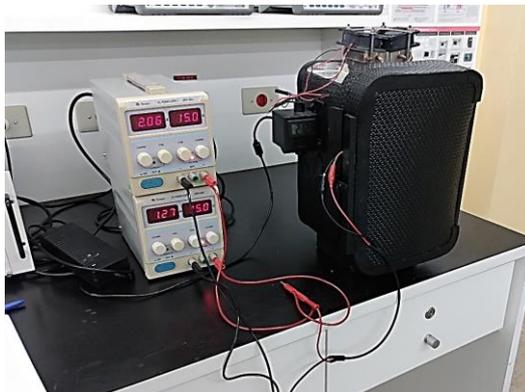


Figure 11. Last test of TEC1-12715, with two sources connected in parallel for the 15 V supply.

Each test started when the temperature inside the compartment, with the cover open, was balanced with the ambient temperature of laboratory, around 24.6°C. Soon after stability, the ventilation system was activated, the cover was closed and then the selected tablet was turned on with its respective analysis voltage.

Thermodynamically, heat is transferred from the inside of compartment to the outside environment, that is, there is a reduction in its internal temperature, which characterizes it as a refrigerator.

Minute by minute, the temperature observed on the thermometer of the outer capsule of refrigerator was recorded and the thermal variation was analyzed, in order to construct future graphic representations.

6. RESULTS

The system as a whole and its effectiveness with different models of Peltier tablets and operating stresses was evaluated with the empty container. The initial temperature of compartment, in all tests, was found to be 24.6°C, in stability with the ambient temperature of laboratory, and was evaluated over 25 minutes.

The internal volume of compartment is approximately 0.0046 m³ (4.6 liters) due to the internal insulation layers.

The specific heat of air \bar{c}_{air} at atmospheric pressure and 20°C (approximately the average temperature) is approximately 1007 J/(kg·°C).

The specific mass of air $\bar{\rho}_{air}$ is found from the average temperature parameters between that obtained and the ambient temperature of each test at 475 m above sea level (altitude of the University) and relative humidity of 20% (approximation of the interior of compartment).

By observation, the steady state in all system combinations began around minute 23 (after 1320 seconds).

The operating temperature, voltage and current results obtained with the TEC1-12708 tablet in the transient regime are presented in the graphical representation of Figure 12.

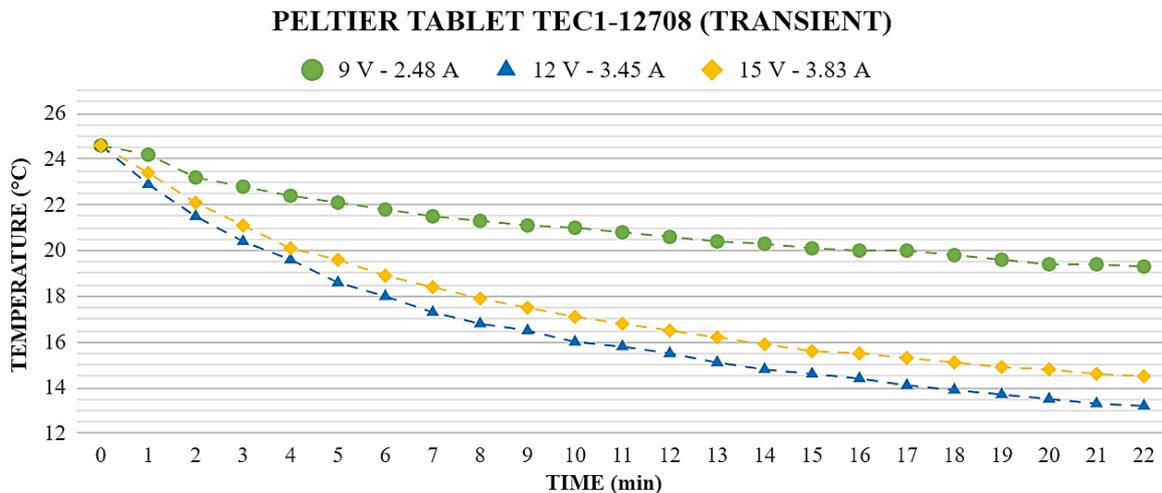


Figure 12. Graphical representation of TEC1-12708 operation in transient regime.

The operating temperature and *coefficient of performance* (COP) results obtained with the tablet TEC1-12708 in steady state are presented in the Table 1.

Table 1. Steady-state characteristics, *coefficient of performance* (COP) and *Carnot Efficiency* (η_{Carnot}) of system with TEC1-12708.

TEC1-12708	AVERAGE STEADY STATE TEMPERATURE	AVERAGE COMBINATION TEMPERATURE	$\bar{\rho}_{air}$	COP	η_{Carnot}
9 V – 2.48 A	19.167°C	21.883°C	1.125 kg/m ³	$0.961 \cdot 10^{-3}$	1.825%
12 V – 3.45 A	12.933°C	18.767°C	1.138 kg/m ³	$1.126 \cdot 10^{-3}$	3.918%
15 V – 3.83 A	14.300°C	19.450°C	1.135 kg/m ³	$0.714 \cdot 10^{-3}$	3.459%

On the other hand, the TEC1-12710 tablet presented the following results in a transient regime (0 - 22 minutes), shown in the graphical representation of Figure 13. The voltage obtained in the last test was 14.5 V for a current of 6.08 A was considered convenient, to avoid connecting another source in parallel.

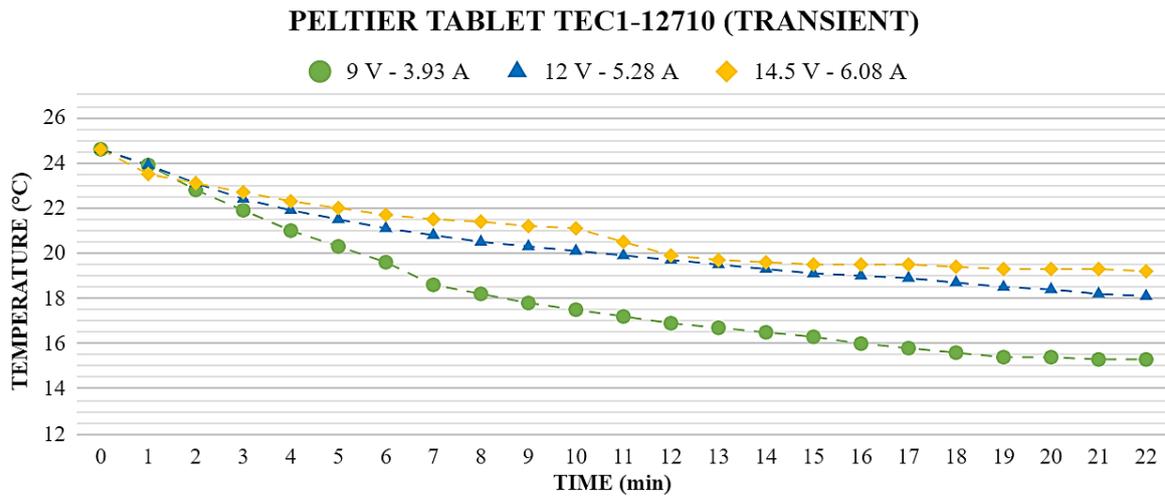


Figure 13. Graphical representation of TEC1-12710 operation in transient regime.

The operating temperature and *coefficient of performance* (COP) results obtained with the tablet TEC1-12710 in steady state are presented in the Table 2.

Table 2. Steady-state characteristics, *coefficient of performance* (COP) and *Carnot Efficiency* (η_{Carnot}) of system with TEC1-12710.

TEC1-12710	AVERAGE STEADY STATE TEMPERATURE	AVERAGE COMBINATION TEMPERATURE	$\bar{\rho}_{air}$	COP	η_{Carnot}
9 V – 3.43 A	15.100°C	19.850°C	1.134 kg/m ³	$1.069 \cdot 10^{-3}$	3.191%
12 V – 5.28 A	17.800°C	21.200°C	1.128 kg/m ³	$0.425 \cdot 10^{-3}$	2.284%
14.5 V – 6.08 A	19.200°C	21.900°C	1.125 kg/m ³	$0.242 \cdot 10^{-3}$	1.814%

For the TEC1-12715 tablet, the transient regime results (0 - 22 minutes) are shown in the graphical representation of Figure 14.

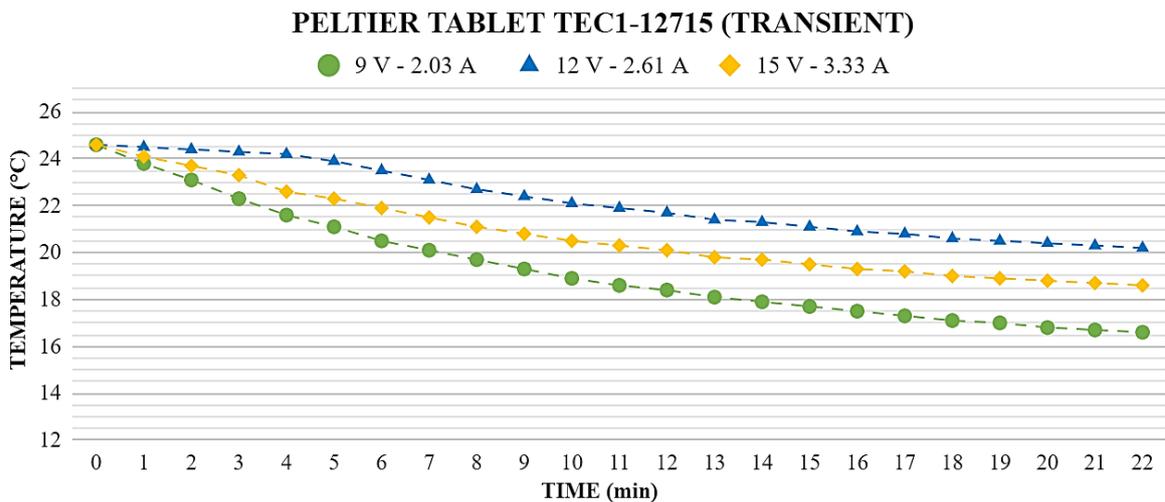


Figure 14. Graphical representation of TEC1-12715 operation in transient regime.

The operating temperature and *coefficient of performance* (COP) results obtained with the tablet TEC1-12715 in steady state are presented in the Table 3.

Table 3. Steady-state characteristics, *coefficient of performance* (COP) and *Carnot Efficiency* (η_{Carnot}) of system with TEC1-12715.

TEC1-12715	AVERAGE STEADY STATE TEMPERATURE	AVERAGE COMBINATION TEMPERATURE	$\bar{\rho}_{air}$	COP	η_{Carnot}
9 V – 2.03 A	16.467°C	20.533°C	1.131 kg/m ³	$1.767 \cdot 10^{-3}$	2.732%
12 V – 2.61 A	20.067°C	22.333°C	1.123 kg/m ³	$0.571 \cdot 10^{-3}$	1.523%
15 V – 3.33 A	18.467°C	21.533°C	1.127 kg/m ³	$0.485 \cdot 10^{-3}$	2.060%

The comparison between the Peltier tablets and the applied electrical voltage in relation to the *Carnot Efficiency* calculated based on the initial and final temperatures is shown in Figure 15.

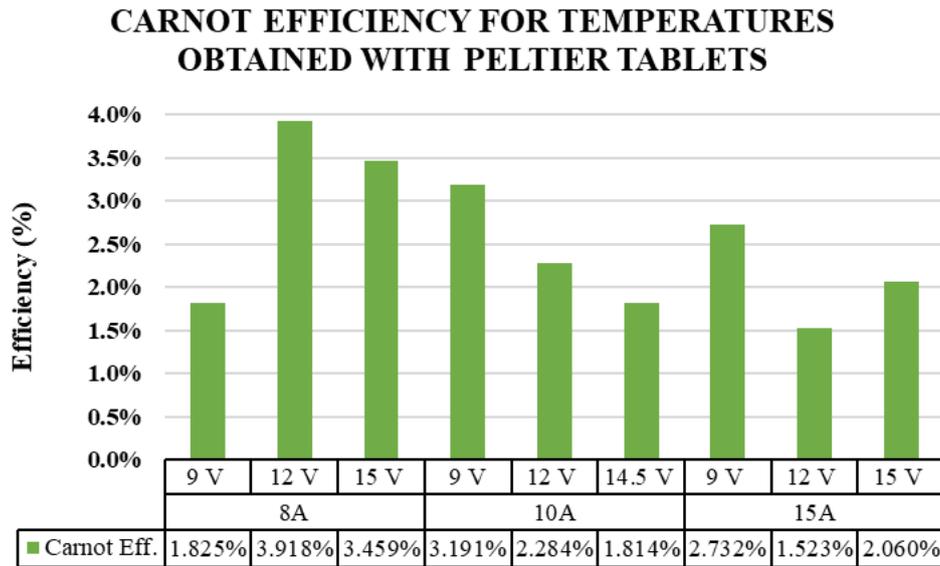


Figure 15. Comparison of COP at different tablet temperatures and voltages.

During laboratory practice, it was found that the Peltier tablets operated, in all cases, with a current lower than that indicated in their technical sheets, identifying a topic responsible for reducing their overall efficiency. Possible technical flaws in the manufacturing of TEC1-12715 tablet exposed electrical current consumption substantially lower than expected.

The occurrence of non-homogeneous regions in the structure of refrigeration compartment, such as the front cover and the Peltier module housing, or even insufficient thermal insulation on the walls, reduces cooling in general.

The incompatibility of ventilation and heat dissipation system, which was not readjusted or resized during the different tests, was enough to make the cooling process difficult even in the models where higher expectations were placed, in this case, the TEC1-12715, although it has the best COP with a voltage of 9 V.

Another consideration to be raised, as a result of those observed previously, is the general inefficiency of heat sinks, especially when it comes to dissipating heat from the hot side, as heat transfer in tablets is concentrated in their small area (Júnior, 2019).

In view of the above, in the real and current conditions of built cooling system, with regard to the thermal insulation structure and the ventilation and heat dissipation system, the model that best meets the expected results is the TEC1-12708 tablet set, operating with 12 V and 3.45 A, reducing the temperature by 11.7°C in 25 minutes of operation. Other significant results are also observed, such as TEC1-12708 operating at 15 V (10.3°C) and TEC1-12710 operating at 9 V (9.5°C). The best *Carnot Efficiency* results also follow those previously obtained for the temperature difference.

Regarding the *coefficient of performance* (COP), the combination that presents the best result is TEC1-12715 with 9 V, followed by TEC1-12708 (12 V) and TEC1-12710 (9 V).

7. CONCLUSION

Despite the benefits offered by Peltier tablets, exemplified in their applications and observed in the built equipment, this device has limitations. The efficiency and technical reliability are still challenges to be overcome when applied in refrigeration systems, since they do not surpass other conventional methods. Furthermore, the significant heat generated on the hot side, in addition to being closely related to the thermoelectric cooling potential on the cold side, requires a precise and individual analysis, which depends on the model of tablet and the electrical voltage applied for sizing a system of efficient thermal dissipation. The ability of the built system to transfer heat from its interior to the external environment, regardless of test, corroborates the use of Peltier tablets in refrigeration, due to its compactness, uniqueness and simplicity

of operation. Specifically, it was concluded that the combination of TEC1-12708 tablet, operating with 12 V and a current of 3.45 A, presented the most relevant result, with a reduction in temperature of 11.7°C in 25 minutes of operation, combined with other also significant results.

It is intended to identify in the future the correct dimensioning of Peltier module in terms of dissipation and ventilation system, the association of Peltier Effect tablets and the use of a better thermally insulated container to obtain even better results, which can be compared with other systems thermal refrigeration, such as compression refrigeration systems.

Through continuous advances in semiconductor technologies, it is expected that Peltier tablets will be the object of studies and research that may, in addition to contributing to their efficiency and performance, insert them even more strongly in the various branches of society.

8. ACKNOWLEDGEMENTS

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